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Chapter 1

Environmentally Friendly Alternative Wood Protections: Natural Products

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1. INTRODUCTION

Wood is one of the main material resources for human beings since prehistoric times. Because of its sustainability, it has become the preferred material in modern times as well. In this regard, it has been utilized in countless ways in many end-use applications and is not only used in indoor or outdoor applications but also used in very special productions (Fengel and Wegener 2011; FPL, 2010; Sahin and Onay, 2020). Although numerous advantages have already been reported regarding wood-based products by a number of researchers, there are also some important drawbacks arising from its natural properties (FPL, 2010; Sahin et al., 2020a). Due to its sensitive chemical constituents and anatomical structures, wood could interact with environmental conditions, including abiotic (e.g., moisture, light, heat) and biotic (e.g., fungi, insects and creatures) factors (Papadopoulos and Hill, 2003; Sahin et al., 2022; Zabel and Morrell, 2020). However, the hygroscopic and vulnerability to creatures are far more important than others.

To overcome the drawbacks of wood, many methods have been developed. The earliest wood protection technique was to use creosote in the 1600s. However, from the 1800s to the early 1900s (1930s), some impregnation methods (i.e., full cell, empty cell, vacuum and pressure) were developed. In the 1980s, some alkaline ammonium, chrome and copper-based impregnation substances were introduced. In the 2000s, more environmentally friendly alternative technologies have become used for wood conversations (Bozkurt et al., 1993; FPL, 2010).

As a result of technological developments and advances in science, there are numerous modern methods that have already been developed to protect wood, namely susceptibility to biodegradability by microorganisms and dimensional instability. Those include thermal-, chemical-, surface-, or bulk modification methods (Hill, 2006; Papadopoulos and Hill, 2002; Sahin et al., 2020b). Some of the widely accepted and commercialized techniques are:

- Impregnation with chemicals,
- Thermal treatments,
- Chemical modifications.

These have primarily been applied to extend the stability of wood at the end-of-use place against all factors that adversely affect the desired properties (Gérardin, 2016; Papadopoulos and Hill, 2003; Sahin et al., 2022; Sandberg et al., 2017). Thanks to these technologies, wood has become more resistant to biological, physical and chemical factors.

Although wood preservation is one of the main subjects in wood science, including numerous approaches, this study reviews the conventional and alternative wood protection techniques. However, properties associated with the use of alternative natural products in wood protection are discussed, showing the potential prospects of their potential utilization. Secondary sources, such as natural plant-based products, are appealing alternatives to synthetic petrochemical-based sources with an eco-friendly protection approach.

2. WOOD PRESERVATION TECHNIQUES

Due to its natural structure and sensitivity to environmental conditions, wood must be treated specially to achieve the desired properties in end-use applications. This clearly improves its vulnerable properties against abiotic and biotic factors. There have been numerous techniques developed, and some of them have already been commercialized. Broadly, wood treatments for protection could be studied in three main groups, which may have further subgroups (FPL, 2010; Hill, 2006; Sahin et al., 2022; Mantanis, 2017). Figure 1 briefly summarizes the current main wood treatment techniques. Further detailed information on wood-preservation techniques could be found elsewhere (Hill, 2006; Papadopoulos and Hill 2003; FPL, 2010; Gérardin, 2016; Sandberg et al., 2017; Mantanis, 2017; Sahin et al., 2022).

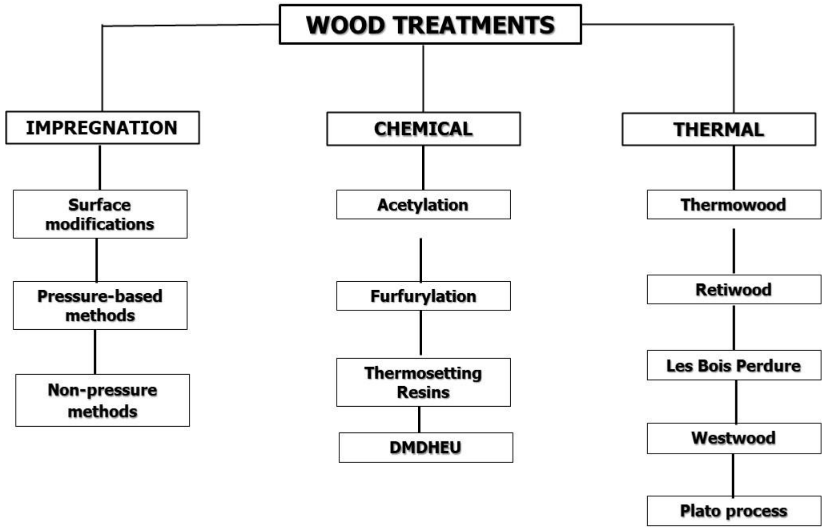

Figure 1. Wood treatment techniques

2.1. Wood impregnation

Since the colonization of fungi and detrimental biochemical reactions mainly depends on the availability of foods with specific groups (i.e., OH-), one of the approaches is to control those using some hydrophobic and toxic agents (Sahin et al., 2022; Mantanis, 2017). However, impregnation is the process of penetrating chemicals into wood using various techniques to protect it within certain limits from biotic and abiotic factors. As a result of these treatments, wood has become toxic to creatures that use it as food or shelter. There are numerous types of impregnation compounds that can be found, which can be classified under their chemical properties. These are: (Bozkurt et al., 1993; FPL, 2010; Sahin et al., 2022).

oily impregnation substances,

organic solvent substances,

water-soluble substances

Although impregnation has been utilized on various types of wood-based materials at a commercial scale worldwide, it provides some level of protection, performance on wood products with environmental interactions of reagents during outdoor exposure, has received a great deal of attention. Because the effectiveness of an impregnation system is a function of formulations (preservative type, pigment properties, resin content, quantity of compounds) that are applied to the wood, these chemicals provide proper protection, while many are synthetic petrochemicals and hazardous to the environment and human health (FPL, 2010; Sahin et al., 2022). Therefore, many conventional wood preservatives have been restricted owing to their detrimental effects on humans and the environment; alternative new types of formulations have become an emerging issue and have impaired the need for wood protection.

2.1.1. Plant-based compounds for wood protection

As mentioned above, due to increasing environmental concerns in recent years, the use of some conventional impregnation materials has been restricted. Because of their toxic effects on humans, animals and all other living things that disrupt the ecological balance, the use of creosote, copper and arsenic-based impregnation chemicals (i.e., CCA) has been restricted by the Waste Management and Regulatory Authorities worldwide (Bozkurt et al., 1993; Singh and Singh, 2012; Broda, 2020). Regarding environmentally friendly compounds used for wood protection, there has been growing interest in developing alternative new preservation methods and chemicals that do not harm living things or humans. Numerous studies have been conducted to find potential new wood preservatives from plants and/or secondary lignocellulosics that have been reported to contain many antifungal derivatives (Kalemba and Kunicka, 2003; Singh and Singh, 2012). There have been some valuable reports that some of those agents had significantly lower ecotoxicity in comparison with current commercial wood preservatives, making them a potential feedstock for wood preservation (Broda, 2020; Singh and Singh, 2012; Teaca et al., 2019; Broda, 2020).

It has already been well established that plants, from primitives to trees, have carried many volatile natural secondary mixture compounds (e.g., essential oils, tannins, flavonoids, alkaloids, and extracts) that can be obtained by distillation, steaming, physical mixing, or extraction (Kalemba and Kunicka, 2003; Singh and Singh, 2012; Teaca et al., 2019; Broda, 2020). However, those compounds typically contain a variety of special groups, including terpenes, alcohols, aldehydes, hydrocarbons, ethers and ketones, that may provide some biological activity (e.g., antioxidant, antibacterial and antifungal) (Singh and Singh, 2012; Broda, 2020). Moreover, many of those plants have already been used in folk medicine and added to food as both flavoring and preservative agents for centuries. Therefore, those groups of compounds have found applications in perfumery, aromatherapy, food and cosmetics (Broda, 2020). There has been countless research for plants, on determining physicochemical structures, physical and chemical composition, and other desired properties together with potential activities (e.g., anti-inflammatory, antimicrobial, antiviral, anti-cancer, antidiabetic or antioxidant) (Kalemba and Kunicka, 2003; Singh and Singh, 2012; Teaca et al., 2019; Broda, 2020;).

As described above briefly, there is a growing interest in bio-friendly, non-toxic natural substances with antifungal properties that make these chemicals potentially useful as preservatives for wood. Due to the proven antifungal properties against wood-decaying fungi, some attempts have also been made to apply secondary plant chemicals from annual plants, woods, herbs and spices as wood protective agents (Singh and Singh, 2012; Teaca et al., 2019; Kalemba and Kunicka, 2003). However, one of the important drawbacks of plant extracts applied for the antifungal treatment of woods is their diversity and inconsistency in their biological activity, as well as problems with leachability to wood (Singh and Singh, 2012; Teaca et. al., 2019; Broda, 2020).

To overcome those, their fixation on the wood could be tailored by using various chemical-mediated reactions. Table 1 summarizes some plant-based extracts that have already been reported in the literature for potential use in wood preservation.

Table 1. Some plant based extracts reported in the literature are potentially useful for wood preservation.

Plant material	Chemical group	Ref.
• Anise (*Pimpinella anisum*) • Basil (*Ocimum basilicum*) • Cumin (*Cuminum cyminum*) • Oregano (*Origanum vulgare*) • Thyme (*Thymus vulgaris*)	• Thymol • Carvacrol • Trans-anethole • Methyl chavicol • Cuminaldehyde	Voda et. al., 2003; Xie et. al., 2017; Reinprecht et. al., 2019.
• Lemongrass (*Cymbopogon citratus*) • Sweet scented geranium (*Pelargonium graveolens*) • Cinnamon tree (*Cinnamomum zeylanicum*) • Clove (*Eugenia caryophyllata*) • Lemon-scented gum (*Eucalyptus citriodora*)	• Carvacrol • Citron • Citronellol • Cinnamaldehyde • Eugenol • Thymol • Linalool	Pánek et. al., 2014; Xie et. al., 2017; Reinprecht et. al., 2019.
• Birch (*Betula spp*.) • Lavender (*Lavandula spp*.) • Sweet flag (*Acorus calamus*) • Savoury (*Satureja hortensis*) • Sage (*Salvia* officinalis) • Tea tree (*Melaleuca alternifolia*) • Eucalypt (*Eucalyptus spp.)* • Lemon (*Citrus*)	• Carvacol, • Eugenol, • Thymol • Cis-isoasarol, • Trimethylether	Pánek et. al., 2014; Mohareb et. al., 2013.
• Formosan juniper (*Juniperus formosana*)	• Cadinol, • Elemol	Su et. al., 2013.
• Florin (*Calocedrus formosana*)	• Cadinol, • T-muurolol	Cheng et. al., 2004.
• Common mugwort (Artemisia monosperma) • Mediterranean cypress (Cupressus sempervirens) • Rose geranium (Pelargonium graveolens) • Pepper tree (Schinus molle) • Northern white cedar (Thuja occidentalis)	• Azadirachtin, • α-pinene, • δ-3-carene, • Limonene, • α-terpinolene	Mohareb et. al., 2013; Mansour and Salem, 2015.
• Teak (tectona spp.)	• Anthraquinines • Tectoquinones • Deoxylapachol • Isolapachol • Dehydrotectol • Naphthoquinone	Anda et. al., 2019; Windeisen et. al., 2003.
Camphor Tree (Cinnamomum camphora),	• Camphor, • Terpineol.	Li et. al., 2014.

White mullberry (Morus alba)	• Linoleic acid, • Palmitic acid, • Oleic acid	Mansour and Salem, 2015.
Pitch pine (Pinus rigida)	• Terpineol, • Borneol, • Terpin hydrate, • D-fenchyl alcohol, • Limonene glycol.	Salem et. al., 2016.

However, certain chemicals (mainly tannin and phenolic compounds) that are resistant to microorganisms, could be found and/or isolated in different parts (i.e., bark, leaves, and cones) of trees or plants rather than wood. Table 2 shows some tree species whose different parts could be protected by some level of wood protection compounds.

Table 2. Antifungal properties of some plant species and their parts (Broda, 2020)

Wood	Bark	Leaves	Cone	Wood
Norway spruce	+		+	
Maritime pine (Pinus pinaster L.)	+			
Calabrian pine (Pinus brutia Ten.)	+			
Fir (Abies nordmanniana)	+			
Iron tree (Casuarina equisetifolia L.)	+			
White oak (quercus alba)	+			+
Valonia oak (Quercus ithaburensis)	+	+		
Black locust (Robinia pseudoacacia L.)		+		+
Quebracho tree (Quebracho Colorado)				+

The secondary wood preservatives from plants may be applied to wood in the following distinctive ways:

- a full formulations through impregnation,
- mixture formulations with other impregnation chemicals,
- surface treatment agents.

2.2. Chemical modifications

In recent years, wood protection has increased interest as an environmentally friendly new method for improving durability without the use of toxic substances. In this regard, many new alternative techniques developed for bulk and surface treatments with specially formulated chemicals have already been introduced with many comparable results (Hill, 2006; Sahin et al., 2020a,b; Mantanis, 2017). However, chemical modification can be based on various reaction principles (e.g., grafting, substitution, and crosslinking) (Hill, 2006; Mantanis, 2017; Sandberg et. al., 2017). The modified wood should itself be non-toxic under service conditions, and there should be no release of any toxic substances during service life, while wood chemical constituents can be chemically modified. Although wood chemical modification includes very complex reactions, there are some hypotheses that it can be related to reacting hydroxyl groups of the cellulose, lignin and hemicelluloses, which are main polymers that are the most reactive sites in cell wall (Mantanis and Lykidis, 2015; Sandberg et. al., 2017). These groups are also responsible for the dimensional instability through their hydrogen bonding to water (FPL, 2010, Fengel and Wegener, 2011). Therefore, it is one of the easiest ways to modify wood by using those reactive hydroxyl groups. With this well-established knowledge, specially formulated agents have been fixed to cell walls and engineered to certain specifications, resulting in resistance against them.

A number of researchers have already proposed that wood chemical modification clearly improves its properties, especially in outdoor conditions, because it has gained resistance against various abiotic and biotic factors at some level (Mantanis and Lykidis, 2015; Mantanis, 2017). Although it is very difficult to explain all physicochemical reactions, there is some commonly accepted hypotheses have been reported (Papadopoulos and Hill, 2003, Hill, 2006; Mantanis, 2017). These are:

1.Reacting hydroxyl groups with a covalently bounded hydrophobic group leads to an increased dimensional stability (lowering equilibrium moisture content),

2. It is more difficult for fungi to get the moisture required for decay at a lower equilibrium moisture content, which the fungal enzymes need for hydrolysis,

3. The chemicals bound to the cell wall could have an inhibitory effect on decay enzymes,

4.The enzyme penetration might be prevented by physical blocking of the cell-wall micropores.

The acetylation, furfurylation, thermosetting resin and 1,3-dimethylol-4,5-dihydroxyethyleneurea (DMDHEU) treatments have already progress considering wood modification against various factors. In those cases, typically the cell wall is filled with introduced groups that take up space within the cell wall. The resulting physicochemical properties are changed considerably as compared to untreated wood (Papadopoulos and Hill, 2003; Hill, 2006; Mantanis, 2017). Table 3 summarizes some common chemical modification processes, and Figure 2 shows an example of a typical acetylation reaction under ambient conditions.

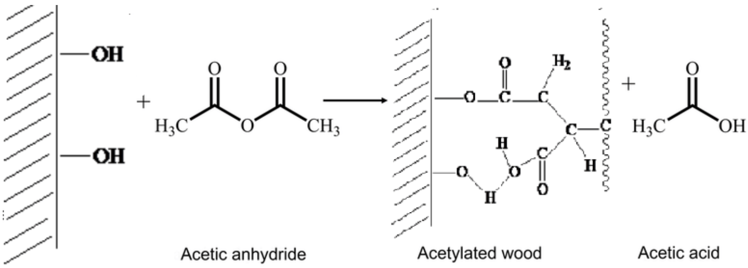

Figure 2. The acetylation of wood (Papadopoulos and Hill, 2003)

Table 3. Some common wood chemical modification process (Hill, 2006; Mantanis, 2017; Mantanis and Lykidis, 2015).

Process	Specifications
Acetylation	• It is primarily based on esterification reactions in the liquid phase of the accessible hydroxyl groups with acetic anhydride at 100 to 120 °C. • Acetyl weight gain of 16% to 19%, approximately 90% of the lignin and 25% of the holocellulose are esterified. • During acetylation, lignin is the most reactive constituent of the cell wall. • The timber has considerably improved physical, mechanical, and biological properties.
Furfurylation	• Wood is impregnated with a mixture of furfuryl alcohol ($C_5H_6O_2$) with catalysts, and then heated to cause polymerization. • The furfurylated wood is evidence of grafting reactions and most of all, the lignin is dominant. • The furfurylated wood has resistance to biological degradation, resistance to weathering, marine borers and improved dimensional stabilization.

	• The leachates from furfurylated wood have negligible toxic effects.
Thermosetting Resins	• Wood is impregnated with phenol-formaldehyde and melamine-formaldehyde (MF) resins in addition, which results in improved dimensional stability and resistance to biodeterioration. • Applying impregnation with phenol-formaldehyde (PF) resins, and also heat and compression, products called Compreg and Impreg. • The main drawbacks that still remain are the high production cost and the tendency of such wood products to crack under humid-dry cycle conditions.
DMDHEU	• It is impregnation of the reagent 1,3-dimethylol-4,5-dihydroxyethyleneurea (DMDHEU). • Wood modification with DMDHEU has been shown to improve dimensional stability and durability, and to slightly reduce the moisture uptake of wood. • The anti-swelling efficiency was found to be in the range of 30-40% The main drawbacks are brittleness, the tendency to crack and high emissions of formaldehyde from the product.

2.3. Thermal modification of wood

The thermal modification of wood is a recent technology that has gained attention on these days. It is a controlled pyrolysis process in which wood is heated at above 175 °C in a low oxygen content environment. During those high temperatures, various complex reactions take place, particularly with chemical constituents (cellulose, hemicellulose and lignin). As a result of those complex treatments, wood has altered on a cellular level, fostering many noteworthy improvements (Hill, 2006; Sahin et. al., 2011; Mayes and Oksanen, 2002). One of the main reactions is the hydrolytic cleavage of covalent bonds, further cross-link formations and lowering reactive groups within chemical constituents. Regarding those modifications, the wood hygroscopic restraint of the wood cell Wall because the accessible OH content decreased.

Because of a chemical process, the effective of thermal modifications depends on wood species and reaction conditions, such as; temperature, durations, and treatment intensity. It has already been reported by a number of researchers that wood density, and some physical properties, such as strength properties, have been found to be reduced by up to 30% at higher temperatures (Hill, 2006; Mantanis, 2017; Sandberg et. al., 2017). At present, some of the thermal wood modification methods, Thermowood, Retiwood, Les

Bois Perdue, Westwood, and Platowood, have been commercialized specifically for the architectural construction market in worldwide (Hill, 2006; Sandberg et. al., 2017).

3. SUSTAINABILITY AND WASTE MANAGEMENT IN THE WOOD PRODUCTS

The United Nations Sustainable Development Goal (SDG 15) emphasizes the importance of conserving biodiversity and natural habitats, along with specific targets for the protection of mountain ecosystems. It underscores the necessity of preserving, restoring, and promoting the sustainable management of all types of forests. (Özçelik et. al., 2023). Also, from a sustainability stadpoint, the significance of wood conservation within the forest industry is increasingly recognized. Although there are numerous advantages to using wood in the forest products industry, there is one important drawback: toxic chemicals are used in some wood products which toxic waste can be generated during or after the utilization of those products (FPL, 2010). However, increasing environmental pressures and bans on conventionally used wood preservatives, which usually carry toxic components in their formulations, have led to the development of alternative, environmentally friendly wood preservation chemicals, either surface or bulk treatments.

Recently, some studies have been conducted for determination of indoor air pollutants. These pollution sources are reported to be mostly volatile organic compounds (VOCs), such as aromatic compounds, alcohols, hydrocarbons, etc. (Salthammer et. al., 2002). It has been suggested that a significant proportion of volatile compounds released into the environment originate from furniture and wood products. In addition, the gaseous forms of these compounds released can form secondary harmful substances (Salthammer et al., 1998).

Significant contributions have already been made to prevent environmental pollution by using naturally-derived dyes in indoor furniture, toys, and interior wooden structures for decoration purposes (Ulusoy et al., 2016). One example is dyes obtained from acorn powder, is an eco-friendly approach for wood coatings. It is suggested to use aesthetically pleasing paints for furniture surfaces (Ulusoy et. al., 2016).

However, one of the appropriate disposal methods for impregnated wood material may be partial recycling or energy recovery. Studies are being carried out on innovative purification methods by absorbing the hazardous metals contained in wood material with various materials such as carbon, yeast and tree barks (Lahtela et. al., 2023). It has been proposed that up to 60% copper can be removed from impregnated and out-of-serviced wooden materials with oak bark and apple peels, while chromium removal could be absorbed up to 25% (Kartal et. al., 2008). Absorption studies using chitin and chitosan have proven that copper can be removed at rates of 74% and 57%, respectively (Kartal and Imamura, 2005). With the combination of citrus acid dissolution and fungi, 87% of copper and 80% of chromium could be removed (Sierra-Alvares 2009). Much higher results can be achieved using bacteria. In this regard, wood chips treated with L. Bulgaricus and S. Thermophilus, removed copper, chromium, and arsenic from samples by 93%, 86.5%, and 97.8%, respectively, after 4 days of extraction (Chang et al. 2012). Although the combination of oxalic acid extraction and sequential electrokinetic treatment is also among the methods that provide high removal, it should not be forgotten that the applicability of these methods is not cheap (Lahtela et. al., 2023). For this reason, natural wood preservatives are demanded as important alternative materials compared to synthetic-based ones (Coskun and Sahin, 2024).

CONCLUSIONS

Environmental problems have increased dramatically during the last two decades. However, the economic growth that has driven uncontrolled development has often not been balanced by environmental concerns. Regarding that, the utilization of plant-based compounds has the potential to reduce the costs and environmental concerns and thus facilitate the successful implementation of alternative preservative agents for wood protection. Those natural compounds could be introduced to enhance their bioactivity, such as co-impregnation with different formulations, cross-linking, or antioxidants. Moreover, these alternative chemicals could improve the properties of wood and alter its original features to some extent. But one of the main drawbacks of those agents is the legislative and consumer-related problems related to the lack of standards and the performance of natural formulations. This creates an emerging need for further thorough research on wood preservation.

The precautions that can be taken to control environmental pollution in the forest products industry from an ecological perspective;

(1) Reducing the consumption of water, and energy,

(2) Control of wastes (liquid, solid, and gaseous wastes),

(3) Evaluation of the environmental effects of waste (measuring, examining and monitoring the remaining effects) (Ulusoy et. al., 2016).

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Chapter 3

Natural Ventilation and Temperature Analysis in Dairy Cattle Shelters With Autodesk Cfd Design

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1-INTRODUCTION

Most dairy cattle barns are constructed using natural ventilation systems to meet ventilation needs. Natural ventilation offers several advantages over other ventilation systems, including lower energy consumption, less equipment and more economical ventilation. Natural ventilation is a preferred passive cooling method in animal shelters. This method, which allows air flow and circulation, plays an important role in protecting the health of animals by regularly renewing the air quality in shelters.

Natural ventilation occurs due to temperature differences and wind movement and is supported by the chimney effect. When the right decisions are taken at the design stage of the buildings, it is possible to make the most effective use of the prevailing wind to expel the polluted air in the building.

Natural ventilation not only saves energy but also improves indoor air quality. The removal of pollutants from the environment is of great importance for the health of living things. At the same time, it is also possible to keep the indoor temperature of the space under control thanks to natural ventilation. Natural ventilation is an important method to create a healthy living environment indoors, to save energy and to control the temperature of the space. A properly designed building can provide the fresh air flow it needs with natural ventilation and minimize the need for mechanical systems.

When numerical technologies are integrated into design processes, they can continue to use traditional representation techniques as auxiliary tools. The computational and algorithmic nature of computers today offers new possibilities in design processes and research. These structures facilitate the formulation of design strategies and provide more detailed results in the analysis stages. Formal research and performance tests can also be carried out faster and more effectively by utilizing this structure of computers.

Computational fluid dynamics (CFD) is a field of engineering used to solve fluid mechanics problems based on numerical methods.

Since the late 1960s, CFD has been one of the major developments in engineering. Today, the application of CFD is used in aerodynamics, thermal analysis, chemical reactions and many other fields.

One of the most important advantages of this technology is that it does not require laboratory experiments or field tests. This reduces costs, speeds up the design process and provides more flexibility to solve complex problems.

The first use of Computational Fluid Dynamics in 1970 by Peter V. Nielsen to model air movement in a ventilated room formed an important bridge between fluid mechanics and computer science. The advent of this technique revolutionized the ability to numerically analyze the complex motion of fluids and became a vital tool for many industries and academic fields.

Since then, with the rapid increase in computational processing power, the development of efficient numerical discretization methods and the implementation of these advances in modern computer systems, the use of Computational Fluid Dynamics has increased dramatically. This technique has become a unique tool for simulating the complex behavior of fluids.

According to Norton et al. (2007), Computational Fluid Dynamics (CFD) is a sophisticated tool that is used to simulate various phenomena such as heat, mass transfer, phase changes, chemical reactions, etc. This method enables computational study in a wide range of conditions of interest by creating models of various physical systems. In CFD, it is known that nonlinear partial differential equations are solved by numerical methods using the finite volume method to simulate the behavior of the fluid. (Kim et al.,2022; Kwon et al. 2015).

The fundamental equations in fluid dynamics form the basis of CFD modeling and according to Kim et al. (2016), these equations govern continuity, momentum and heat transfer phenomena. Thanks to these equations, which contain mathematical formulations of the physical laws governing fluid flow, heat transfer and related phenomena, it is possible to describe the rate of change of the fluid properties of interest as a function of external forces (Oliveira et al., 2023).

CFD analyses are used in 4 different stages of the building design process. These are layout planning, natural ventilation studies, HVAC system designs, pollution distribution and controls. Good layout planning can reduce the impact on environmental pollution, increase comfort, support natural ventilation and reduce energy consumption. In natural ventilation studies, CFD analysis can be used to analyze the air movements inside the building and reach the optimum result.

Due to its versatility, the CFD technique is also used for modeling airflow and humidity conditions in agricultural facilities and is an ideal complement to field measurements (Domibia et al., 2021). CFD is widely used for heat and mass transfer modeling in dairy facilities and contributes greatly to the understanding of thermal environmental. The vast majority of CFD modeling studies in dairy facilities have been performed on typical conditions of mass-housing systems in individual stalls (Oliveira et al., 2023).

In the light of these developments, the future of Computational Fluid Dynamics looks very bright. The ever-increasing computing power and the continuous development of numerical methods will make the modeling in this field even more complex and realistic. This will make it an important tool to better understand the behavior of fluids in industry and science, and to meet the engineering and scientific challenges we may face in the future.

Choosing the right simulation program is one of the most important steps in this process and should be treated with care. For architects, integrating technology and innovation into the design process will play a key role in determining future design approaches.

Autodesk® CFD (Computational Fluid Dynamics) software is a tool for creating computational fluid dynamics simulations that allow engineers and analysts to intelligently predict the performance of liquids and gases. This powerful software provides users with a variety of tools for system design optimization and allows them to simulate fluid flow, free surface motion and analyze thermal effects for product design. It also integrates with other Autodesk software and allows CAD models to be imported into Autodesk CFD from programs such as Autodesk Inventor, Autodesk Revit, AutoCAD Architecture and AutoCAD MEP (Autodesk, 2024).

Research into the analysis of models used in livestock structure design has been increasing over the last four decades. JM Bruce's “Design of Livestock Buildings for Natural Ventilation: The Theoretical Basis and a Rational Method of Design” by JM Bruce provides a comprehensive overview of theoretical models. This book provides information on ventilation rates and wind-driven natural ventilation in livestock buildings (Tomasello et al., 2019). Recent research has applied computational software tools to analyze the ventilation rate, study how external conditions affect the environment inside the building and find appropriate design solutions. These developments improve the efficiency of livestock buildings, positively affecting both the welfare of the animals and the profitability of the operators.

Sapounas et al. (2012) used a three-dimensional simulation model to analyze the airflow in a dairy barn with different roof types and wall ventilators; the simulation model is based on a detailed description of the barn reflecting its actual characteristics. At the beginning of the study, the geometric structure and material properties of the barn were modeled and transferred to the simulation environment. Then, the airflow was analyzed by adjusting the parameters related to different roof types and side ventilator positions. The results show that the roof shape plays an important role in the uniformity of the indoor climate.

Research by Norton et al. (2010) examines the factors affecting the thermal environment and natural ventilation performance in calf buildings. In particular, considering the importance of natural ventilation, it shows the most efficient ventilation system in calf buildings and the effect of ventilated cladding that can be used to provide thermal comfort, and also investigates the effect of the height of the eave opening on the average air velocity at animal level. In this context, the effect of permeable windbreak materials and the effect of varying the height of the eave opening on these objectives were examined. As a research method, Norton and his team conducted experiments in a calf building. In these experiments, they controlled the flow of air using different permeable windbreak materials. They also measured how changing the height of the eave opening affected the average air velocity at animal level. The data showed that the use of ventilated cladding significantly increased natural ventilation and that the average air velocity at animal level decreased as the height of the eave opening increased.

Norton et al. (2009) developed a CFD model to study the natural ventilation of a naturally ventilated commercial calf shed under different wind effects with three different inlet openings. This study was an important step towards understanding and optimizing the airflow inside the shed. According to the results of the study, the highest ventilation homogeneity was obtained when the wind was perpendicular to the building. However, the maximum environmental heterogeneity was obtained at a wind angle of 10-40◦. These results emphasize the importance of wind orientation in the design and operation of calf sheds.

In commercial animal husbandry, the aim is to obtain the highest yield for a given cost. This can be possible with the provision of appropriate genetic structure and environmental conditions that will enable this genetic structure to reveal (Mutaf & Sönmez, 1984). The environment and interactions to which livestock are exposed during the growth, lactation and maximum genetic potentials in the fertility, growth and development stages and the subsequent adult period are important (Johnson, 1987). Environmental conditions include all external factors that affect the growth, development and productivity of the animal. Factors such as temperature, relative humidity, air movement, radiation, illumination, air quality, shelter characteristics (ventilation, insulation, etc.) equipment, feeding system, water supply, social hierarchy in the herd, amount of space allocated per unit, lighting, sound, odor, atmospheric pressure, disease factors can be listed as important environmental conditions (Ekmekyapar, 2001).

The most suitable environmental conditions as comfort zone for farm animals are climatic conditions where they can maintain their productivity and body temperature without any difficulty (Akman, 1998). These conditions are upper and lower atmospheric temperature values of 13-15 oC, 60-70% for relative humidity, 5-8 km/h wind speed and moderate solar radiation (Yousef, 1985).

However, due to some characteristics of livestock, they have the ability to maintain their productivity in a much wider range than these temperature values without significant decreases compared to this region. This region, defined as the favorable temperature zone, is between - 5 oC and +25 oC. The temperature values at which livestock cannot compensate for the decline in their productivity and start to suffer damage are called lower and upper critical temperature values. The lower point is -18 oC and the upper point is +27 oC for these critical temperature values, which can vary depending on factors such as humidity and wind speed in addition to factors such as age, nutrition level, etc. (Akman, 1998).

2- MATERIALS AND METHOD

In this research study, a 50-head free-stall dairy cattle barn was modeled. The environmental conditions of the barn modeled in the center of Bursa province, which has a temperate climate, are based on annual average values. The temperature was 14.7 °C, wind speed was 8.3 km/h and the prevailing wind direction was north-east.

Computational fluid dynamics (CFD) modeling and simulation can be used to determine how the airflow within the barn is distributed and how animals are affected.

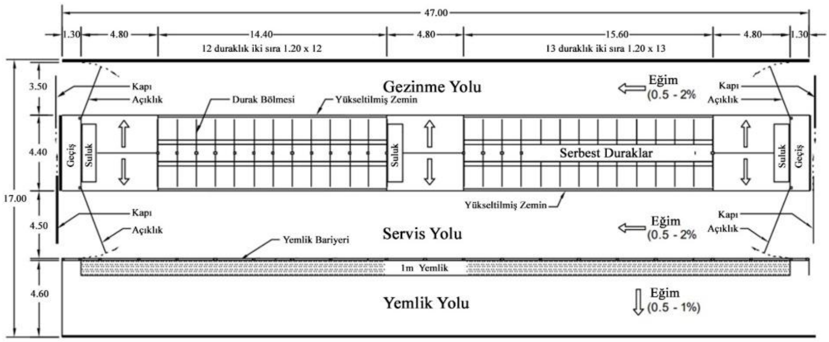

Figure 1. Sketch of 50 head free stall dairy cattle shelter in plan plane

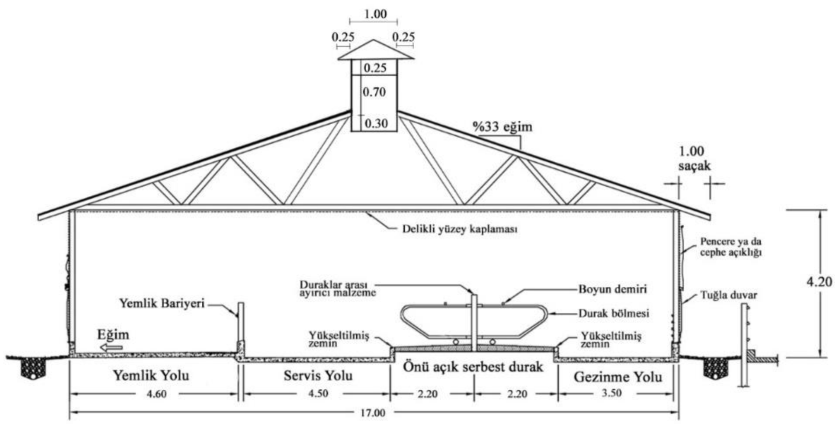

Figure 2. Sketch of 50 head free stall dairy cattle shelter study 1 in cross-section plane

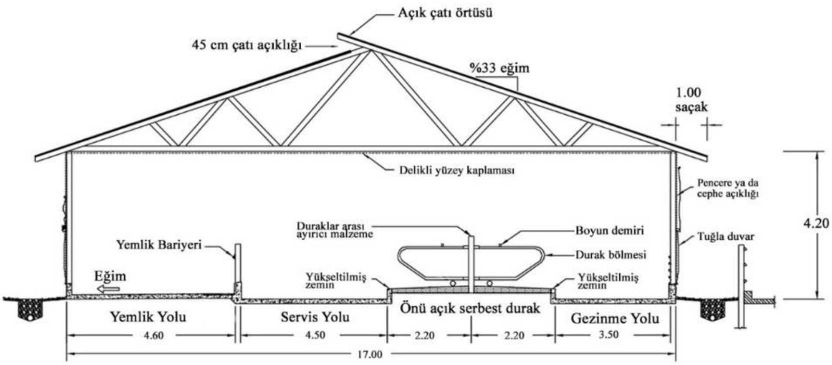

Figure 3. Sketch of the 50 head free stall dairy cattle shelter study 2 in cross-sectional plane

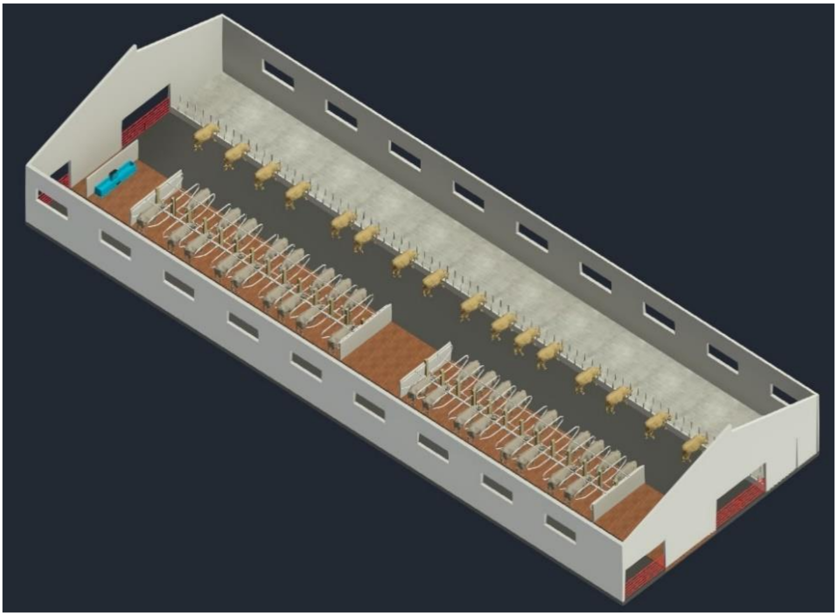

Figure 4. Perspective view of 50 head free stall dairy cattle shelter Autodesk Revit model

The planning and implementation of natural ventilation systems requires consideration of a number of factors. The location, area and proportions of air inlet and outlet points, height difference, wind direction and speed, building geometry and many other factors determine the effectiveness of the natural ventilation system. For this reason, a suitable shelter type should be selected and natural ventilation systems should be planned by considering the characteristics of the area where the shelters will be built. In this design process, computational fluid dynamics (CFD) modeling and simulation can be used to determine how the air flow in the barn is distributed and how the animals are affected by this flow, increasing the time efficiency against numerical calculations.

Simulations are often important tools used to model and analyze specific situations. These situations usually occur under steady-state conditions. Especially for air velocity measurements, simulations are used as an important tool to provide average values of actual measurements in this field.

The simulation was studied with Autodesk CFD, since the program could not open the large dimensions of the Autodesk Revit model, the dairy cattle models were modeled again as a rectangular prism by framing the dimensions of the dairy cattle models and the mesh density was reduced and introduced into the simulation.

3- FINDINGS AND DISCUSSION

The geometry of the barn (Figure 1), the building had a rectangular plan 47 m long and about 17 m wide. The height (Figure 2) is 4.2 m at the eaves and 7.85 m at the ridge (roof pitch 33%). The long side of the barn and the façade with the window openings were positioned at right angles to the prevailing wind from the North East direction. A free stall barn system for dairy cattle was implemented in the barn. The main functional areas consist of one two-row 12 stalls and one two-row 13 stalls with a total of 50 stalls, walkway, service road, feeder road and feeder, drinkers and passage areas. Passageways and gates are positioned on the short side of the shelter (Figure 4). Two 50-head shelter types were modeled for comparison. In both studies, the window openings on the short sides and long sides were modeled as the same, and in order to observe the differences in the exits on the roof of the shelter, the chimney openings on one roof (Figure 2) and the ridge (Figure 3), opening in the other study were wrapped.

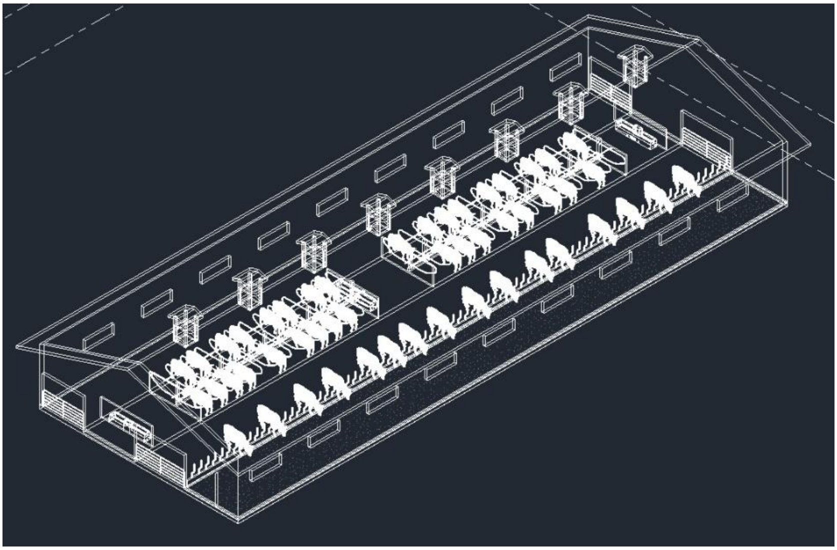

Figure 5. Auto-desk Revit model of the 50 head free stall dairy cattle shelter study 1 angle 1

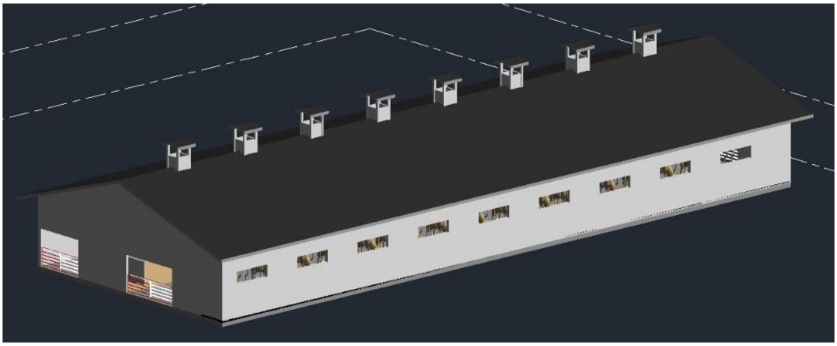

Figure 6. Auto-desk Revit model of the 50 head free stall dairy cattle shelter study 1 angle 2

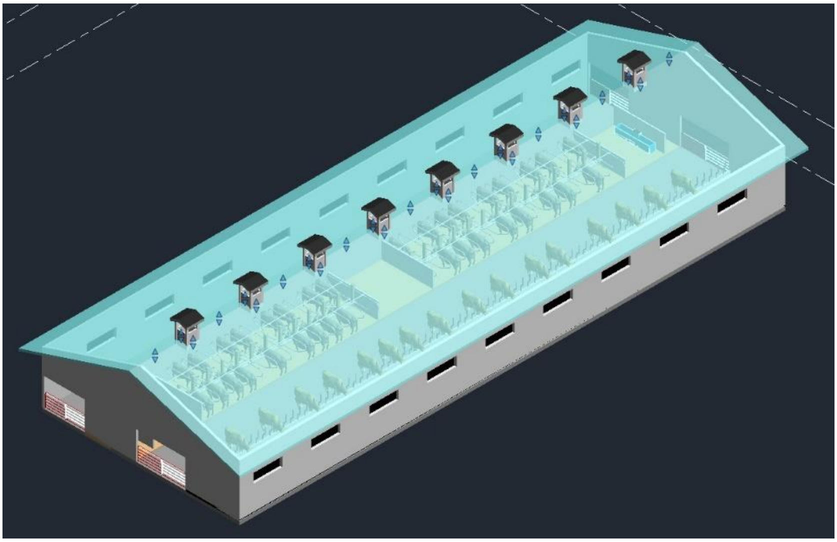

Figure 7. Auto-desk Revit model of the 50 head free stall dairy cattle shelter study 1 angle 4

In the first study, the windows were modeled so that they meet each other diagonally on opposite walls (Figure 5) and the surface area is not less than 5% of the building floor area. The building floor area is 799 m², 5% of which is 39.95 m². Window openings are one-to-one with each other and their dimensions are 0.80x2.80 m. The area of one window is 2.24 m² and the sum of the areas of 9 window openings on the two long facades is 40.32 m². As a result, from the equation 40,32 > 39,95, the surface area of the window openings is designed to be more than 5% of the floor area of the building. The bottom elevation of the window openings started from 2.40 m above the floor slab. Since at least one chimney should be calculated for 100 m² building floor area, 8 chimneys were placed in proportion to the floor area of 799m² (Figure 6). In order for the chimney to work well, it should be covered with insulated materials, the height of the chimney from the roof ridge should be at least 60 cm and the end of the chimney should enter into the ceiling by 15-20 cm, and due to the size of the shelter, the chimney was designed to enter 30 cm into the ridge (Figure 7). The chimney extends 70 cm from the ridge and there is a 25 cm space for air outlet. The eaves of the cover on the chimney are also left 25 cm on all four sides as much as the chimney opening. Since the vertical distance between the top level of the chimney should be at least 4 m and the height of the chimney from the ridge should be at least 50 cm, the shelter section of the study extends to a ridge height of 7.85 m, the chimney gives 30 cm teeth inside, and the distance of the chimney to the base corresponds to

7.55 m in the vertical plane. Since the chimneys should be quadrangular with a cross-sectional dimension of at least 40x40 cm or circular with a diameter of at least 45 cm, the cross-section of the chimney in the plan plane is 100 cm x 100 cm, the thickness of the walls is drawn as 10 cm and the net width is designed as 80 cm x 80 cm.

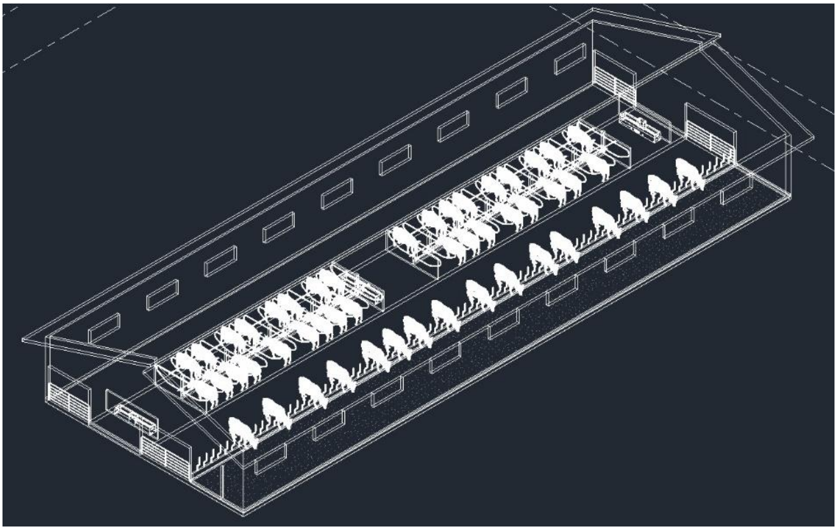

Figure 8. Autodesk Revit model of free stall dairy cattle shelter study 2 with 50 head angle 1

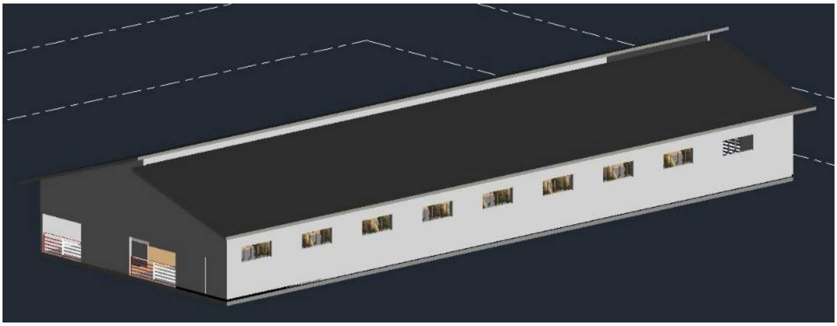

Figure 9. Autodesk Revit model of free stall dairy cattle shelter study 2 with 50 head angle 2

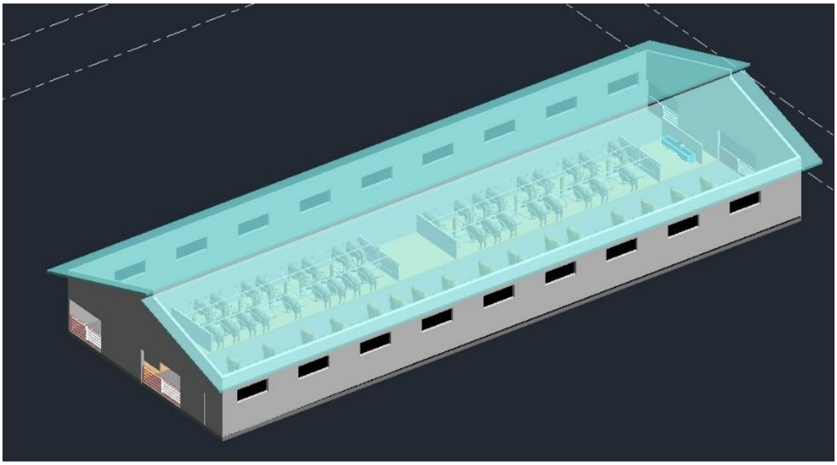

Figure 10. Autodesk Revit model of free stall dairy cattle shelter study 2 with 50 head angle 3

In the second study (Figure 8), the windows were modeled in the same shape and dimensions as in the first study in such a way that they meet each other diagonally on opposite walls and the surface area is not less than 5% of the building floor area. The building floor area is 799 m², 5% of which is 39.95 m². The window openings are one to one with each other and their dimensions are 0.80x2.80 m. The area of one window is 2.24m² and the sum of the areas of 9 window openings on the two long facades is 40.32 m². As a result, from the equation 40,32 > 39,95, the surface area of the window openings is designed to be more than 5% of the floor area of the building. The bottom elevation of the window openings started from 2.40 m above the floor slab level. In barns with long facade lengths, ventilation can also be provided by leaving the ridge open throughout (Figure 9).

Since the aim of these two studies is to observe the natural ventilation and temperature analysis inside the building with roof differences, the size and number of all openings except the roof are kept constant, and in study 2, the ridge opening will be left completely instead of the chimney (Figure 10). The ridge opening continues along the roof with a fixed width of 45 cm.

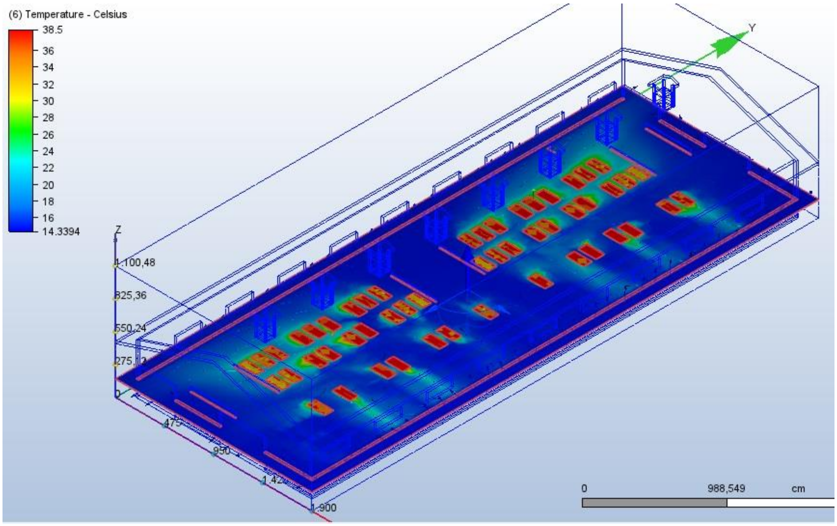

Figure 11. Autodesk CFD simulation temperature value of Study 1

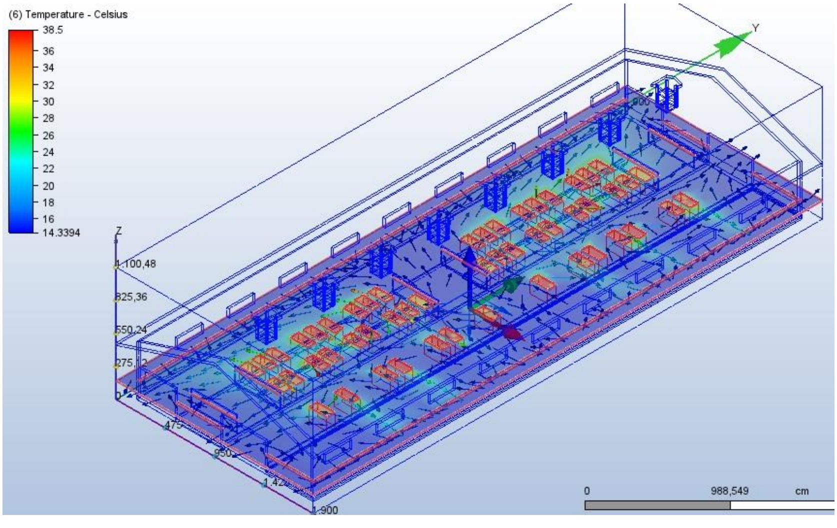

Figure 12. Autodesk CFD simulation of Study 1 temperature value and direction of motion

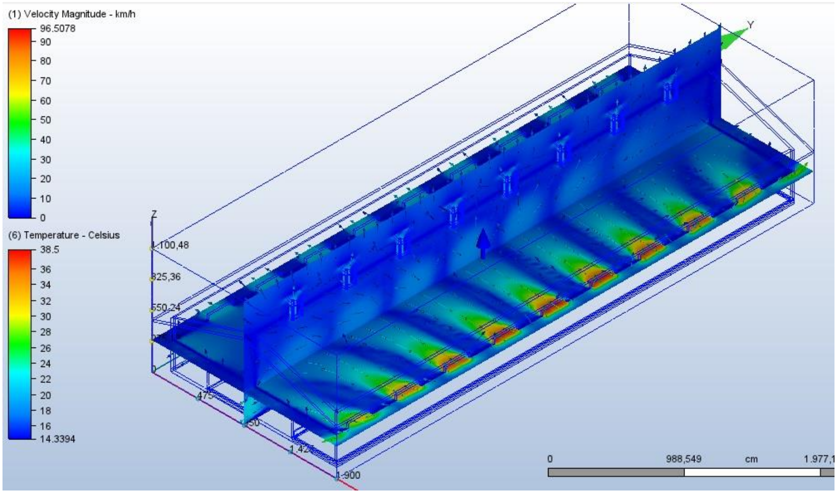

Figure 13. Autodesk CFD simulation natural ventilation movement velocity data for Study 1

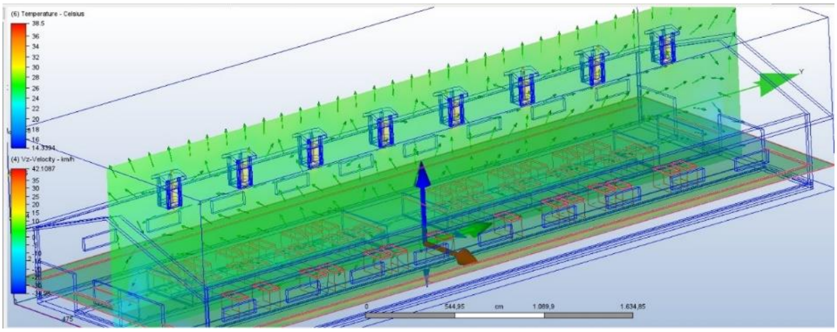

Figure 14. Data and movement of natural ventilation velocity in vertical direction (z-axis) in Autodesk CFD simulation of Study 1

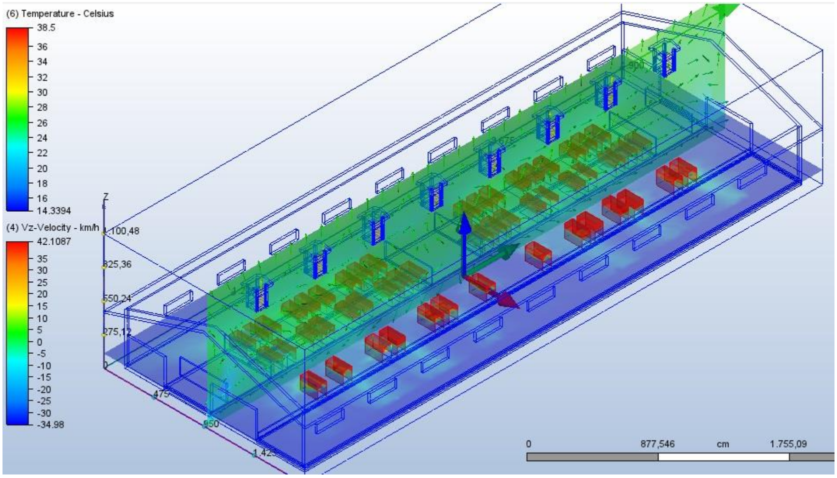

Figure 15. Autodesk CFD simulation of Study 1 data and movement of temperature value and natural ventilation rate in vertical direction (z-axis) at dairy cattle height

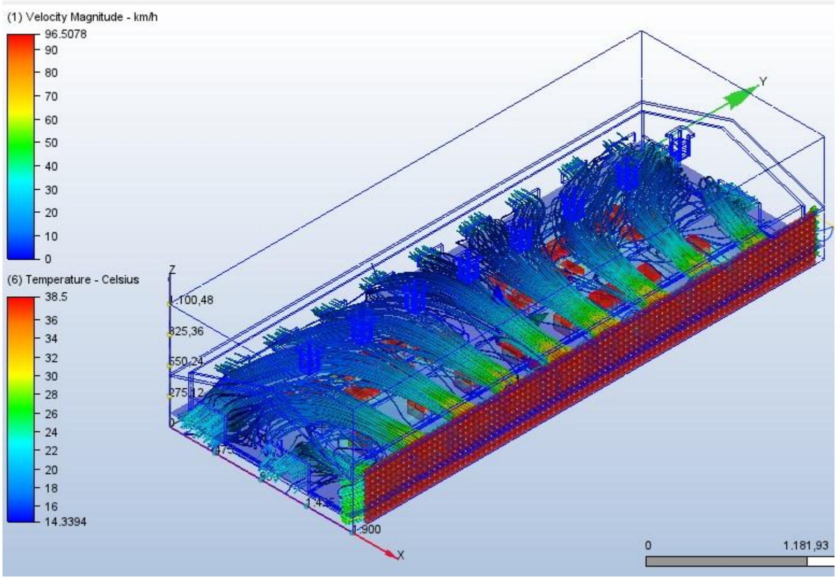

Figure 16. Autodesk CFD simulation temperature value and natural ventilation movement of Study 1

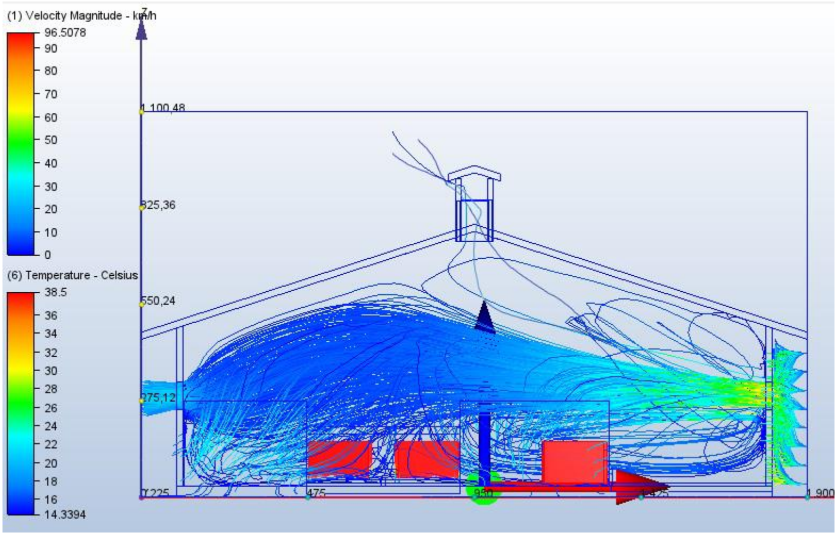

Figure 17. Autodesk CFD simulation of Study 1 natural ventilation movement 1

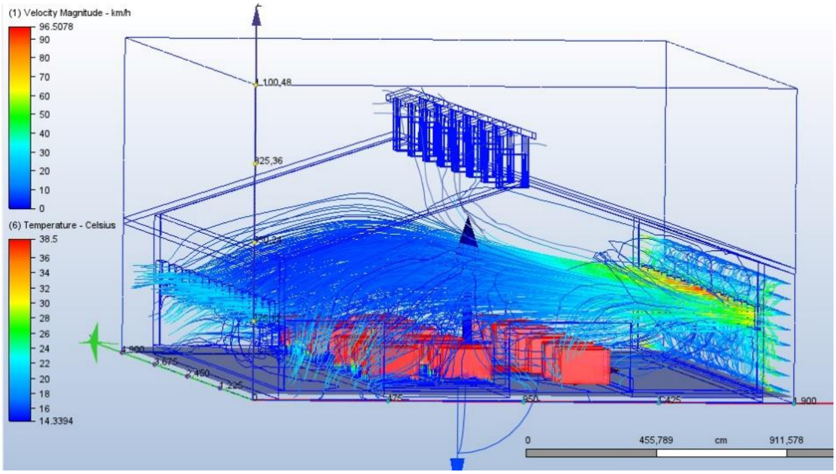

Figure 18. Autodesk CFD simulation of Study 1 natural ventilation movement 2

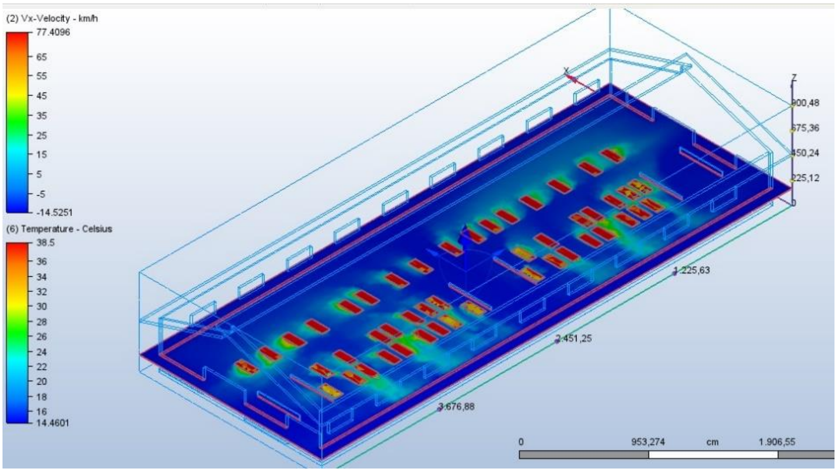

Figure 19. Autodesk CFD simulation temperature value of Study 2

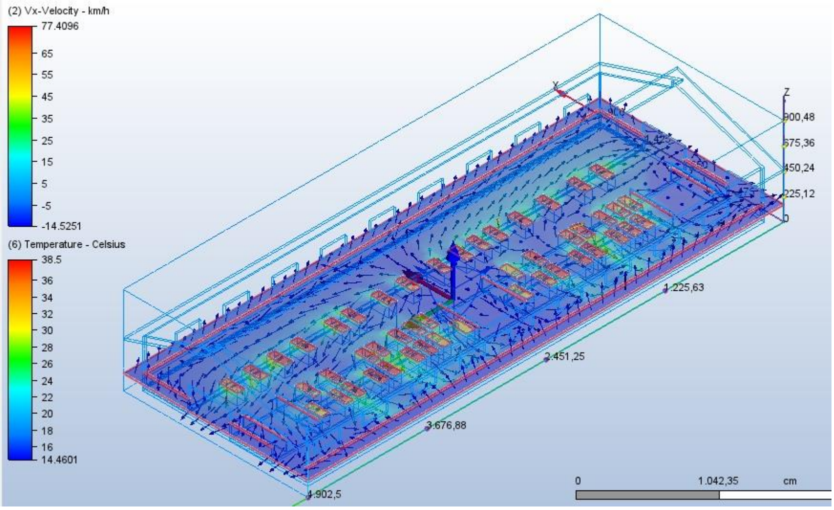

Figure 20. Autodesk CFD simulation of Study 2 temperature value and direction of movement

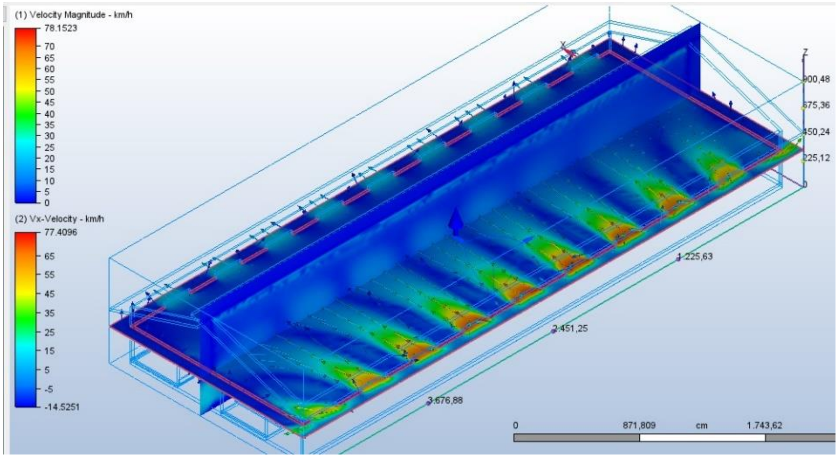

Figure 21. Autodesk CFD simulation natural ventilation movement velocity data for Study 2 1

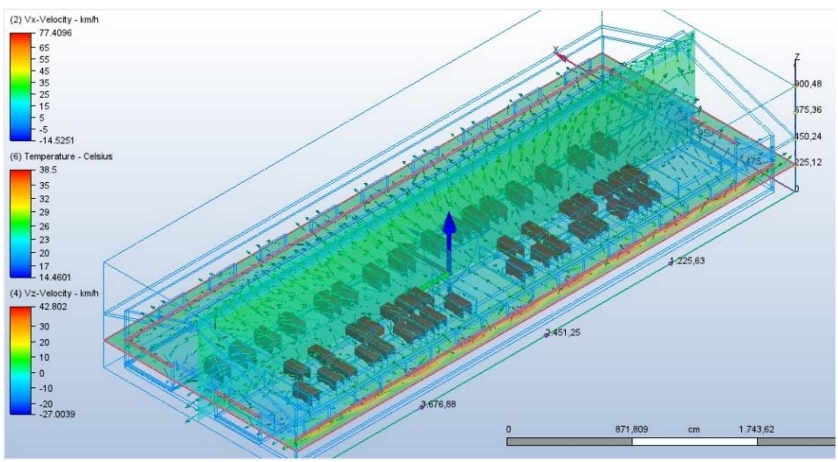

Figure 22. Autodesk CFD simulation of Study 2 data and movement of natural ventilation velocity in the vertical direction (z-axis)

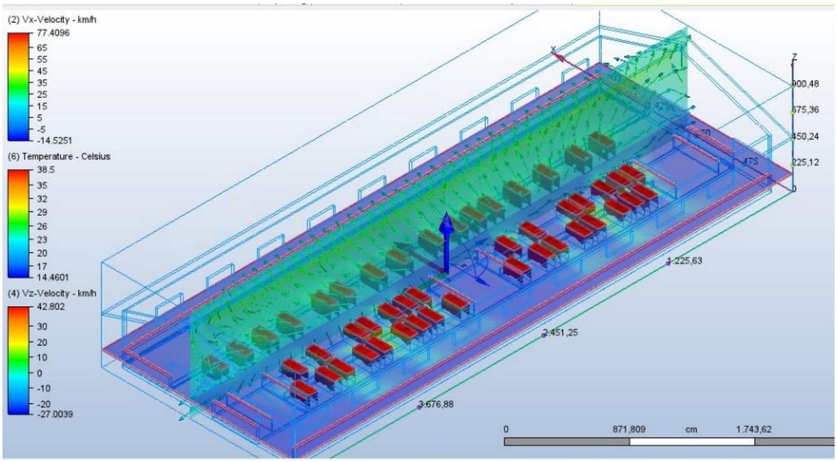

Figure 23. Autodesk CFD simulation of Study 2 data and movement of temperature value and natural ventilation rate in vertical direction (z-axis) at dairy cattle height

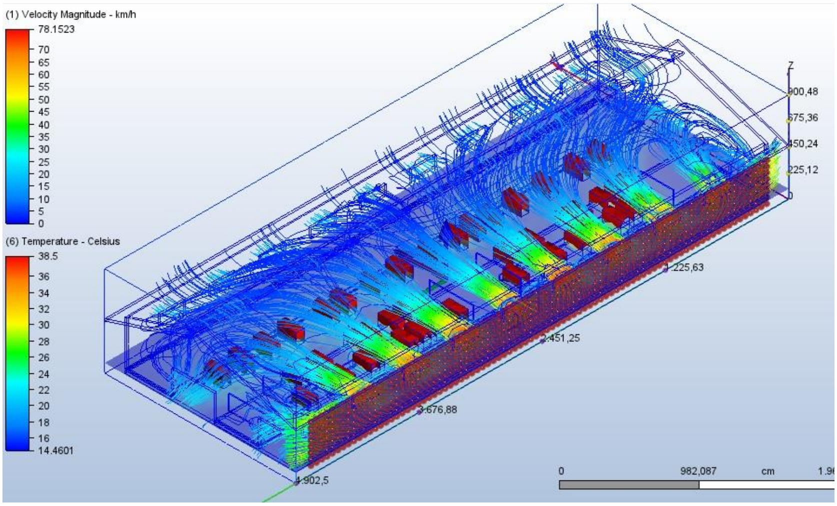

Figure 24. Autodesk CFD simulation of Study 2 temperature value and natural ventilation movement 1

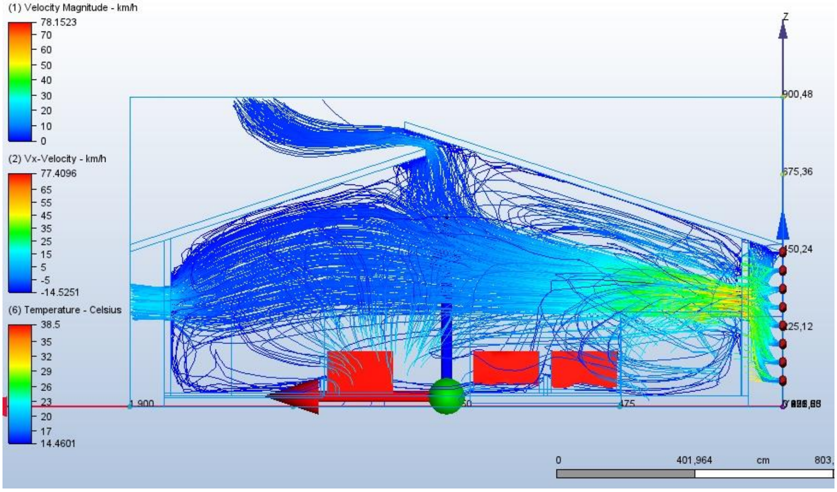

Figure 25. Autodesk CFD simulation of Study 2 natural ventilation movement 1

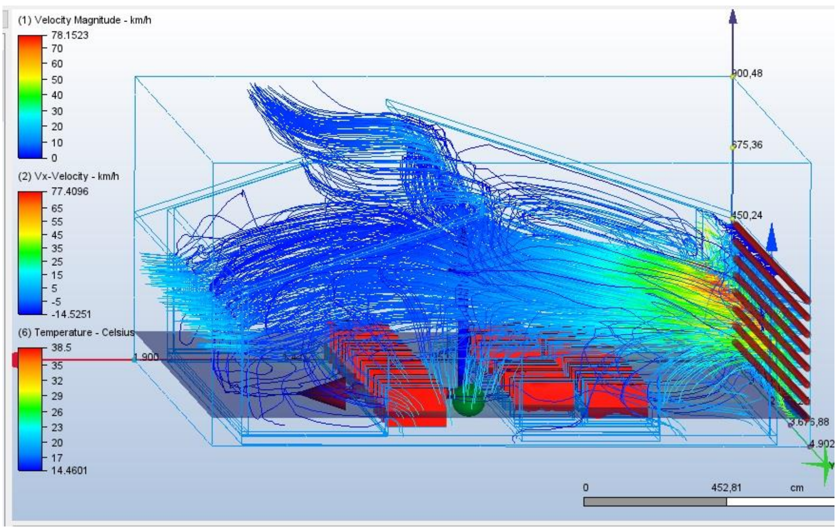

Figure 26. Autodesk CFD simulation of Study 2 natural ventilation movement 2

The body temperature of the dairy cattle was 38.5 °C and the outdoor temperature was assumed to be 14.7 °C based on the annual average of Bursa center. Window openings were started 60 cm above the height of the dairy cattle. Wind speed was entered as 8.3 km/h based on the annual average of Bursa center.

Temperature Analysis

In Study 1, the temperatures of the dairy cattle in the stalls in the y plane, which generally spread to their immediate surroundings, are between 24-30°C (Figure 11). In the x direction, there is less spread than in the y direction and a temperature change is observed within half a meter. In general, the body temperature of dairy cattle in the stalls decreases up to 32°C (Figure 11). Dairy cattle on the feedlot road did not experience a large heat loss compared to those in the stalls, and temperature data decreasing up to 24°C in the x-plane were observed around them (Figure 11). In Study 2, a decrease of up to 30°C was observed for dairy cattle in the corners of the stalls (Figure 19). For those in the center of the stalls, body temperatures did not drop below 37°C. For those on the way to the feeders, no change in body temperature was observed and the temperature around them seemed to drop to 24°C in a radius of less than 1m (Figure 19). In Study 1, the overall temperature inside the shelter drops rapidly to 14.33°C as you move away from the dairy cattle and continues (Figure 11). In Study 2, it slowly decreases to 22°C and then drops directly to 14.46°C and is generally observed at this value in the shelter (Figure 19). Total temperature graph in study 1, the temperature inside the shelter was mainly observed between 14.33-15°C (Figure 11), while in study 2 it was observed between 14.46-16°C (Figure 19). In Studies 1 and 2, the wind coming from the windows created horizontal axes in the x-direction inside and changed the temperatures of these zones until the stops between 24-28°C in Study 1 (Figure 12) and 22-26°C in Study 2 (Figure 20).

Natural Ventilation Analysis

Cross (reciprocal) ventilation is realized in the shelter of study 1 and study 2, which have opposite window openings on two sides. The air flow coming from the northeast facade exits through window and door openings on the other facades. In study 1, in addition, it exits through the chimney openings (Figure 16) and in study 2 through the ridge opening (Figure 24). Wind creates a positive (+) pressure area on the northwest façade of the building and creates a venturi effect through the window opening. The venturi effect increases the speed of the wind as it enters through the window opening, decreases its effect as it moves towards the inside of the building, and increases it again when it is thrown out of the building, but this effect is much less compared to the data at the entrance (Figure 13, Figure 21). On the south and east façades of the building, the wind speed decreases, and the separation of the negative (-) pressure from the main wind flow creates a wind shadow with vortices. The incoming air follows diagonal paths, creating a turbulence effect inside and providing natural ventilation (Figure 17, Figure 25). At the same time, wind speed increases in the ridge cavity and chimney cavities where negative pressure is created and contributes to the removal of polluted air (Figure 18, Figure 26).

The air flow entering the internal environment of the building through the window openings in the outer shell of the building realizes the air circulation in the internal environment and ensures that the air is discharged to the external environment through the ridge, chimney, door and window openings, dirty air outlet gaps, thus providing natural ventilation of the internal environment.

In Study 1, the wind that starts to enter the building envelope reaches a speed of 40-50 km/h at the beginning with the effect of the venturi, decreases to 35 km/h until it reaches the manger area on the x-axis, decreases to 10 km/h until it reaches the stops and increases to 30-35 km/h again when leaving the window opening (Figure 13). As it continues to circulate within the building, it generally travels below 10 km/h vertically and below 6 km/h when it reaches the axis of the dairy cattle (Figure 16). This speed is also below 10 km/h at the chimney outlets (Figure 14). The high amount of negative pressure is covered by the window opening of the opposite façade, and air flow is not seen intensively at the chimney outlets (Figure 15).

In Study 2, the wind entering the building envelope starts at 50 km/h at the beginning with the effect of the venturi, decreases to 30 km/h until it reaches the stops on the x-axis, decreases to 10 km/h until it reaches the manger road and increases again to 20-25 km/h when leaving the window opening (Figure 21). As it continues to circulate within the building, it generally travels below 10 km/h vertically and below 5 km/h when it reaches the axis of the dairy cattle (Figure 22). This speed increases up to 25 km/h when exiting the ridge opening (Figure 23).

4- RESULTS

In study 1, where the chimney opening was left, there were more decreases in dairy cattle body temperatures, while in study 2, where the ridge opening was left, temperature decreases were observed in a wider area around the dairy cattle.

In both studies, it is seen that ventilation is provided by turbulence effect inside. When the air flow graph in the vertical plane is monitored, the speed is observed between 0-12.5 km/h in study 1 and between 0-10 km/h in study 2. In both studies, since the long facades of the building are more than the short facades, the air flow axes are short and the window opening ratio is high, dairy cattle are exposed to flow at a speed above 8 km/h, which may adversely affect their health and welfare.

When the roof opening types in study 1 and study 2 are compared, it is seen that the ridge opening meets the air outlet at a higher rate than the chimney opening. These studies show that in shelter types designed in temperate climatic conditions where opposite window openings are left on the walls, leaving a ridge opening along the entire roof is more beneficial on air flow than leaving a chimney opening.

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Chapter 4

Nature's Healing Power: Natural Herbal Teas Prepared With Certain Medicinal and Aromatic Plants

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1. Introduction

Since the earliest times, humans have utilized plants growing in their surroundings in various ways. Through instincts, observation of animal behavior, or trial and error, people have identified which plants are suitable for food, which are toxic, and which can be used for treating diseases. Due to living in rural areas, most of the population in Anatolia has closely engaged with wild plants in their environment (Genç, 2010).

Undoubtedly, different plants that stand out more prominently will vary by region and country. Initially, teas were prepared by gathering wild plants. Even today, some countries and plant species continue to follow this method. Using abundantly available natural plants can be preferred due to cost reduction. However, the risks of material supply, quality variations, and damage to flora should not be overlooked. Furthermore, the inability to distinguish plant species containing particularly high levels of toxic compounds can lead to harmful consequences for health (Akgül and Ünver, 2001).

Medicinal and aromatic plants have been an integral part of human history for centuries, serving as sources of healing in both traditional and modern treatment methods. Due to their bioactive components, these plants hold significant importance in pharmaceutical, food, cosmetic, and aromatherapy industries. With the rising demand for natural products worldwide, the economic, ecological, and scientific importance of medicinal and aromatic plants continues to grow. Today, the terms "medicinal" and "aromatic" plants are often used interchangeably. Medicinal and aromatic plants refer to plants used as medicine to prevent diseases, maintain health, or cure illnesses. While medicinal plants are utilized in nutrition, cosmetics, body care, incense, or religious ceremonies, aromatic plants are mainly used to impart fragrance and flavor. Aromatic plants also have extensive applications in the food, cosmetic, and perfumery industries (Bayram et al., 2010). Medicinal plants refer to those parts of the plant or active substances derived from them, used internally or externally to treat diseases in humans and animals (İşler, 2016). Medicinal and aromatic plants are represented by hundreds of different species in various regions, known for their richness in biodiversity. Their chemical components, such as flavonoids, alkaloids, terpenoids, and phenolic compounds, exhibit various biological activities, including antioxidant, anti-inflammatory, antimicrobial, and anticancer properties. These attributes have made medicinal plants a cornerstone in traditional medicine for treating and preventing diseases for centuries.

Among the oldest discoveries to date are Neanderthal skeletons and pollen from various plants found in the Shanidar Cave of Anatolia and Mesopotamia, dating back to 50,000 BC. Fossil remnants of some medicinal plants still in use today were found in the Chauvet Cave in France and other caves dating back to around 30,000 BC during the "Paleolithic Age." Archaeobotanical evidence of the first agricultural activities was also identified around 10,000 BC (Genç, 2010).

According to archaeological findings from ancient times, humans initially relied on plants for food and to address health problems (Faydaoğlu and Sürücüoğlu, 2011). The number of plants used for treatment has steadily increased since antiquity. During the Mesopotamian civilization, around 250 plant-based drugs were utilized (Baytop, 1999).

The synthesis of sulfa drugs in the 1930s and organic chemicals in the 1940s encouraged the production of synthetic medicines in addition to medicinal plants. Economic and social changes following World War II, along with industrial advancements in synthetic chemical drugs, led to a decline in the use of plant extracts and plants in modernized Western countries until the late 1970s. Concerns about genetic diversity and the globalization of trade during the late 1990s and early 2000s influenced the cultivation of medicinal plants. Quality standards for plant materials and the demand for clean (free from physical and chemical residues), consistent, and certified products have increased (Bayram et al., 2010). As a result, the cultivation of numerous medicinal and aromatic plants has grown significantly.

For centuries, raw materials of plant origin were obtained wild from nature. Only a small portion of these plants was cultivated and farmed for food purposes. Even fewer species, typically high-value spice plants, were farmed. The cultivation of plants for medicinal purposes mostly began after the 19th century. Today, the farming, production, standardization, packaging, and marketing of medicinal plants are often carried out in separate countries (Europe and America), reaching significant commercial scales in economic activities (Genç, 2010).

Medicinal and aromatic plants are used as medicines in traditional and modern medicine to prevent diseases, maintain health, and cure illnesses. Additionally, they are utilized as dietary supplements, herbal teas, flavorings, and spices in nutrition. They also find wide application in the perfume and cosmetics industries as fragrances, body care products, and even insect repellents. The dried, processed plant parts, known as "drugs," are widely used in various fields. The demand for medicinal and aromatic plants as biological, cultural, and industrial resources has significantly increased in recent years and continues to grow. Their value is further elevated due to their multi-faceted effects and minimal side effects compared to synthetic alternatives in medicine and health (BAKA, 2012).

According to information provided by the World Health Organization (WHO), approximately 20,000 medicinal plants exist globally. However, some are not fully listed due to their localized use, suggesting the number may be as high as 75,000. The renewed focus on natural treatment methods in recent years has brought medicinal plants back into the spotlight. It is estimated that about 70% of currently used medicinal plants are collected from the wild, while 30% are cultivated (İşler, 2016).

This article examines the biological properties, historical uses, economic potential, and roles of medicinal and aromatic plants in modern science. It also aims to discuss strategies to ensure the sustainability of these plants in various industrial sectors. The solutions offered by medicinal and aromatic plants, described as "nature's cure," deserve a multidimensional approach, both scientifically and practically.

2. Medicinal and Aromatic Plants

Medicinal and aromatic plants hold a significant place in the global economic system. These plants are utilized across various industries such as pharmaceuticals, cosmetics, food, and beverages, creating a market worth billions of dollars. For instance, the demand for herbal medicines and supplements is rapidly increasing in both developed and developing countries. In 2020, the global herbal medicine market was reported to exceed $100 billion, with projections indicating further growth in the coming years.

In many countries, medicinal and aromatic plants have become an integral part of the agricultural economy. Their cultivation and processing generate a wide range of economic activities, from small farms to large agricultural enterprises. Countries like India, Turkey, and Morocco rank among the world’s leading producers due to their diversity and export volumes. In particular, Turkey, with its geographical diversity and favorable climate, serves as a major supplier of plants such as linden, thyme, sage, and lavender.

Additionally, the contribution of medicinal and aromatic plants to ecosystem services is economically valuable. These plants provide ecological benefits, such as reducing soil erosion, supporting biodiversity, and maintaining the carbon cycle. Beyond direct economic gains, these ecosystem services play a critical role in sustainable development and environmental balance.

Herbal teas, prepared by immersing leaves or flowers of certain plant species in hot water, briefly boiling, or pouring hot water over the plant, are widely consumed. For example, sage, traditionally used in folk medicine, typically includes species from the genera Salvia and Sideritis. The well-known genus Salvia derives its name from the Latin word Salvare, meaning "to heal." Species commonly known as mountain tea or upland tea in Turkey, such as Salvia L. and Sideritis L., are often sold as sage herbal products (Erez et al., 2014).

Herbal teas are prepared using extraction methods such as infusion, decoction, and maceration, with water serving as the solvent. The infusion method involves adding boiling water to finely chopped medicinal and aromatic plants (dried parts), allowing the mixture to stand at room temperature for a certain period (3–15 minutes) in a covered container before straining (Güven et al., 2014).

In recent years, the growing interest in natural treatment methods has accelerated scientific research on medicinal and aromatic plants. These studies particularly focus on identifying the active components of these plants for the development of medicines and herbal supplements. Moreover, the ecological importance of these plants and their contributions to sustainable agricultural practices are increasingly emphasized.

3. Natural Herbal Teas Prepared with Certain Medicinal and Aromatic Plants

Herbal teas made from medicinal and aromatic plants are renowned for their health benefits and are often used either as remedies for various ailments or as supportive elements for general well-being. These teas are derived from different parts of the plants, such as dried leaves, flowers, roots, or fruits. The plants and their benefits listed in this table have been compiled from various sources. The preparation methods have been described based on information obtained from local herbalists. Here is some information about herbal teas and a few examples:

Table 1. Plant Species Used for Preparing Natural Herbal Teas

Turkish name	Scientific name	Benefits	Preparation
Adaçayı	*Salvia officinalis* L.	It is used for stomach disorders and as a urea excretor (Selvi et al., 2013).	Infuse 1 teaspoon of sage leaves in 1 cup of hot water for 7–10 minutes.
Adi ardıç	*Juniperus comminus* L.	It is used for stomach pain (İlbaş et al., 2024).	Infuse crushed berries or leaves in hot water for 10 minutes; sweeten with honey if desired.
Ak söğüt	*Salix alba* L.	Willow bark tea is drunk (Sagiroglu and Aydin, 2024).	Infuse 1 teaspoon of willow bark in 1 cup of hot water for about 10 minutes before straining.
Alıç	*Crataegus monogyna* Jacq.	Its flowers are prepared by decoction and consumed against shortness of breath and heart diseases (Elçi and Erik, 2006). The fruit is prepared by decoction and consumed against circulatory system diseases (Polat and Satıl, 2012). Fruit and flowering branches are prepared by decoction and consumed against headache, stomach disorders and urinary tract diseases (Bulut and Tuzlacı, 2013).	Prepare using the decoction method with flowers or fruits.
Altınotu	*Ceterach officinarum* DC.	The leaves are brewed and drunk like tea to reduce kidney stones (Nacakcı and Dutkuner, 2018). It is drunk as a diuretic (Yalçın, 2005).	Infuse 3–4 sprigs in hot water for 10–15 minutes, strain and consume warm.
Anadolu Karaçamı	*Pinus nigra subsp. Pallasiana* (Lamb.) Holmboe	Drink the boiled juice for urinary tract pains and ulcers (Sagidroğlu and Aydın, 2024).	Boil the cones in water and consume.
Anason	*Pimpinella anisum* L.	It helps digestion and eliminates gas problems. It is used in menopause complaints (Faydaoğlu and Sürücüoğlu, 2011).	Crush 1 teaspoon of anise seeds, add to hot water, and steep for 5 minutes.

Aslanpençesi	*Alchemilla sp.*	It is used for lung diseases and kidney disorders (Erşen Bak and Çiftçi, 2020).	Boil the leaves and flowers and consume as tea.
Avokado	*Persea americana* Mill.	It supports kidney health (Sıcak et al., 2013).	Add 1–2 avocado leaves to hot water and steep for 10 minutes.
Aynısefa	*Calendula* sp.	It is drunk for liver disorders (Nacakcı and Dutkuner), menopause, ulcer, blood purifier and fungal diseases (Acartürk, 1996)	Add 1–2 teaspoons of dried flowers to 150 ml of hot water and steep for infusion.
Ayva	*Cydonia vulgaris* Pers.	It is used to relieve the common cold (Sıcak et al., 2013).	Add 1–2 slices of quince to hot water and steep for 5 minutes.
Biberiye	*Rosmarinus officinalis* L.	It can strengthen memory, improves blood circulation. Stomachic, diuretic, used for colds (Selvi et al., 2013).	Infuse 1 teaspoon of dried rosemary in 1 cup of hot water for 7–10 minutes.
Böğürtlen	*Rubus* sp.	It is used as a diuretic, to increase body resistance, in diabetes, mouth sores, hemorrhoids and wound treatment (Gül & Dinler, 2016).	Infuse 1 teaspoon of dried blackberry leaves in hot water for 10 minutes.
Ceviz	*Juglans regia* L.	The leaves are used as a germicide (Sıcak et al., 2013).	Infuse 1 teaspoon of finely chopped walnut leaves in hot water for 10 minutes.
Civanperçemi	*Achillea millefolium* L.	It relieves menstrual pains and soothes stomach and intestinal disorders (Yalçın, 2005).	Infuse 1 teaspoon of dried yarrow leaves in hot water for 10 minutes.
Çitlembik	*Celtis australis* L.	It is used for diarrhea (Sagiroglu and Aydin, 2024).	Boil leaves in water and strain to consume.
Çoban çantası	*Capsella bursa-pastoris* (L.) Medik.	It is used for diarrhea (Sagiroglu and Aydin, 2024).	Infuse dried aerial parts in hot water and strain.
Dağ çileği	*Fragaria vesca* L.	In urea and diabetes diseases, it removes toxins in the body, strengthens the immune system, regulates the digestive system, bad breath, reduces stress, has appetizing properties.	Infuse fresh or dried strawberry leaves in hot water for 15–20 minutes.

Defne	*Laurus nobilis* L.	The leaves are prepared by decoction and the juice is consumed against infertility (Polat and Satıl, 2012). The leaves are prepared by decoction and consumed against abdominal pain, colds and shortness of breath (Gürdal and Kültür, 2013).	Infuse 2–3 bay leaves in hot water for 10 minutes.
Dişbudak	*Fraxinus excelsior* L.	The leaves are boiled and drunk as a diuretic (Sagiroglu and Aydin, 2024).	Boil ash leaves in water and strain to consume.
Doğu Çınarı	*Platanus orientalis* L.	It is drunk against arthritis in the joint region (İlbaş et al., 2024).	Boil leaves in water and strain to consume.
Ebegümeci	*Malva sylvestris* L.	It is used in sore throat, cough and respiratory tract infections, burn treatment, stomach disorders, constipation, gum diseases (Gül and Dinler, 2016).	Infuse 1 teaspoon of dried mallow leaves in hot water for 10 minutes.
Ekinezya	*Echinacea purpurea* (L.) Moench	It strengthens immunity and is used for colds (Faydaoğlu and Sürücüoğlu, 2011).	Infuse 1 teaspoon of dried echinacea in hot water for 10 minutes.
Fesleğen	*Ocimum basilicum* L.	It reduces stress and supports the immune system. It is used as a carminative as well as for kidney and stomach disorders (Sıcak et al., 2013).	Infuse 1 teaspoon of dried basil in hot water for 7–10 minutes.
Gelincik	*Papaver rhoeas* L.	It is used for coughs, colds, bronchitis, colds and as an expectorant. It is good for calming and insomnia (Gül and Dinler, 2016).	Steep dried poppy flowers in hot water.
Hatmi Çiçeği	*Althaea officinalis* L.	It soothes cough and is good for throat irritation (Sıcak et al., 2013).	Infuse 1 teaspoon of dried hollyhock flowers in hot water for 10 minutes.
Hayıt	*Vitex agnus-castus* L.	It is used to eliminate menstrual irregularities (Sıcak et al., 2013).	Steep 1–2 teaspoons of chaste tree seeds in hot water for 5–10 minutes.
Hozan çiçeği	*Anthemis cotula* L.	It is boiled and drunk for stomach pains and colds (Sagiroglu and Aydin, 2024).	Boil flowers in water and strain to consume.

Hünnap	*Ziziphus zizyphus* (L.) Karst.	It is used for cough (İlbaş et al., 2024).	Boil fruits in water and strain to consume.
Ihlamur	*Tilia* sp.	It is very effective in cough, chest softener, intestinal worm reducer, asthma, heart diseases, insomnia, insomnia, as a sedative, arteriosclerosis, diuretic, gout, rheumatism, antispasmodic, colds, boils, burns and abscesses (Gül and Dinler, 2016).	Infuse 1–2 teaspoons of dried linden flowers in hot water for 10 minutes.
Isırgan Otu	*Urtica dioica* L.	It is protective against cancer. It is useful against rheumatic pains, eczema and boils. Increases urine and cleanses the blood. It removes harmful substances from the body. Cleans the kidney and liver. It is good for sore throats. It helps to pour kidney sand. It is an expectorant (Gül and Dinler, 2016).	Infuse 1 teaspoon of dried nettle leaves in hot water for 10 minutes.
İğde	*Elaeagnus angustifolia* L.	It is used in the treatment of ulcers (Sagiroglu and Aydin, 2024).	Steep dried leaves in hot water for 5 minutes.
Kara dut	*Morus nigra* L.	It is effective in blood pressure, diuretic, stress, anemia, worm reducer, diabetes, insomnia, thrush, mouthwash in mouth, gum and throat diseases, increasing body resistance, stomach and lung diseases (Gül & Dinler, 2016).	Boil dried leaves in water and strain to consume.
Karabaş otu	*Lavandula stoechas L.*	It is used as an expectorant (Sıcak et al., 2013).	Steep dried lavender flowers in hot water for 5–7 minutes.
Karaçalı	*Paliurus spina-christi* P. Mill.	It is used for kidney and urinary tract (Erşen Bak and Çiftçi, 2020).	Infuse dried spiny branches in hot water.
Karahindiba	*Taraxacum officinale*	It is good for diabetes and liver disease, eczema, constipation, body resistance, blood purification, calluses and warts, gall bladder and	Infuse 1 teaspoon of dried dandelion leaves in hot water for 10 minutes.

		bladder stones (Gül & Dinler, 2016).	
Katırtırnağı	*Spartium junceum* L.	It is used as a diuretic (Sıcak et al., 2013).	Boil in water and sweeten with honey.
Kekik	*Thymus vulgaris* L.	It is used for respiratory tract infections, cough, bronchitis, bad breath, rheumatism, sedatives, insomnia, cholesterol, dis and stomach pains, anemia, whooping cough (Gül and Dinler, 2016).	Infuse 1 teaspoon of dried thyme in hot water for 5 minutes.
Kızılcık	*Cornus mas* L.	It is used to reduce bile (İlbaş et al., 2024).	Boil and strain to consume.
Kuşburnu	*Rosa canina* L.	It is rich in vitamin C and strengthens immunity (Selvi et al., 2013).	Infuse 1 teaspoon of dried rosehip in hot water for 10–15 minutes.
Laden	*Cistus laurifolius* L.	It is drunk as an aid in cancer treatment (Nacakcı and Dutkuner, 2018).	Infuse dried flowers in hot water.
Lavanta	*Lavandula angustifolia* Mill.	It is brewed and drunk like tea against arteriosclerosis and tumors (Nacakcı and Dutkuner, 2018).	Infuse 1 teaspoon of lavender flowers in hot water for 5–7 minutes.
Melisa Çayı	*Melissa officinalis* L.	It is used as a carminative and digestive system regulator, in bronchitis, asthma, anemia, insomnia, appetite stimulant, indigestion, stomach and intestinal pain, migraine, dizziness, tinnitus, and as a sedative (Gül and Dinler, 2016). It is used to reduce chest and heart pain (Sıcak et al., 2013).	Infuse 1–2 teaspoons of dried lemon balm in hot water for 10 minutes.
Mercanköşk	*Origanum majorana* L.	It prevents stomach and intestinal disorders, stimulates appetite, increases urine, increases urine output, relieves flatulence, constipation, headache, cramps and pain (Gül and Dinler, 2016).	Boil dried marjoram in water and sweeten with honey.
Saçlı meşe	*Quercus cerris* L.	Infections, hemorrhoids, skin diseases and consumed against eczema (Arı et al., 2015).	Prepare decoction of oak fruits and consume.

Mısır	*Zea mays L.*	It is used for diabetes, urine enhancer, urinary tract inflammation (Erşen Bak and Çiftçi, 2020).	Boil corn silk in water and consume.
Nane-Limon	*Mentha piperita + Citrus limon*	It is good for colds and calms nausea. It is used to relieve rheumatism, abdominal and muscle pain (Sıcak et al., 2013).	Steep fresh mint leaves and lemon slices in hot water for 5–7 minutes.
Papatya	*Matricaria chamomilla* L.	It regulates digestion, relaxes and helps sleep (Yalçın, 2005). It is drunk for inflammation of the throat, rheumatism and hemorrhoids (Treben and Giray, 2009).	Infuse 1 teaspoon of dried chamomile in hot water for 5–10 minutes.
Portakal	*Citrus sinensis* L.	It is used in cases of tonsillitis and colds (Sıcak et al., 2013).	Boil orange peels in water for 10 minutes and strain to consume.
Rezene	*Foeniculum vulgare* Mill.	It relaxes digestion and relieves gas problems. It is drunk for stress, depression and sleep disorders (Faydaoğlu and Sürücüoğlu, 2011).	Infuse lightly crushed fennel seeds in hot water for 5–10 minutes.
Sarı Kantaron	*Hypericum perforatum* L.	It can alleviate the symptoms of mild depression and relaxes the nervous system. It is used for stomach pain, wounds and burns, rheumatic pains (Sıcak et al., 2013).	Infuse 1 teaspoon of dried St. John's wort in hot water for 10 minutes.
Sığırkuyruğu	*Verbascum orientale subsp. orientale* (L.)	It is used in the treatment of asthma and cough (Sagiroglu and Aydin, 2024).	Boil leaves in water and strain to consume.
Sumak	*Rhus coriaria* L.	It strengthens the immune system, facilitates digestion and has anti-inflammatory properties (Akay et al, 2023).	Infuse dried sumac fruits in hot water.
Şerbetçiotu	*Humulus lupulus* L.	It supports sleep patterns and may reduce anxiety (Faydaoğlu and Sürücüoğlu, 2011).	Infuse 1 teaspoon of dried hops flowers in hot water for 5–10 minutes.
Uludağ Göknarı	*Abies nordmanniana*	It is good for colds (Sagiroglu and Aydin, 2024).	Boil fir leaves in water and strain to consume.

	subsp. *born-muelleriana* (Mattf.) Co-ode & Cullen		
Yaban mersini	*Myrtus communis* L.	It supports eye health and strengthens immunity with its antioxidant effect. It is used as an expectorant (Sıcak et al., 2013).	Infuse 1 teaspoon of dried myrtle leaves in hot water for 10 minutes.
Yeşil Çay	*Camellia sinensis* (L.) Kuntze	With its antioxidant properties, it accelerates metabolism and supports cell health. It is drunk for forgetfulness and memory weakness and high cholesterol (Faydaoğlu and Sürücüoğlu, 2011).	Steep green tea leaves in hot water for 2–3 minutes.
Zahter (Dağ Kekiği) Çayı	*Thymbra spicata* L.	It is used for painkillers, cough suppressants, colds, flu, abdominal pain, stomach pain (Yeşil and İnal, 2021).	Infuse 1 teaspoon of dried thyme leaves in hot water for 5–7 minutes.
Zencefil	*Zingiber officinale* Roscoe	It is used for nausea and pain and sexual reluctance (Faydaoğlu and Sürücüoğlu, 2011).	Boil fresh ginger slices in water for 10 minutes.
Zerdeçal	*Curcuma longa* Linn.	It is known for its anti-inflammatory effects and strengthens immunity. It is drunk for gall bladder disorders, prostate enlargement and weight loss (Faydaoğlu and Sürücüoğlu, 2011).	Mix 1 teaspoon of powdered turmeric with hot water and steep for 5 minutes.
Zeytin	*Olea europaea* L.	It is drunk for diabetes (Erşen Bak and Çiftçi, 2020).	Infuse 1 teaspoon of dried olive leaves in hot water for 5 minutes.

4. Conclusion

Medicinal and aromatic plants have been an indispensable source of healing throughout history and continue to hold their importance today. With their natural components, these plants find extensive applications in various sectors such as healthcare, food, cosmetics, and aromatherapy. They contribute to ecosystems by enhancing biodiversity and offer significant economic opportunities. In regions like Anatolia, known for its rich biodiversity, the sustainable use of these plants is both a vital resource for local economies and a necessity for environmental sustainability.

In recent years, the growing interest in natural treatment methods has accelerated scientific studies on the active compounds of medicinal and aromatic plants. These studies have the potential to further enhance their use in both traditional and modern medical practices. However, ensuring their sustainable supply, maintaining quality standards, and reducing ecological pressure must be approached as a long-term strategy.

In the future, innovations in the cultivation and processing of medicinal and aromatic plants could fully unlock their potential. In this context, collaboration, knowledge sharing, and educational activities at both local and international levels are of great importance. These plants should be regarded as a gift of nature, and the necessary steps should be taken to preserve this rich heritage for future generations.

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Chapter 5

ANN-Powered Forestry: Enhancing Accuracy in Height-Diameter Models Predictions

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1. Introduction

Forest inventory is one of the most important bases for national and international reports (e.g. FAO, UNDP and WWF). Moreover, forest inventories, tree volume, stand conditions, forest biomass and carbon stocks are among the most important characteristics reported on (Vidal et al., 2016). The relationship between tree height and diameter is one of the most fundamental and widely studied aspects in forest inventory and forest management practices (Van laar and Akça, 2007; Özçelik et al., 2018; Ciceu et al., 2023). Accurate height-diameter models are essential for a variety of forestry applications, including estimating some stand and forest variables (Lei and Parresol, 2001; Özçelik and Alkan, 2020). These models also play a critical role in sustainable forest management, site productivity assessments, and understanding forest growth dynamics (Bronisz and Mehtätalo, 2020). Given their importance, effective modeling of these relationships has been a focus of forestry research for decades (Carus and Çatal, 2005; Carus, 2010; Özçelik et al., 2013; Diamantopoulou et al., 2015; Ercanlı, 2020; Özçelik and Alkan, 2020; Diamantopoulou et al., 2023).

Traditionally, height-diameter models have relied on statistical regression techniques, ranging from simple linear models to more complex nonlinear and mixed-effects models (Özçelik et al., 2018; Alkan and Özçelik, 2022). While these methods have proven effective in many contexts, they come with inherent limitations. For instance, traditional models often struggle to account for the variability introduced by diverse forest types, uneven-aged stands, and environmental factors such as soil quality and climate (Peng, 2000; Weiskittel et al., 2011). Additionally, these methods rely on extensive field data collection, which can be costly and time-consuming, particularly in large or remote forested areas (Vidal et al., 2016).

The emergence of ANNs has transformed the field of forestry by offering a powerful alternative for height-diameter modeling. ANNs, with their ability to capture complex nonlinear relationships, have demonstrated superior predictive capabilities compared to traditional approaches (Li et al., 2021; Bayram et al., 2024). They are particularly adept at handling diverse datasets and incorporating multiple variables, such as competition indices and site-specific conditions. As a machine learning technique, ANNs not only improve prediction accuracy but also reduce the reliance on exhaustive field data collection, making them a cost-effective solution for modern forestry challenges. In this chapter, we dive into the transformative potential of ANNs in height-diameter modeling. Leveraging recent advancements in neural network design and optimization, ANNs represent a promising path forward for sustainable forest management and ecological research (Abdolrasol et al., 2021)

Artificial Neural Network (ANN) modeling is a computational tool designed to describe input-output relationships in processes or systems where developing mathematical models is challenging. Inspired by the structure of biological neural networks, ANNs use artificial neurons, with feedforward multilayer perceptrons being a notable example (Diamantopoulou, 2005). Learning in these networks is facilitated by algorithms such as gradient descent, Levenberg-Marquardt, or genetic algorithms (Russell and Norvig, 2003; Haupt, 2004; Diamantopoulou et al., 2023; Kardeş et al., 2024). ANN structures consist of nodes, where input nodes represent independent variables and output nodes represent dependent variables. Research highlights the effectiveness of ANNs in such as turbidity removal modeling, showcasing their ability to predict turbidity removal performance and accurately capture complex linear and nonlinear input-output relationships (Ezemagu et al., 2021; Diamantopoulou et al., 2023; Kardeş and Öngen Bilir, 2024). The ANN model used includes an input layer, a hidden layer, and an output layer (Figure 1).

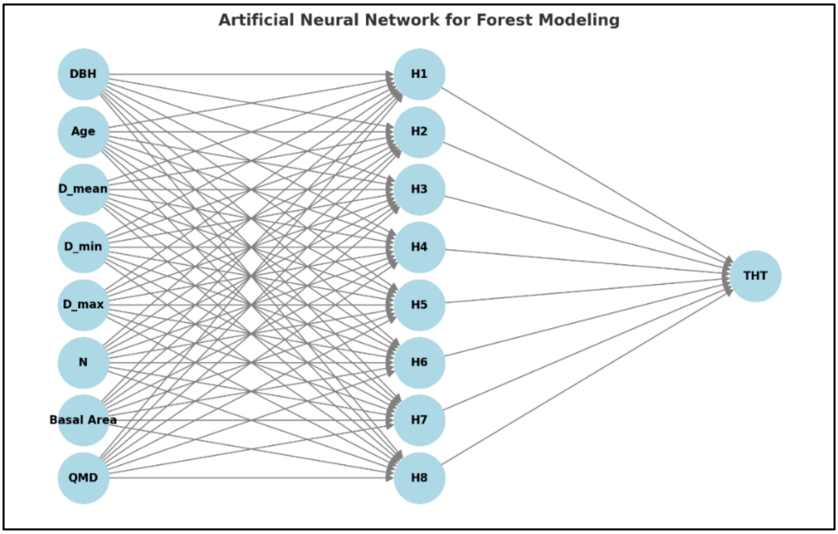

Figure 1. Input-Output Relationships in Forest Modeling Using ANN

Figure 1 illustrates the input-output relationships in forest modeling using ANNs. In this model, ANNs predict total tree height (THT) based on input variables such as $DBH, Age, Dmean, Dmax, Dmin, N, Basal\ Area$ and

Quadratic Mean Diameter (QMD). These inputs represent raw data describing tree and stand characteristics, providing crucial insights into forest structure. The variables are normalized or scaled to ensure consistent ranges for optimal processing within the ANN, which transforms features through hidden layers and optimizes weights to achieve accurate predictions of THT.

2. Artificial Neural Networks in Forestry

The ANNs are a subset of machine learning inspired by the structure and functionality of biological neural networks. ANNs are designed to process information and identify patterns in data by simulating interconnected neurons organized in layers. The three primary components of an ANN are:

- **Input Layer:** This layer receives raw data, such as tree diameter, site conditions, and other predictor variables relevant to height-diameter relationships.
- **Hidden Layers:** These layers perform computations to detect patterns and relationships in the data. Each neuron in the hidden layers applies an activation function (e.g., Sigmoid, ReLU, Levenberg-Marquardt) to combine and transform the input data.
- **Output Layer:** This layer produces the final predictions, such as tree height, based on the processed inputs.

Training an ANN involves adjusting the network's weights through algorithms like backpropagation, which minimizes the difference between predicted and actual values. Optimization techniques, such as Stochastic Gradient Descent (SGD), Adam, and Levenberg-Marquardt algorithms, are used to enhance learning efficiency. Advanced features like dropout regularization and cross-validation are often implemented to prevent overfitting and improve generalization (Salehnasab et al., 2022). A basic ANN formula is given Equation 1. Also, the formula for multi-layer neural networks, which form the basis of deep learning, is given Equation 2.

$$y = f(\sum_{i=1}^{n} w_i x_i + b) \qquad \text{Eq. 1}$$

Here f = Activation function (introducing nonlinearity (e.g., Sigmoid, ReLU, Tanh)), y= Output of the neuron, either the final prediction or input to subsequent layers., b =Bias, w_i = Weight corresponding to -th input, x_i= The -th input feature.

$$a^{(x)} = f\left(W^{(x)} a^{(x-1)} + b^{(x)}\right) \qquad \text{Eq. 2}$$

Here $a^{(x)}$= Activation output of the current layer x, $W^{(x)}$ = Weight matrix of layer x, where each weight determines the strength of the connection between the neurons in the previous layer (x-1) and the current layer (x), $a^{(x-1)}$= Activation output of the previous layer (x-1), it serves as the input to the current layer, b = Bias vector for layer x, f = Activation function applied element-wise to the weighted sum.

3. Applications for Height-Diameter Modeling

ANNs have proven to be innovative tool in forestry for modeling height-diameter relationships. These relationships, critical for forest inventory, biomass estimation, and sustainable forest management, are often nonlinear and complex. ANNs' ability to model these intricate relationships stems from their flexibility, adaptability, and advanced learning capabilities. This makes them particularly suitable for modern forestry challenges, where traditional regression and mixed-effects models may fall short.

Advantages Over Regression and Mixed-Effects Models

Nonlinear Flexibility: Traditional models, such as linear and nonlinear regression, depend on predefined equations that may struggle to fully capture the variability in height-diameter relationships, especially in diverse and complex forest ecosystems. In contrast, ANNs operate without such assumptions and can approximate any nonlinear function given adequate data and network complexity. This flexibility is particularly advantageous in forests with steep environmental gradients, such as varying soil types or altitudinal zones, where ANNs can dynamically adapt to these changes and more accurately model the height-diameter relationship.

Higher Predictive Accuracy: ANNs consistently outperform regression and mixed-effects models in terms of accuracy metrics, including Root Mean Square Error ($RMSE$), Mean Absolute Error (MAE), and R^2 values (Ercanlı, 2020; Diamantopoulou et al., 2023). In a comparative study, ANNs achieved a reduction in $RMSE$ by up to 15% compared to traditional models in mixed-species forests (Skudnik and Jevšenak, 2022). This notable improvement enhances the precision of predictions for key forest metrics such as timber volume, carbon stock, biomass, and volume estimation, making ANNs a powerful tool for forest management and planning.

Adaptability to Diverse Forests: Traditional models often require significant customization to accommodate different forest types, such as even-aged, mixed, or uneven-aged stands. In contrast, (ANNs) are inherently versatile, capable of integrating diverse inputs like soil properties, climatic variables, and competition indices to generate predictions tailored to specific forest conditions. This adaptability is particularly advantageous in uneven-aged forests, where high species and structural variability pose challenges for conventional methods. For example, ANNs have demonstrated superior performance in capturing the unique growth dynamics of individual trees in such forests, as highlighted by Shen et al. (2020).

Handling Noisy and Incomplete Data: Forestry data often faces challenges such as missing measurements and variability in sampling methods, which can hinder accurate modeling. ANNs offer a significant advantage in such scenarios due to their robustness to noise and their ability to infer relationships even with incomplete datasets. Unlike traditional methods that typically require complete and consistent data, ANNs can effectively handle these imperfections, making them particularly valuable for addressing real-world forestry data complexities.

4. Case Studies and Applications

Diverse Forest Conditions: In mixed-species forests, such as those in Northern Iran or tropical rainforests, ANNs have demonstrated superior performance in capturing the variability of height-diameter relationships compared to traditional models (da Silva et al., 2020; Skudnik and Jevšenak, 2022). By incorporating additional variables, such as competition indices, ANNs have achieved higher predictive accuracy and lower error rates. Moreover, in forests with limited height data, ANNs have been effectively utilized to impute missing values, facilitating more comprehensive and reliable forest inventories. These capabilities make ANNs a valuable tool for managing complex and data-scarce forest ecosystems.

Deep Learning Innovations: The integration of deep learning techniques into forestry has further enhanced the predictive capabilities of ANNs. Deep neural networks with multiple hidden layers have been successfully utilized to model complex relationships in large datasets, such as those derived from UAV (Unmanned Aerial Vehicle) imagery and LiDAR scans (Ercanlı, 2020; Júnior et al., 2020). For instance, a study focusing on Crimean Pine stands demonstrated that deep learning models with optimized architectures, including nine hidden layers and 100 neurons, significantly outperformed traditional regression and mixed-effects models, achieving an RMSE of less than 0.6 (Ercanlı, 2020).

Integration with Advanced Data Sources: The integration of ANNs with remote sensing data, such as UAV-based spectral indices and airborne LiDAR, has significantly advanced the prediction of forest stand height and diameter relationships on a broader scale (da Silva et al., 2020). These combined approaches have proven instrumental for large-scale forest management and carbon accounting. For instance, ANN models utilizing UAV-derived vegetation indices have successfully estimated eucalyptus tree heights and diameters, demonstrating higher correlations with field measurements compared to traditional regression models (da Silva et al., 2020; Dindaroğlu et al., 2022). This emphasizes the potential of integrating ANNs with remote sensing technologies to improve precision and efficiency in forest assessments.

Applications in Mixed and Uneven-Aged Forests: Mixed and uneven-aged forests pose significant challenges for traditional modeling approaches due to their structural and compositional heterogeneity. However, ANNs have demonstrated the ability to effectively model height-diameter relationships in these complex systems by incorporating diverse variables such as diameter at breast height (DBH), basal area, and competition indices (Bayat et al., 2020; Skudnik and Jevšenak, 2022). For instance, Costa et al. (2022) explored the use of ANNs to estimate tree heights for *Araucaria angustifolia* in Uneven-aged Mixed Forests (UMF) in southern Brazil. This study utilized a dataset including continuous variables like DBH and height at the base of the crown (HCB) alongside a categorical variable representing the tree's sociological position (dominant, codominant, dominated). The data was split into training and validation sets, with tree height modeled as the continuous output variable, the ANN's capacity to handle the complexities of UMFs.

Future Directions in ANN Applications: Hybrid modeling approaches, such as combining ANNs with other machine learning techniques like Random Forest or Support Vector Machines, offer promising avenues for enhancing predictive accuracy in forest height-diameter modeling (Diamantopoulou et al., 2023). Additionally, incorporating detailed climatic and environmental data as input variables can significantly improve model robustness and applicability, particularly in the context of changing climate conditions (Pérez-Sánchez et al., 2019). Moreover, integrating ANN models with IoT (Internet of Things) sensors and real-time data collection systems presents an opportunity for dynamic forest management and decision-making through real-time monitoring and predictions (Atighi and Zhou, 2023).

5. Comparison of Techniques Across Studies:

Mixed-effect models have demonstrated strong performance for small datasets or localized conditions, providing reliable predictions in specific contexts. In contrast, ANNs and Deep Learning Algorithms (DLAs) excel in processing large and diverse datasets, making them well-suited for broader applications. Furthermore, the integration of remote sensing technologies, as highlighted by da Silva et al. (2021), has emerged as a transformative innovation, enabling accurate large-scale predictions without the need for extensive fieldwork, thereby enhancing efficiency and scalability in forest modeling.

Hybrid Approaches: Hybrid modeling approaches combine the strengths of multiple methodologies, offering a promising avenue for advancing predictive capabilities in forestry. By integrating ANNs with other machine learning techniques or statistical models, researchers have demonstrated significant improvements in addressing site-specific variability and enhancing model robustness.

For instance, the combination of ANNs with Adaptive Neuro-Fuzzy Inference Systems (ANFIS) has shown promise in capturing intricate relationships in mixed-species forests. These hybrid models leverage the adaptability of ANNs and the rule-based reasoning of ANFIS, enabling a nuanced understanding of ecological dynamics. A study by Bayat et al. (2020) demonstrated that hybrid models incorporating ANN and ANFIS outperformed standalone regression models in predicting tree height in the Hyrcanian forests of Iran.

Another promising direction involves combining ANNs with Random Forests (RF) or Support Vector Machines (SVM), creating ensembles that optimize predictive performance across diverse datasets (Ciceu et al., 2021; Costa et al., 2022). Such hybrid approaches have been particularly effective in addressing issues of overfitting and improving generalization, as they benefit from the complementary strengths of different algorithms.

Future Research Directions: To further enhance the adaptability and accuracy of ANN models, incorporating additional environmental factors, such as climate, soil properties, and topographical data, is a crucial next step. These variables can provide a more holistic understanding of tree growth dynamics, particularly under the pressures of climate change. For instance, integrating long-term climate data into ANN models could allow for predictions of forest growth under various climate change scenarios, aiding in the development of adaptive management strategies.

The use of real-time data from UAVs and IoT sensors represents another frontier in forest modeling. By dynamically updating ANN models with live data streams, researchers can create responsive systems capable of real-time monitoring and decision-making. For example, Atighi and Zhou (2023), explored the potential of integrating IoT-based environmental sensors with ANN models to predict growth rates and health conditions in managed forests. Such advancements could enable proactive interventions, such as identifying and addressing drought stress or pest outbreaks before they cause significant damage.

Forestry Applications: The versatility of ANN and deep learning techniques is evident in their applications across diverse forest ecosystems worldwide. These methodologies have been successfully employed in temperate zones like Türkiye, where Özkal et al. (2021) demonstrated their superiority over traditional regression models for height-diameter modeling in fir stands. Similarly, in tropical regions, Ogana and Ercanlı (2020) utilized deep learning algorithms to model complex relationships in diverse ecosystems, achieving high accuracy despite the challenges posed by structural and compositional variability.

In arid zones, such as the Hyrcanian forests, Bayat et al. (2020) highlighted the effectiveness of ANN and ANFIS models in predicting tree height and diameter. These forests, characterized by uneven-aged stands and mixed-species compositions, present significant challenges for traditional modeling approaches. The use of ANN models in these contexts has provided actionable insights for sustainable forest management.

Sahin et al. (2023) aimed to compare ANN and OLS methods for *Quercus petraea* (Matt.) Liebl.) stands in the Marmara region. They tested the models with machine learning techniques such as ANN, decision trees, support vector machines, and random forests. ANN model was selected as the best estimation method according to the relative ranking method. They also reported that adding stand variables along with DBH as input to the model increased (R^2) by approximately 36% and reduced the error rate by 55%.

Thanh et al. (2019) compared six nonlinear equations and ANN models for modeling and validating the height-diameter relationship in three different stand densities within a 43-year-old even-aged Korean pine (*Pinus koraiensis*) is a commercially important tree species in Northeast China. ANN models significantly outperformed nonlinear models, reducing the Root Mean Square Error ($RMSE$) by up to 40% compared to the Power function.

Ou and Quiñónez-Barraza (2023) evaluated the nonlinear mixed effect modeling (NLMEM) and resilient backpropagation artificial neural network (RBPANN) approaches for modeling the total tree height (H) and diameter at breast height (DBH) relationship in *Durango pine* species within mixed-species forests in Mexico. Using a dataset of 11,472 measured trees from 1,000 inventory plots, the data was divided for training and testing and grouped into 10 clusters via k-means clustering. Various RBPANN activation functions (tanh, softplus, logistic) and hidden layer vectors were tested, with performance assessed using statistics like SSE, FI, E, RE, logLik, RSEE, RMSE, AIC, and BIC. The ANN approach, particularly RBPANN-tanh, demonstrated superior performance over NLMEM in both training and testing datasets. Figure 2 shows various vector trials for the basic ANN model developed by the researchers for the RBPANN model. Here, the best model structure was found to be with 10 hidden layers and DBH and clustered input variables.

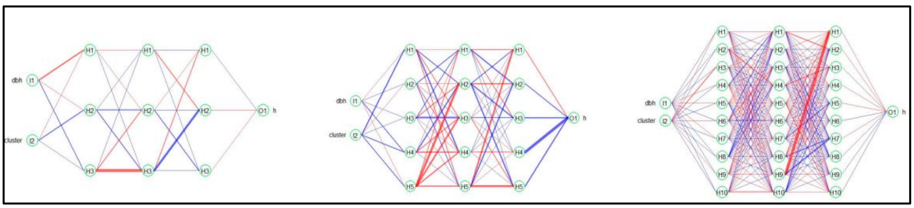

Figure 2. Diagram showcasing the architectures of ANNs with three hidden layer configurations: c(3, 3, 3) (left), c(5, 5, 5) (center), and c(10, 10, 10) (right) (Ou and Quiñónez-Barraza (2023).

Shen et al. (2020) conducted on poplar plantation data from Guangdong, China, utilized a backpropagation (BP) neural network model with two hidden layers and five neurons per layer, achieving better accuracy than traditional regression and mixed-effects models. Compared to the Mitscherlich height-diameter model, the BP neural network increased the coefficient of determination (R^2) by 10.3% and reduced root mean square error ($RMSE$) and mean absolute error (MAE) by 12% and 13.5%, respectively. The study highlighted the importance of determining the optimal number of hidden layers, neurons, and transfer functions in neural network structures.

Ciceu et al. (2023) utilized an open-source dataset available from the *lmfor R* package to conduct measurements on 1,678 trees. Their study found that mixed-effect calibration yielded better results based on six different statistical criteria. Notably, the inclusion of dominant diameter as a variable significantly improved calibration performance. In this study conducted by Ciceu et al. (2023), the use of various calibration methods in height-diameter models is presented. Here, this study can serve as a reference for determining which variables should be included in the model structure in height-diameter models using the ANN method to enhance the model's prediction performance (Figure 3).

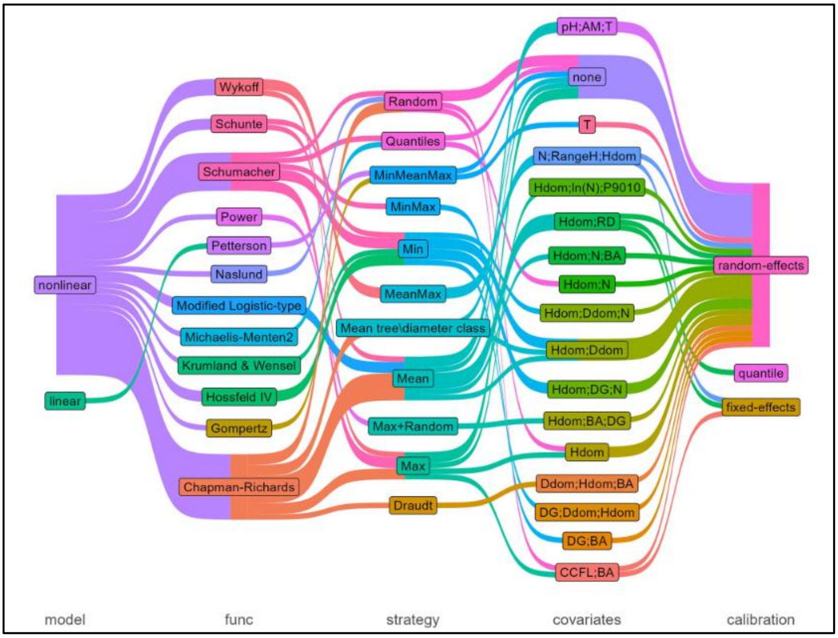

Figure 3. Different calibration methods in height-diameter models (Ciceu et al., 2023)

Similarly, Ogana and Ercanlı (2020) applied the k-means clustering technique to group data based on diameter-to-height ratios. In their study, measurements were taken on 1,736 tropical trees from 52 sample plots. The best modeling results were obtained with ANNs using between six and nine hidden layers, with performance highly dependent on the number of hidden layers and neurons. That research demonstrated the potential of deep learning as a powerful tool for predicting dendrometric variables in complex tropical ecosystems.

Özkal et al. (2021) explored height-diameter modeling for natural fir (*Abies nordmanniana*) stands in Türkiye. They compared traditional statistical methods with artificial intelligence techniques, particularly feed-forward backpropagation ANNs implemented in MATLAB (Mathworks, 2017). Using the Levenberg-Marquardt algorithm for weight and bias updates and Mean Squared Error (MSE) as the performance metric, the ANN model outperformed traditional approaches, demonstrating its effectiveness for such modeling tasks.

da Silva et al. (2021) combined machine learning methods with remote sensing techniques to estimate tree diameter and height. Their research on Eucalyptus species tested various machine learning techniques, including random forest (RF), REPTree (DT), alternating tree model (AT), k-nearest neighbors (KNN), support vector machines (SVM), ANN, linear regression (LR), and radial basis functions (RBF). The results showed that integrating machine learning techniques with vegetation indices derived from UAV imagery provided accurate predictions DBH and THT. This approach highlights the potential of UAV-based precision forestry techniques for enhancing forest inventories (da Silva et al., 2021)

Özçelik et al. (2013),) tested height-diameter models for Crimean juniper trees in their study. The calibrated basic h-d mixed model generalized h-d model and back-propagation ANN h-d models were compared in the study. Mixed effect nonlinear regression and back-propagation neural network modeling approaches produced up to 20% better results than the basic model in $RMSE$ metric.

In another study, Ercanlı (2020) developed a height-diameter model for Crimean pine (*Pinus nigra*) in the Konya region using a deep learning algorithm (DLA). The study identified the optimal DLA model with nine hidden layers and 100 neurons, outperforming traditional nonlinear regression, mixed-effects models, and standard ANNs in predictive accuracy. This underscores the growing importance of DLAs in forestry applications, particularly for modeling complex relationships.

Bayat et al. (2020) investigated tree height predictions in uneven-aged, mixed-species forests of the Hyrcanian region in northern Iran. Using artificial intelligence (AI) methods, including ANNs and Adaptive Neuro-Fuzzy Inference Systems (ANFIS), along with ten nonlinear empirical models, they demonstrated the superiority of AI approaches over empirical models. The ANN model achieved an R^2 of 0.78 and an $RMSE$ of 18.49%, indicating significantly better performance than traditional methods for modeling height-diameter relationships.

6. Conclusion

This chapter highlights the significant advantages of ANNs over traditional methods in modeling tree height-diameter relationships. The superior capability of ANNs to capture complex, nonlinear interactions has established them as indispensable tools for both academic research and sustainable forestry practices. Their adaptability to diverse forest types and environmental conditions allows them to surpass traditional regression and mixed-effects models in terms of accuracy and generalization (Diamantopoulou, 2005; Ercanlı, 2020; Skudnik and Jevšenak, 2022; Diamantopoulou et al., 2023). Additionally, innovative approaches such as integration with remote sensing data have further enhanced the potential of ANNs for large-scale forest management and carbon accounting (da Silva et al., 2021). These technologies effectively address challenges like data scarcity and noise, while also reducing field measurement efforts, saving time and costs (Ogana and Ercanlı, 2022).

Future advancements in ANN applications, such as incorporating climate change variables and real-time data from IoT sensors, could provide a more comprehensive understanding of forest ecosystems and enable dynamic management strategies (Atighi and Zhou, 2023). For example, ANN models enriched with detailed climatic and soil data can better predict forest growth under various climate scenarios, aiding in adaptive management efforts (Pérez-Sánchez et al., 2019). In conclusion, ANNs represent a transformative paradigm in forestry, offering robust solutions for complex ecological modeling and sustainable forest management.

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Chapter 6

Inbreeding Relationships in Poultry Science and Their Assessment

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1. INTRODUCTION

Animal breeding is a branch of science that works to obtain new individuals with the desired genotypes by effectively using the genetic potential of existing animal material. Animal breeding science is directly related to genetics, mathematics, statistics, computers, animal breeding and animal nutrition sciences. The type of data obtained from animals, their distribution, modeling, discussion of production methods and decision processes are related to statistics and mathematics. Differences between animals and generations, distributions at the population level, molecular structures that provide efficiency in animals are related to genetics. Providing physiological needs and providing appropriate environmental conditions to transform the genetic potential of animals into products are also feeding and breeding issues. Information technology also allows these scientific fields to function interactively (Elzo, 2009; Lio, 2009).

There are important differences that distinguish poultry breeding from breeding of other animals. Especially the fact that the animals used in commercial broiler and layer chicken breeding have hybrid characteristics makes chicken breeding special. In order to obtain hybrid products, long-term selection studies should be carried out on pure lines with different genotypic structures and suitable combinations of lines should be determined and should show significant heterotic effects. Another important difference in poultry breeding is that the animals in the lines are in family structure. Selection in poultry breeding is carried out by selecting families within the line, selecting individuals within the family and applying their combinations with a certain order. Commercial poultry breeding is carried out under environmentally controlled conditions and due to the short intergenerational periods, the number of fixed effects and variation originating from the environment in statistical models are low compared to other species. The high measurable yields in poultry animals increase the number of characteristics emphasized in parallel with the principle of gene dependency (Quinton, 2003).

Breeding studies on poultry animals begin with identifying existing animals and determining the direction of genotypic development in these animals. Determining the productivity characters and related traits to be improved, and which traits to focus on in which animal groups are among the first steps to be taken. For example, in a breeding study aimed at increasing egg productivity, a large number of traits such as egg count, egg quality, age at sexual maturity, weight at sexual maturity, adult live weight in the sire line, egg weight, viability, and fertility are considered together. The direction of breeding practices is decided with the parameters obtained as a result of the phenotypic and genetic variation measured in the existing population in terms of traits (Szwaczkowski, 2003).

The selection of the parents that will form the next generation is one of the most important stages of animal breeding. Selection application in poultry breeding has been going on for many years compared to the breeding of other species. Today, it is estimated that selection has been applied for 60-90 years in the lines owned by multinational companies that breed broilers and laying hens. The first selection application in poultry breeding was carried out in the early twentieth century with the mass selection method, which was carried out by ranking the animals according to their own productivity. In the following years, with the establishment of family structures in animals, the emergence of differences in full-sibling and half-sibling groups and the ability to associate gender-specific characteristics with sibling and offspring productivity, mass selection was replaced by the application called index selection (Quinton, 2003). The selection index method, whose theory was put forward by Pearson and used to estimate the genetic values of individuals based on different information, was developed in later years with the contributions of Wright, Lush and especially Smith and Hazel. The method assumes that the records are correctly corrected by fixed effects and assumes multivariate normal distribution (Muir 2000). With the introduction of the index selection method in poultry breeding, genetic parameters were taken into account in the selection of animals, relationships between related groups were calculated, and evaluations were made for many traits. Great progress was made in poultry breeding with the selection index methods that began to be used in the mid-twentieth century. Today, selection index methods are widely used, and successful results are obtained.

The biggest disadvantages of the selection index application are the necessity of estimating the correction factors in terms of fixed effects and the inability to fully use the kinship information of individuals. Henderson combined the selection index and EKK methods by developing mixed model equations, thus reaching the BLUE (best linear unbiased estimation) estimates for fixed effects and BLUP (best linear unbiased estimation) estimates for random effects in the same model (Muir and Aggrey, 2003).

In the mid-twentieth century, hybrid products were obtained in chickens as a result of poultry breeding studies. Poultry breeders who used selection index methods in the development of lines to produce hybrids did not show much interest in the mixed model equations (MME) enriched by Henderson. Today, the use of MME in poultry breeding studies is quite limited. On the other hand, MME has found an important area of use especially in cattle breeding. While the BLUP results obtained from MMEs provide significant superiority over index selection, especially in terms of taking into account the relationships between relatives, the processing volume is expanded by including the kinship matrix in the calculations (Muir 2000). While there is no problem in the calculation of small data sets, it is necessary to perform the calculation of MME with appropriate software on a computer with sufficient processor speed in large data sets that require the solution of a large number of equations.

By using different models in the evaluation of data through some software for animal breeding, variance elements, heritability levels, phenotypic, genetic and environmental correlations for traits, and breeding values can be calculated. Since poultry breeding studies require more special procedures and there are only a few research institutions worldwide that conduct breeding studies on poultry, there is no computer program specific to poultry breeding. The breeding software used is generally programs designed with cattle in mind. These software include PKREML, DFREML, MTDFREML, PEST, VCE, ABTK, DMU, JAA, MTC, JSPFS, MTGSAM, QUERCUS and ASREML. The common feature of these programs is that they are written in programming languages that have lost their popularity today. Similarly, many of the programs run in DOS environments and some run in UNIX/LINUX operating systems that are not widely used. There is no program with a suitable user graphic interface in Windows. The MTDFREML program and its latest version, WOMBAT, run in both LINUX and DOS environments, and ASREML, which runs on a graphical interface as an add-on to R and S-PLUS programs, are the most widely used animal breeding software.

SAS (Statistical Analysis System) program was developed at NC State University in the 1970s for use in agricultural research and has become one of the largest software programs in the field of analysis and data management over time. Today, with its advanced modules, it produces data analysis, data management, and database application solutions in the fields of social and science sciences. It offers users a wide range of processing options with its open-ended codes and has a macro language that can be developed by users.

In this study, it was aimed to analyze the kinship relationships in animal breeding in SAS software and to introduce the SAS PROC INBREED procedure.

2. RELATIONSHIPS AND INBREEDING

Kinship refers to the resemblance in genetic structure derived from common ancestors, whereas individuals with such similarities are termed relatives. Kinship, inbreeding and covariances between relatives are important factors in animal breeding. The inbreeding coefficient, which is a measure of kinship, is a value ranging from 0 to 1, estimated by keeping pedigree records of individuals. The inbreeding coefficient quantifies the likelihood that two alleles at a locus in an individual originate from a shared ancestor or the proportion of homozygous loci to the total loci present in an individual. The inbreeding coefficient is sometimes defined as the ratio of homozygous individuals in a population for a given locus or the ratio of homozygous loci to all loci in the population (Kumlu, 2003). The inbreeding coefficient "F" was initially proposed by Sewall Wright in 1922 and is computed using the subsequent equation;

$$F_x = \sum \left[\left(\frac{1}{2}\right)^{n+1} (1 + F_A) \right]$$

In the equation, F_x, represents the inbreeding coefficient of the X individual, n, represents the number of connections from the common ancestor through the parents, and F_A; represents the inbreeding coefficient of the common ancestor. The inbreeding coefficient is generally not calculated for more than 5-6 generations due to the numerical values falling to very small sizes.

The relationship coefficient (R) measures the relationship between two individuals by using their family information. The relationship coefficient takes a value between 0-2 and is calculated with the following equation.

$$R_{XY} = \frac{\sum \left[\left(\frac{1}{2}\right)^{n_1+n_2} (1 + F_A) \right]}{\sqrt{(1 + F_X)(1 + F_Y)}}$$

In the equation, R_{XY} represents the degree of kinship (relationship coefficient) between individuals X and Y, n_1 and n_2 represent the relevant paths, F_A represents the inbreeding coefficient of the common ancestor, and F_X and F_Y represent the inbreeding coefficients of individuals X and Y (Stalder and Saxton, 2004).

Inbreeding is achieved by mating individuals that are more related than the average in the population. Homozygous structuring increases with inbreeding. Inbreeding applied together with selection ensures that genes that reveal desired characteristics are quickly gathered. Inbreeding, in addition to its beneficial effects, sometimes creates some problems because of homozygous formation that can occur in an undesirable direction. Phenotypic variation decreases, especially in characters with low heritability, and there is a decline in characteristics such as reproduction and survival. In addition, homozygous formation caused by inbreeding generally leads to the emergence of lethal genes with a recessive structure and hereditary abnormalities.

Inbreeding results in the fixation of certain gene combinations, which are then passed on to future generations through genetic selection techniques. This process results in subsequent generations acquiring the structure of "pure breed" or "pure line". Genotypic structures with hybrid features can be generated by crossbreeding pure lines possessing distinct genotypic configurations. Currently, hybrid materials of poultry and pigs utilized in commercial production have been developed by this process.

There are computer programs that enable kinship-related computations. The INBREED procedure, part of the “GENETICS” library since version 8.2 of the SAS program, calculates coefficient of inbreeding and coefficient of relationship, with numerous options and commands (SAS Institute Inc., 2008).

Table 1. Options and commands of the SAS INBREED procedure.

Options	Commands
Average (a)	BY variable
Cov (c)	CLASS d variable
Ind (i)	GENDER variable
Matrix	MATINGS individual1/individual2
Indl	VAR individual parent1 parent2 (covariance)
Matrixl	
Init=	

The methodology enables analysis of extensive data sets, facilitating observations on the fundamental population or on records maintained across generations of a population. When the generation and sex values of individuals are included in the pedigree data, inbreeding coefficients and coefficient of relationship can be computed, categorized by generations, sexes, and mating types. Distinct covariance values or a singular covariance value may be incorporated into the pedigree data for each individual with unknown parentage. The options and commands of the INBREED procedure are shown in Table 1.

The "VAR" command defines which of the lineage information read into the software are the individual, parents and, if any, covariance values. The "Average" option is used to calculate inbreeding coefficients for individuals. If the "Average" option is used with the "matrix" option, the inbreeding coefficients form a diagonal matrix, and if the "ind" option is used, it forms a vector matrix. When used with the "Gender" command, it calculates inbreeding coefficients by categorizing them according to mating types. When the "cov" option is used, the coefficients of relationship are calculated instead of the inbreeding coefficients calculated with the "Average" option, and it is used in the same way with other options. The "CLASS" command classifies data according to groups, families or generations in the population and performs calculations within these classes and presents the results according to classes in the output file. The "Indl" and "Matrixl" options are used with the "CLASS" command and create an index and matrix only for individuals belonging to the last group, family or generation. The "GENDER" command calculates the average inbreeding coefficients or relationship coefficients according to mating categories. In order to use the "GENDER" command, sexes must be defined in the pedigree file as M (male) and F (female). The "MATINGS" command reads the desired matings for individuals in the pedigree file into the software as individualX/individualY and calculates the inbreeding coefficients or covariance values for these matings. The "init" option is used to assign a general covariance value in the population for individuals whose past kinship relationships are unknown (SAS Institute Inc., 2004).

2.1. Inbreeding Strategies and PROC INBREED Utilizations

Some breeding types, such as cloning and selfing in plants, provide a rapid increase in the inbreeding coefficient in the population. In terms of animal breeding, the fastest increase in the inbreeding coefficient occurs with parent-offspring and full sibling matings. While half-siblings, grandparent-grandoffspring, uncle-cousin, aunt-cousin matings produce lower values, mating of cousins gives the lowest inbreeding coefficients (Stalder and Saxton, 2004).

2.1.1. Parent-Offspring Mating

Parent-offspring mating methods are generally applied to obtain pure breed or pure line. Parent-offspring mating occurs in two ways as "young parent-offspring mating", which occurs when parents change places with their offspring, and "line breeding", which occurs when the offspring of the same parent are constantly mated with their offspring and their offspring with their offspring. Young parent-offspring mating is especially applied in poultry breeding in the form of mating roosters with their daughters in in-line families. The second type, parent-offspring mating, is not widely applied in animal breeding because its application with selection is limited (Singh and Kumar, 1994). Figure 1 shows the M, I, A, S, D and Z individuals whose pedigrees are given for young parent-offspring mating.

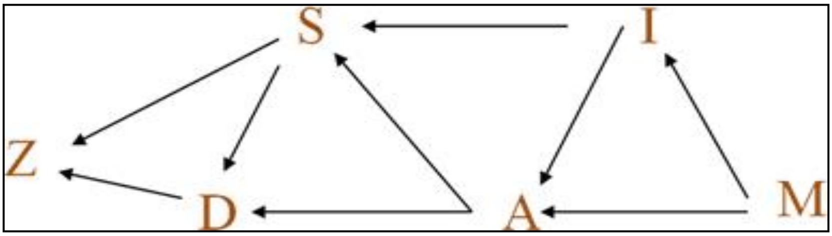

Figure 1. Example lineage traces of young-parent-offspring matings.

The commands required to define SAS data generated from the lineage traces of the individuals in Figure 2 and to calculate inbreeding coefficients are provided below.

```
DATA parentoffspring1;
 INPUT offspring $ maleparent $ maleparent $ @@;
 DATALINES;

 M . .   I M .
 A M I   S A I
 D A S   Z D S
 ;

PROC INBREED data=parentoffspring1 average matrix;
 VAR offspring maleparent femaleparent;
 RUN;
```

Figure 2. SAS commands of young-parent-offspring matings.

The inbreeding coefficient matrix obtained by using the average and matrix options is presented in Figure 3.

Individual	Father	Mother	M	I	A	S	D	Z
M			0	0.2500	0.3750	0.3125	0.3438	0.3281
I	M		0.2500	0	0.3750	0.4375	0.4063	0.4219
A	M	I	0.3750	0.3750	0.2500	0.5000	0.5625	0.5313
S	A	I	0.3125	0.4375	0.5000	0.3750	0.5938	0.6406
D	A	S	0.3438	0.4063	0.5625	0.5938	0.5000	0.6719
Z	D	S	0.3281	0.4219	0.5313	0.6406	0.6719	0.5938

Figure 3. Inbreeding coefficients calculated for the young parent-offspring sample.

The cov and matrix options were used to calculate the relationship coefficients, and the init = 0.25 option was added to assign a starting value for the M individual whose parents are unknown. The command body used to calculate the relationship coefficients is presented below (Figure 4). The results are given in Figure 5.

```
PROC INBREED data=parentoffspring1 cov matrix init=0.25;
VAR offspring maleparent femaleparent;
RUN;
```

Figure 4. SAS commands used to calculate relationship coefficients.

Individual	Father	Mother	M	I	A	S	D	Z
M			1.1250	0.6875	0.9063	0.7969	0.8516	0.8242
I	M		0.6875	1.1250	0.9063	1.0156	0.9609	0.9883
A	M	I	0.9063	0.9063	1.3438	1.1250	1.2344	1.1797
S	A	I	0.7969	1.0156	1.1250	1.4531	1.2891	1.3711
D	A	S	0.8516	0.9609	1.2344	1.2891	1.5625	1.4258
Z	D	S	0.8242	0.9883	1.1797	1.3711	1.4258	1.6445

Figure 5. Relationship coefficients calculated from a sample of young parent-offspring matings.

Example lineage traces of line breeding mating, where a parent remains stationery and mates with its offspring and its offspring, are shown in Figure 6.

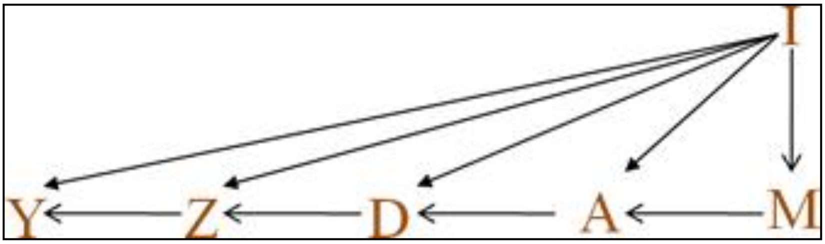

Figure 6. Example lineage traces of line breeding mating.

```
DATA parentoffspring2;
INPUT offspring $ maleparent $ femaleparent $ @@;
DATALINES;

I . .   M I .
A I M   D I A
Z I D   Y I Z
;
PROC INBREED data=parentoffspring2 average ind;
VAR offspring maleparent femaleparent;
RUN;
PROC INBREED data=parentoffspring2 cov matrix;
VAR offspring maleparent femaleparent;
RUN;
```

Figure 7. SAS commands used to calculate relationship coefficients of line breeding mating.

In the first command body, the inbreeding coefficients of 6 individuals were displayed in a column by using the “IND” option. Accordingly, the inbreeding coefficients of individuals I, M, A, D, Z, Y were calculated as 0, 0, 0.2500, 0.3750, 0.4375 and 0.4688, respectively. The inbreeding coefficients calculated with the second command body are presented in Figure 8.

Individual	Father	Mother	I	M	A	D	Z	Y
I			1.0000	0.5000	0.7500	0.8750	0.9375	0.9688
M	I		0.5000	1.0000	0.7500	0.6250	0.5625	0.5313
A	I	M	0.7500	0.7500	1.2500	1.0000	0.8750	0.8125
D	I	A	0.8750	0.6250	1.0000	1.3750	1.1250	1.0000
Z	I	D	0.9375	0.5625	0.8750	1.1250	1.4375	1.1875
Y	I	Z	0.9688	0.5313	0.8125	1.0000	1.1875	1.4688

Figure 8. Relationship coefficients calculated in the line breeding example.

2.1.2. Full-Sib Mating

Another mating method that rapidly increases the inbreeding coefficient is full-sib mating. Full-sib mating, which is a practical application for obtaining pure lines and pure breeds, is frequently used in lines where crossbreeding studies are conducted (Singh and Kumar, 1994). Sample pedigrees for full-sib mating are presented in Figure 9.

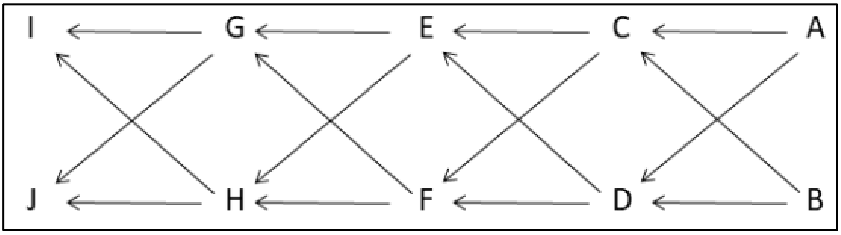

Figure 9. Example lineage traces of full-sib mating.

The SAS data file required for calculations to be performed using sample lineage traces for full sib mating is presented in Figure 10.

```
DATA fullsib;
INPUT offspring $ maleparent $ femaleparent $ @@;
DATALINES;
A . .   B . .
C A B   D A B
E C D   F C D
G E F   H E F
I G H   J G H
;
PROC INBREED data=fullsib average matrix;
VAR offspring maleparent femaleparent;
RUN;
```

Figure 10. SAS commands used to calculate relationship coefficients of full-sib mating.

Individual	Father	Mother	A	B	C	D	E	F	G	H	I	J
A	.	.	0	0	0.2500	0.2500	0.2500	0.2500	0.2500	0.2500	0.2500	0.2500
B	.	.	0	0	0.2500	0.2500	0.2500	0.2500	0.2500	0.2500	0.2500	0.2500
C	A	B	0.2500	0.2500	0	0.2500	0.3750	0.3750	0.3750	0.3750	0.3750	0.3750
D	A	B	0.2500	0.2500	0.2500	0	0.3750	0.3750	0.3750	0.3750	0.3750	0.3750
E	C	D	0.2500	0.2500	0.3750	0.3750	0.2500	0.3750	0.5000	0.5000	0.5000	0.5000
F	C	D	0.2500	0.2500	0.3750	0.3750	0.3750	0.2500	0.5000	0.5000	0.5000	0.5000
G	E	F	0.2500	0.2500	0.3750	0.3750	0.5000	0.5000	0.3750	0.5000	0.5938	0.5938
H	E	F	0.2500	0.2500	0.3750	0.3750	0.5000	0.5000	0.5000	0.3750	0.5938	0.5938
I	G	H	0.2500	0.2500	0.3750	0.3750	0.5000	0.5000	0.5938	0.5938	0.5000	0.5938
J	G	H	0.2500	0.2500	0.3750	0.3750	0.5000	0.5000	0.5938	0.5938	0.5938	0.5000

Figure 11. The inbreeding coefficients of full-sib mating.

Individual	Father	Mother	A	B	C	D	E	F	G	H	I	J
A			1.0000	0	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000
B			0	1.0000	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000
C	A	B	0.5000	0.5000	1.0000	0.5000	0.7500	0.7500	0.7500	0.7500	0.7500	0.7500
D	A	B	0.5000	0.5000	0.5000	1.0000	0.7500	0.7500	0.7500	0.7500	0.7500	0.7500
E	C	D	0.5000	0.5000	0.7500	0.7500	1.2500	0.7500	1.0000	1.0000	1.0000	1.0000
F	C	D	0.5000	0.5000	0.7500	0.7500	0.7500	1.2500	1.0000	1.0000	1.0000	1.0000
G	E	F	0.5000	0.5000	0.7500	0.7500	1.0000	1.0000	1.3750	1.0000	1.1875	1.1875
H	E	F	0.5000	0.5000	0.7500	0.7500	1.0000	1.0000	1.0000	1.3750	1.1875	1.1875
I	G	H	0.5000	0.5000	0.7500	0.7500	1.0000	1.0000	1.1875	1.1875	1.5000	1.1875
J	G	H	0.5000	0.5000	0.7500	0.7500	1.0000	1.0000	1.1875	1.1875	1.1875	1.5000

Figure 12. The relationship coefficients of full-sib mating.

2.1.3. Half-Sib Mating

Half-sib mating, which provides a lower increase in relatedness than parent-offspring and full-sib matings, is one of the mating systems frequently used to increase relatedness in a controlled manner (Singh and Kumar, 1994). This type of mating is widely used for genetic parameter estimation studies. In genetic improvement studies, especially those in which selection studies are intense, both full-sib and half-sib matings are included. Figure 13 shows lineage traces from an example stepsib mating.

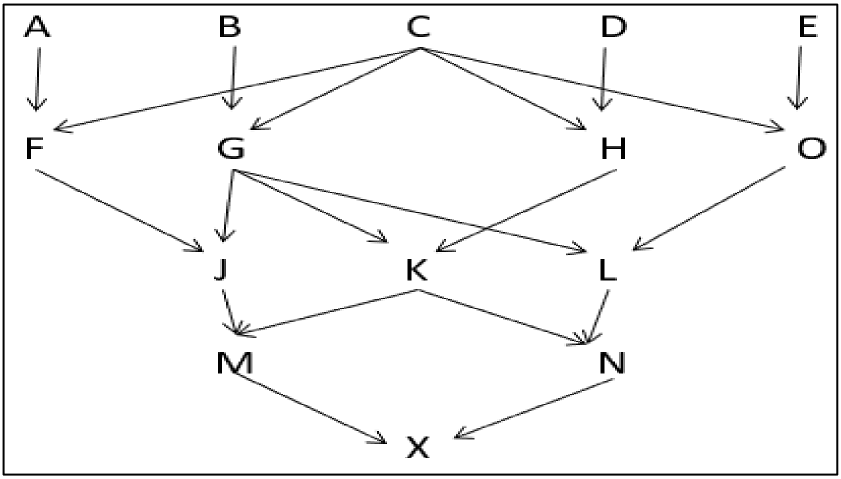

Figure 13. Example lineage traces of half-sib mating.

The commands required for SAS data entry and inbreeding coefficients and relatedness coefficients for the half-sib mating example are given below (Figure 14); inbreeding coefficients are presented in Figure 15, and relationship coefficients are presented in Figure 16.

```
DATA halfsib;
INPUT offspring $ maleparent $ femaleparent $ @@;
DATALINES;
A . .    B . .    C . .
D . .    E . .    F C A
G C B    O C E    H C D
L O G    K H G    J F G
N L K    M J K    X M N
;
PROC INBREED data=halfsib average ind;
VAR offspring maleparent femaleparent;
RUN;
PROC INBREED data=halfsib cov matrix;
VAR offspring maleparent femaleparent;
RUN;
```

Figure 14. SAS commands for half-sib mating.

Individual	Father	Mother	Inbreeding Coefficient
A	.	.	0
B	.	.	0
C	.	.	0
D	.	.	0
E	.	.	0
F	C	A	0
G	C	B	0
O	C	E	0
H	C	D	0
L	O	G	0.1250
K	H	G	0.1250
J	F	G	0.1250
N	L	K	0.2188
M	J	K	0.2188
X	M	N	0.3047

Figure 15. Inbreeding coefficients for half-sib mating.

	A	B	C	D	E	F	G	O	H	L	K	J	N	M	X
A	1.0000	0	0	0	0	0.5000	0	0	0	0	0	0.2500	0	0.1250	0.0625
B	0	1.0000	0	0	0	0	0.5000	0	0	0.2500	0.2500	0.2500	0.2500	0.2500	0.2500
C	0	0	1.0000	0	0	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000
D	0	0	0	1.0000	0	0	0	0	0.5000	0	0.2500	0	0.1250	0.1250	0.1250
E	0	0	0	0	1.0000	0	0	0	0.5000	0	0.2500	0	0.1250	0	0.0625
F	0.5000	0	0.5000	0	0	1.0000	0.2500	0.2500	0.2500	0.2500	0.2500	0.6250	0.2500	0.4375	0.3438
G	0	0.5000	0.5000	0	0	0.2500	1.0000	0.2500	0.2500	0.6250	0.6250	0.6250	0.6250	0.6250	0.6250
O	0	0	0.5000	0	0.5000	0.2500	0.2500	1.0000	0.2500	0.6250	0.2500	0.2500	0.4375	0.2500	0.3438
H	0	0	0.5000	0.5000	0	0.2500	0.2500	0.2500	1.0000	0.2500	0.6250	0.2500	0.4375	0.4375	0.4375
L	0	0.2500	0.5000	0	0.2500	0.2500	0.6250	0.6250	0.2500	1.1250	0.4375	0.4375	0.7813	0.4375	0.6094
K	0	0.2500	0.5000	0.2500	0	0.2500	0.6250	0.2500	0.6250	0.4375	1.1250	0.4375	0.7813	0.7813	0.7813
J	0.2500	0.2500	0.5000	0	0	0.6250	0.6250	0.2500	0.2500	0.4375	0.4375	1.1250	0.4375	0.7813	0.6094
N	0	0.2500	0.5000	0.1250	0.1250	0.2500	0.6250	0.4375	0.4375	0.7813	0.7813	0.4375	1.2188	0.6094	0.9141
M	0.1250	0.2500	0.5000	0.1250	0	0.4375	0.6250	0.2500	0.4375	0.4375	0.7813	0.7813	0.6094	1.2188	0.9141
X	0.0625	0.2500	0.5000	0.1250	0.0625	0.3438	0.6250	0.3438	0.4375	0.6094	0.7813	0.6094	0.9141	0.9141	1.3047

Figure 16. Relationship coefficients for half-sib mating.

3. CONCLUSION

The study of inbreeding relationships in poultry science reveals intricate dynamics that influence the overall productivity and genetic viability of poultry species. Understanding the genetic potential of existing stock is paramount to effective breeding strategies. The integration of various scientific disciplines—genetics, statistics, animal nutrition, and information technology—enables breeders to maximize the genetic potential of poultry for desirable traits such as egg production and growth rates.

Highlights from the history of poultry breeding illustrate how methodologies have evolved from mass selection to more sophisticated approaches such as index selection and the incorporation of mixed model equations (MME). These advancements have enabled breeders to consider genetic relationships more meticulously and leverage kinship data effectively, thus improving selection precision. However, it is noteworthy that while MME has revolutionized the genetic evaluation in livestock breeding, its application in poultry remains limited, indicating a gap in the utilization of available genetic tools.

The inbreeding coefficient serves as a critical tool for assessing genetic relationships, providing vital insights into the genetic health of breeding populations. Monitoring inbreeding through the coefficient enables breeders to prevent the pitfalls associated with excessive homozygosity, such as reduced phenotypic variation and increased risk of recessive genetic disorders. The careful management of inbreeding can lead to the establishment of pure lines, which are instrumental in developing hybrid lines that dominate the commercial poultry industry.

Furthermore, the role of advanced software tools like SAS plays a crucial part in the genetic evaluation of poultry. By facilitating the computation of inbreeding and relationship coefficients, these programs enable breeders to make informed selection decisions based on solid genetic data. However, the predominance of outdated programming languages and the absence of user-friendly interfaces in poultry-specific software solutions underscore the need for modernization in this field.

In conclusion, while the poultry industry has made significant strides in breeding science through the application of genetic principles and advanced methodologies, continuous improvements in computational tools and a focus on genetic diversity are essential for fostering sustainable breeding practices. The ongoing challenge for poultry breeders is to strike a balance between harnessing the benefits of inbreeding for rapid selection while mitigating the risks associated with genetic homogeneity. As the industry progresses, the incorporation of new technologies and greater attention to genetic management will be crucial for ensuring the long-term success and productivity of poultry breeding programs.

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Chapter 7

Trichoderma afroharzianum: Does This Microorganism Help or Harm Maize?

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Introduction

Maize or corn (*Zea mays* L.) is the most significant agricultural crop in terms of human nutrition and animal feed (Chen et al., 2021), with a global production of 1.16 billion tons on 203.4 million hectares (FAOSTAT, 2022). The growth of the global population has been accompanied by a corresponding increase in demand for food. In order to satisfy this demand, proposals have been made to develop new technologies, increase yields in agricultural production areas and implement ecological practices **(**Deguine et al., 2023; Basso and Antle, 2020; Delgado et al., 2019). The threat to food production posed by plant pathogens—which include fungi, bacteria, viruses, pests, and weeds—is significant, as these pathogens cause considerable economic losses (10–15% of the world's major crops) in agricultural crops (Chatterjee et al., 2016; Sood et al., 2020). In recent years, the geographical distribution of plant pathogens has also been subject to change as a consequence of climate change. The initial method of agricultural control, chemical control, has been demonstrated to result in a loss of biodiversity, environmental contamination, and adverse effects on human health (Tudi et al., 2021; Lanzuise et al., 2022). The implementation of agricultural policies in accordance with the United Nations General Assembly Sustainable Development Goals (2015) is intended to facilitate a reduction in the utilization of synthetic chemical products (Woo et al., 2014; Collinge et al., 2022). Nevertheless, despite a continued reduction in the reliance of producers on chemical control measures, the desired outcomes remain elusive. Consequently, regulatory sanctions are being implemented, as evidenced by the recent imposition of sanctions on the active substance Mancozeb (EU, 2020; Saha et al., 2022).

In order to avoid the potential negative consequences of these approaches, there has been a growing emphasis on the use of biological control methods in research. Fungal biocontrol agents (BCAs) are the most preferred biological control agents due to their antagonistic effects against multiple plant pathogens, which are mediated by different mechanisms of action. Additionally, BCAs have been demonstrated to positively influence plant growth (Kohl et al., 2019; Pirttila et al., 2021). Thambugala et al. (2020) reported 300 fungal antagonists (comprising 13 classes and 113 genera) along with their respective efficacious pathogens. The genus *Trichoderma* (Ascomycota, Hypocreaceae) is of significant importance within the fungal kingdom, particularly in the context of antagonistic interactions. *Trichoderma* species (teleomorph: *Hypocrea*) represents a biological control agent that can be identified within the rhizosphere of a vast majority of terrestrial ecosystems and within different plant tissues as endophytes (Druzhinina et al., 2011; Fang et al., 2019). To date, 460 distinct species of *Trichoderma* have been identified based on studies conducted with established molecular identification methodologies (ICTT, 2024).

Biocontrol mechanisms of *Trichoderma* species

Trichoderma exhibits two distinct modes of action, both direct and indirect, against plant pathogens and pests. Among its direct mechanisms of action, it produces potent compounds and secondary metabolites, thereby exhibiting a hyperparasitic effect against pathogens (Harman et al., 2004). Furthermore, this fungus impedes the growth of pathogens by producing enzymes (including chitinases, glucanases, proteases, and cellulases) that degrade the cell walls of plant pathogens (Schuster and Schmoll, 2010). The indirect mechanisms of action can be broadly categorised into three main areas: firstly, the creation of a competitive environment for nutrients within the rhizosphere, which can help to inhibit the growth of pathogens (Druzhinina et al., 2018). Secondly, the promotion of plant growth and the root system of the host plant. Thirdly, the stimulation of acquired or systemic resistance systems within the host plant (Conrath et al., 2015; Palmieri et al., 2022). Additionally, it facilitates the conversion of soil nutrients into accessible forms through the production of siderophores (Srivastava et al. 2018). The action mechanisms of *Trichoderma* are illustrated in Figure 1 (Rodrigues et al. 2023), which provides a representative overview of the subject matter.

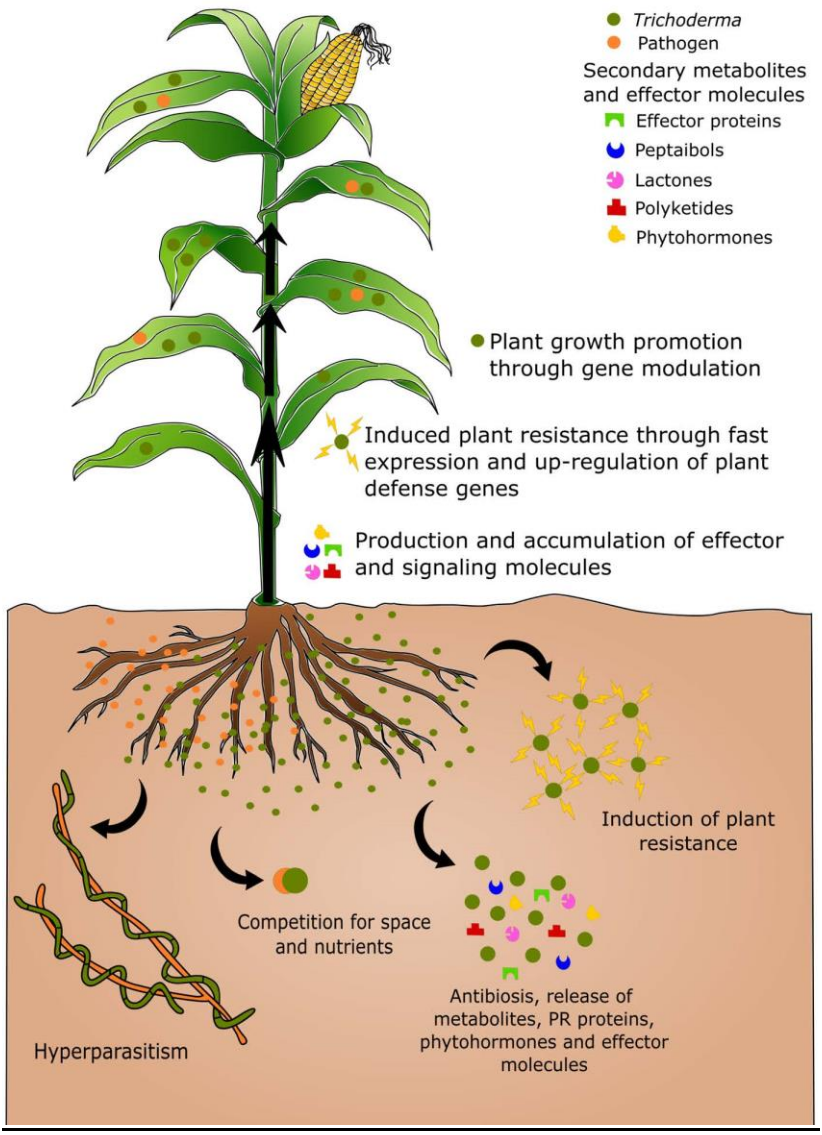

Fig. 1 The graphical representation of the biological mechanisms of action of Trichoderma (Rodrigues et al., 2023)

While *Trichoderma* has a multitude of beneficial effects, certain *Trichoderma* species have also been linked to significant losses in mushroom production. This is particularly cause green mold disease. The *T. aggressivum* and *T. harzianum* species are regarded as significant pests affecting *Agaricus bisporus* (button) and *Pleurotus ostreatus* (oyster) mushroom species globally (Park et al., 2006; Hatvani et al., 2017; Allaga et al., 2021). Another negative effect is that *T. longibrachiatum* causes clinical infections in humans (Kredics et al., 2003; Druzhinina et al., 2008).

Recent Research: The interaction of *Trichoderma afroharzianum* with maize

The certain species of *Trichoderma* are capable of causing disease in corn, a crop of significant commercial importance. The first recognition of this pathogen on maize was documented by Haslam (1910) in Kansas, USA. In this study, *T. lignorium* was identified as a greenish-yellow wet mold that was observed to be growing among maize grains. *T. koningii*, *T. harzianum*, and *T. hamantum* have been reported to cause internode lesions (McFadden and Sutton, 1975). *Trichoderma* ear rot disease was first identified in maize in 1973 (Shurtleff et al., 1973) and then similar findings were made in different locations (Wise et al., 2016; Vincelli, 2014). *Trichoderma viride* has been categorised as an "other corn ear rot" (White, 1999). *T. asperellum* was identified as the causative agent of infection in maize ears (Chen et al., 2023). The most prevalent symptom of *Trichoderma* ear rot is the formation of blue-green sporulation between and on the kernels within the infected ears (Fig. 2). Infected ears exhibit a notable reduction in color intensity compared to healthy ears (Vincelli, 2014; Munkvold and White, 2016; Pfordt et al., 2020).

Fig. 2 *Trichoderma* was showed under field conditions as causing ear rot (A), sporulation (B), and early germination of infected kernels (C) (Pfordt et al., 2024)

Trichoderma afroharzianum has been isolated and identified from maize in twenty different countries across four different continents (Fig. 3) (EPPO, 2024). *T. afroharzianum* was isolated from ears in a maize production area in Southern Germany and was identified as the causal agent of ear rot (78-96%) following pathogenicity testing under greenhouse conditions. Additionally, it was established that 28 days following inoculation, the dry matter content of the ears exhibited a decline, and mechanical injury proved to be inconsequential with respect to infection (Pford et al., 2020). Subsequently, *T. afroharzianum* was identified as a pathogen of maize in Italy and France during the dry season, when temperatures were elevated. The findings of this study are significant in elucidating the epidemiology of *T. afroharzianum* in small grain cereals and maize production (Sanna et al., 2022). Pfordt et al. (2023) were the first to report that *T. afroharzianum* inoculation of barley (*Hordeum vulgare*), two varieties of wheat (*Triticum aestivum*), and sorghum (*Sorghum bicolor*), field crops under greenhouse conditions, caused necrotic symptoms on the flowers 14 days after inoculation and resulted in a reduction of the thousand grain weight of the seeds of the plants.

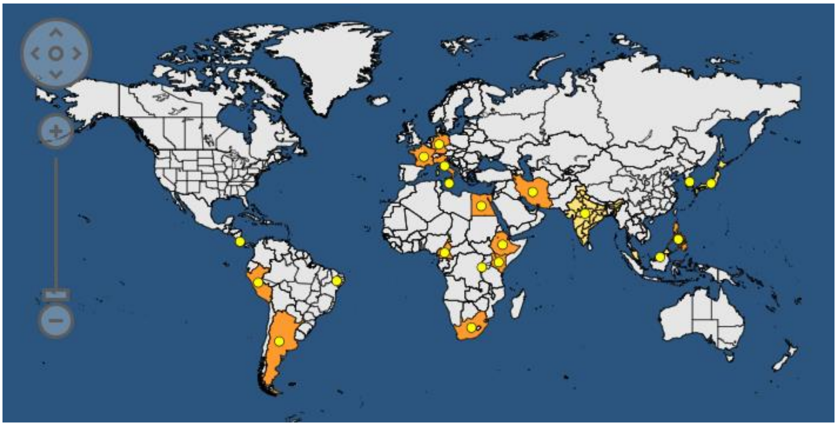

Fig. 3 The fungus *Trichoderma afroharzianum* has been identified from different countries (EPPO, 2024)

Conclusion

The emergence of *Trichoderma* ear rot disease in various countries in recent years has not resulted in any discernible adverse effects on the utilization of commercially available *Trichoderma* preparations in the USA (Trillas et al., 2024). In order to determine the potential of *T. afroharzianum* to cause infection, the environmental conditions that result from climate change must be taken into account. Furthermore, it is crucial to ascertain the sources of inoculum, propagation rates, and alternative host ranges of *T. afroharzianum* in natural infections of maize ears. Furthermore, it is imperative to implement strategies to address this issue. It is important to consider that the initial identification studies may present a challenge in the registration of native *Trichoderma* isolates as biopesticides.

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Chapter 8

Investigation of Inherited and Learned Behaviours in Poultry Farm Animals

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1.INTRODUCTIONS

Mankind, who lived a nomadic life for many years, settled down 12000 years ago (Neolithic period), especially in areas with water, and started the agricultural revolution (Berk, 2020; Yurtseven, 2023). The settled order and climate change caused the nutrients needed by hunter-gatherer people to be insufficiently abundant and this led to an increase in food scarcity. Human beings, who were in search of new foods they needed, first started to domesticate plants and then animals. With the studies conducted, it was determined that the first plant and animal domestication processes started 10000 years ago, and the first domesticated plants and animals were obtained towards 8000 (Çıvgın, 2018). The first domesticated animals are sheep, goats, pigs and cattle in Anatolia. It is thought that the domestication of chicken was carried out in Asia, originating from the red wild chicken (*Gallus gallus*) around 2000. In a study conducted by Peter et al. (2023), it was determined that chickens were domesticated in southeast Asia around 1500 BC and spread from there to the west, south, Africa and Europe. It is thought that cereal cultivation has an important role in the domestication of poultry, which has an important place among other domestic animals today. Especially in Asia, rice and millet fields have brought poultry closer to humans.

While these domesticated animals lived freely in their natural habitats, they had to live in closer contact with humans and in closed environments. Finding their food, defending themselves against their enemies and raising their young are among the behavioural models they perform most in their natural habitats, but the task of performing these behaviours is now the responsibility of human beings. It is necessary to investigate the effects of the disappearance of some habits of animals, which are inherited from their genes, over time. In this study, which we organised in order to shed light on animal welfare studies, it was investigated to reveal the hereditary and learned behaviours in poultry.

2. INHERITED BEHAVIOUR

An animal, whether in wildlife or domestic life, must be able to perform certain behaviours in order to survive and continue its generation. In order for these behaviours to occur, the animal must receive some stimuli from its environment. The nervous system, which is a part of the living organism, receives these stimuli from the environment through its cells and sends them to the central nervous system. The information received here is organised, stored and sent to the relevant region to be used. The stimuli cause the release of hormones according to the region to which they are sent, and with the effect of hormones, behavioural diversity is formed in animals (Şahin and Biricik, 1997; Breed and Moore, 2015).

Some of these behaviours, which are the result of external and internal stimuli, are inherited. Inherited behaviours are innate behaviours and are the same in all individuals of a species. Some of these behaviours wait for a certain period or suitable environmental conditions to emerge. For example, in order for courtship, reproduction and offspring-caring behaviours, which are necessary for a living creature to continue its generation, to occur, the creature must reach sexual maturity, and the hormones related to the effect of the environment (temperature and day length) must be released.

Research is being conducted on whether these behaviours, which are recorded in the genes of living organisms, have an indirect or direct effect on other behaviours. Especially courtship and feeding behaviours have been found to have greater genetic contributions (York, 2018). Dochtermann et al. (2019) found that migration behaviour in birds is the behaviour with the highest heritability.

Şahin and Biricik (1997) examined heritable behaviours in four sections as orientation responses, reflexes, automatisms and instinctive behaviours.

Orienting responses are behaviours in which an animal changes its position depending on a stimulus from the environment. These stimuli can be phenomena such as sound, light, odour or climate, or they can be target objects or organisms. For example, a tennis ball thrown on the ground in a turkey poultry house attracts attention and initiates pecking. A strange creature left in the poultry house may attract the attention of others and

Reflex; **t**hey are stereotyped movements that occur with non-specific stimuli, involuntary, fast and in the same way. It protects the organism against negative effects that may come from outside. In chicken coops, the sense of fear that arises in the animals is responded to at the same time with a loud sound and wing flapping in each chicken.

Automatisms in some animals, organs such as fins and feet move rhythmically in harmony with each other. In aquatic birds, the feet move in coordination with each other in order for swimming to take place, and the harmony between wing movements during flight in winged birds can be given as examples.

Instinctive behaviours are simple behavioural patterns that are performed automatically without thinking as a result of an external stimulus (Breed and

Sanches, 2010). These external stimuli can be a different smell, a different sound or colour, a sudden touch, etc. In addition, climatic changes are among the external stimuli that initiate instinctive behaviours.

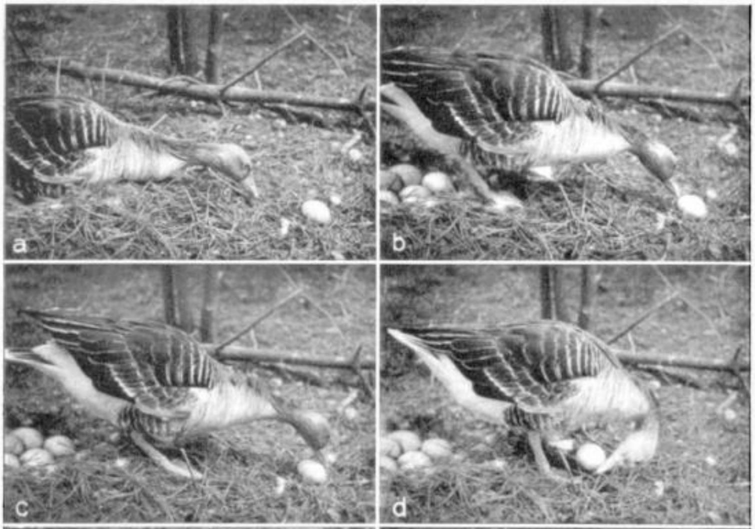

Figure 1: Egg rolling *beha*viour in goose (Lorenz and Tinbergen, 1938)

Lorenz and Tinbergen (1938), one of the founders of ethology, stated that if one of the eggs of a grey goose sitting in the nest slips out of the nest or if an egg-like object is found outside, the goose immediately forms a series of behavioural patterns (following the egg, back and forth movements of the head and pulling the egg towards the nest). In this case, the egg or the object constitutes a warning for the goose and the instinctive action of protecting the egg is initiated (Prevett and Prevett, 1973) (Figure 1). Courtship behaviours can also be given as an example of instinctive behaviours. The warming of the weather has a stimulating effect on animals and causes an increase in sex hormones. As a result of this situation, courtship behaviour between animals starts, as we can see in the peacock example in Figure 2. The male peacock's turning around the female by showing his feathers or performing his unique dance around her, as in the case of ostriches, is not a learnt behaviour.

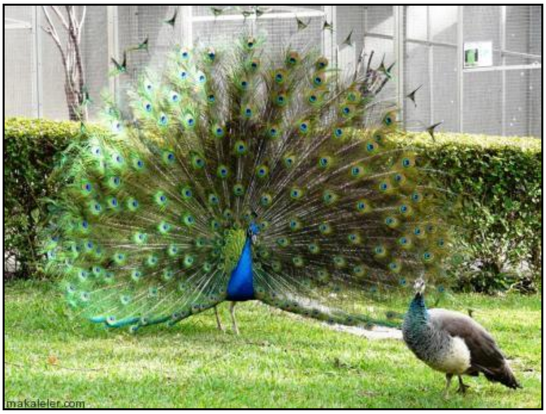

Figure 2. Courtship behaviour of a male peacock towards a female

In poultry farm animals, the newly hatched chicks following their mothers, chickens standing in shady places by fluffing their feathers to cool their bodies in hot weather, distinguishing the chicks they hatch by their voices, and newly hatched chicks pecking around them are examples of instinctive behaviour.

We can observe instinctive behaviours without any stimulus from the environment. When chickens roam freely in nature, they are fed according to the nutritional needs of their bodies. If the content of the feed meets their needs, they reach the feeling of saturation quickly. Otherwise, they continue eating. Here, the effect that stimulates eating behaviour is completely internal needs (Göger and Yenice, 2018). The occurrence of the animal's needs triggered and motivated the feeling of hunger and thus the eating behaviour.

Colours have a different stimulating effect on poultry. The yellow colour of the beak of a newly hatched baby bird triggers the mother to feed the chick. Or, in some poultry, a red spot on the beak may cause the chick to beg for food from its mother. In poultry farm animals, the red colour attracts the animal's attention and stimulates the pecking instinct. Pecking of a red coloured feather sometimes spreads to the whole flock and causes cannibalism. It causes great losses for the enterprise. In order to eliminate this situation, red colour is used in tools and equipment in the poultry sector. Thus, chickens get used to the red colour and this stimulus is eliminated.

These stimuli that initiate behaviour may vary according to the species. If a carer knows what has a stimulating effect on his/her animal, he/she can direct the animal in the desired way. When hens are looking for a place to lay eggs, a dim, quiet place can act as a stimulus for them, while an egg or egg-like object in the desired area can trigger laying. Keepers can take advantage of this situation by placing egg-like objects (fol) in the place where they want the hen to lay, thus attracting the hen's attention. In ethology, this type of false stimulus is called atrap (dummy) (Şahin and Biricik, 1997). In a study on the clothing colours of workers working in laying hen houses, workers wearing dark blue, green, red, yellow and black clothes could cause stress and noise in the animals, and white was the colour in which they felt the safest (Genç and Özentürk, 2024).

3. LEARNED BEHAVIOURS

Animals living in restricted environments change the shape of their innate behaviour under the influence of the environment or in line with their needs. They need to adapt to their new environment in order to survive and reproduce. A chicken that starts to live in a cage can locate feed and water by pecking around. The next time it feels hungry, it remembers where the feed or water is. The new information is stored in the brain via the nervous system. In this case, the instinctive behaviour of pecking and hunger allows the hen to learn the location of the water and the feeder. As in this case, behavioural changes that occur as a result of experiences are called learning, and behaviours that occur through the accumulation of information are called learned behaviours (Şahin and Biricik, 1997; Breed and Moore, 2015).

3.1. Conditions for learning:

Learning is formed by experiences; its results are a change specific to the individual and spread over a long period of time. It requires repetition of the behaviour to be learned. An experience that will be encountered once as long as the individual lives may not leave a permanent trace in the memory. Memory and learning capacity may differ according to the species. Some researchers believe that learning capacity is related to brain size. For example, primate species with larger brain areas responsible for management (neocortex and striatum) are capable of innovative behaviour, social learning and tool use. Although this result is true for many species, studies show that other factors are also effective in learning and remembering in animals (Breed and Moore, 2015). In human and some animal experiments, it has been determined that malnutrition at an early age reduces learning ability and causes forgetting of some information in long-term memory (Kaufman et al., 2010; Laus et al., 2011). Li et al. (2018) investigated whether the behavioural characteristics of broiler chicks such as fear, learning ability and memory retention were affected by feeding a balanced diet with reduced protein content (RP diet) to broiler chicks. In the groups that were subjected to the T-maze test and offered mealworms as a reward, fear and performance slowed down in those fed the RP diet, but learning ability and memory retention were not impaired. Panigrahy et al. (2017) investigated age and sex effects on cognitive ability in Vanaraja chickens.

As a result, learning in an individual requires the perception of a different environment or stimulus (internal or external), a good learning ability and memory, experiences and repetition.

3.2. Learning processes:

Some processes are necessary for learning to take place. The most important teacher for animals in their natural environment is their parents. A newly hatched chick learns many things from its mother until it lives on its own. It knows how to feed itself, how to protect itself, etc. What it will learn next is in the form of trial and error, repetition, etc. In the literature study, learning processes are listed as follows (Şahin and Biricik, 1997; Menzel, 2013; Breed and Moore, 2015).

3.2.1. Learning by acclimatisation process:

The first behaviour of a living creature in the face of a stimulus that it encounters for the first time is to instinctively escape from the stimulus and to protect itself. A carer entering the chicken coop for the first time may scare the chickens at first. Even when he enters in a different outfit, he encounters the same reaction. They get used to the carer over time. In order to eliminate such fear-based stress, it is not recommended to change carers or have different people enter the coop. We can also observe a similar reaction to a piece of equipment placed in the coop for the first time. Over time, they get used to the equipment or the carer and learn that no harm will come to them. It has been observed that animals are initially frightened by the scarecrows placed in the fields or atraps resembling birds of prey, but they get used to them over time.

3.2.2. Classical conditioning:

In this method, a stimulus and a reward are associated in order to teach the planned behaviour. The reward is often food. Parlov's dog experiment is the most common example of this. In the first stage, Parlov saw the dog drooling when it saw the food and recorded this. Then he rang a bell and saw that there was no salivation. In the third stage he gave the bait and rang the bell at the same time. In the last stage, he determined that the dog salivated only when the bell was rung. This experiment, which formed the basis of classical conditioning, contributed to the study of learning and behaviour (Figure 3) (Mcleod, 2024).

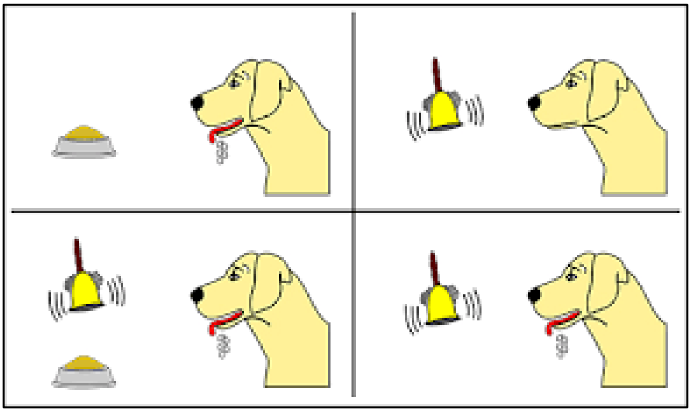

Figure 3. Parlov's dog experiment

A different example of classical conditioning is observed in chickens. When a poultry farmer in a village feeds his animals, he makes a bilibili sound and then gives the feed, or when the feed is automatically distributed from the machines in commercial poultry houses, the sound of the machine causes all the animals to be directed towards the channels of the machine or towards the farmer. The animals have established a connection between the sound and the feed. They have learnt that the feed will be given when they hear the same sound.

3.2.3. Operant Conditioning:

In this learning process, the animal is in contact with its environment. It tries to explore the environment by pecking the stimuli it sees around. As a result of this behaviour, there may be a reward or a punishment. Feed is a reward for it. When the reward is reached, the same stimuli are pecked again at different time periods to try to reach the food. However, if the result of its endeavours has a negative effect, that is, if it turns into a punishment, it will not approach that stimulus again, it will stay away. Here, the stimuli coming from the environment can also trigger the instinctive feeling of hunger.

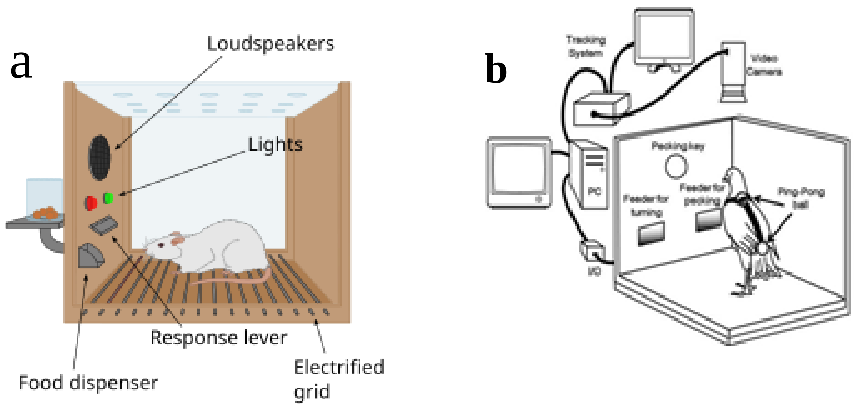

Figure 4: a) Skinner box, b) Manabe box

In order to investigate this behaviour in more detail, the experimental psychology researcher Burrhus Frederic Skinner created the Skinner box (Figure 4a) (Tinbergen, 1968). This box is shaped like a closed chest and contains a glass plate for experiments with poultry and a lever to be pushed down for experiments with cats or rats. On the other side of the box there is a system for dropping food automatically or on demand and equipment (lamp, loudspeaker) to give different warning signals to the animal. Figure 4b shows an improved version. The data obtained here are recorded with a camera and can be saved on a computer (Manabe, 2017).

3.2.4. Conditional orientation learning:

This type of learning is also known as learning by trial and error. Here, the stimuli in the environment are tried in sequence. The result of the trial can sometimes cause irreversible mistakes. A chicken trying to eat the food in front of a dog may be attacked by the dog. Even though the plate of food is a stimulus for it, it may end badly. There are many poisonous plants or animals in nature. For example, a bird eating a monarch butterfly may vomit as a result of the negative taste in its mouth. In this case, the bird is taught by experiment that monarch butterfly should not be eaten.

3.2.5. Storage and retrieval

Many creatures living in wildlife hide the excess food they eat in secret places. These hiding places are sometimes under a rock, sometimes in the soil (burial), sometimes among the grass. When it gets hungry, it returns to the hiding place and searches for its food and finds it. They can memorise certain signs to find their food or they may have a talent that comes from their genes. Paridae (titmice and their relatives) and Corvidae (chestnut crows, crows and their relatives) are champions in hiding and retrieving (Breed and Moore, 2015) (Figure 5).

Figure 5: a) *Parus majör* b) *Garrulus glandarius*

In this form of learning, the animal can improve itself over time. Whether this kind of hiding and re-finding behaviour, so common in their relatives, is present in poultry may be a matter of debate. However, if we observe the foraging behaviour of chickens in free-ranging areas, it has been determined that they eat the feed or feed-like substances they find by digging the soil with their feet or touching everywhere with their beaks.

3.2.6. Learning by observation:

It is based on the rule that an animal learns the location of food sources by observing another animal and fulfils its need for food. This method is simpler and less risky than other learning methods. Crows are among the first in terms of learning by observation. They can even steal food by entering the territory of another animal. A good example of this method is that crows learn to open the lids of milk bottles. These birds, which have the ability to shred the thin bark on trees, have learnt to open the lids of bottles as a result of their observations (Tinbergen, 1968). Chickens living with households in villages learn in time that humans are food providers for them. So much so that a tray placed on the balcony or people sitting at the table are reflected to them as stimuli.

3.3. Repression (Imprinting)

It is a form of rapid learning that takes place during a short-term sensitive period due to an impulse from the animal's genes. During this period, also known as the critical period or sensitive period, neurons in the young brain show high activity and flexibility (Nakomari et all., 2013). Behaviours learned during this period continue for a long time. These behaviours can be manifested as sexual as well as monitoring behaviours (Şahin and Biricik, 1997).

Lorenz (1937), in a study with grey geese, reported that newly hatched goslings memorise the shape of whatever creature they first see and follow that creature (Figure 6). The first shape they see may even be an inanimate object (Nakomori et all., 2013). This situation is also observed in chicken chicks.

Figure 6. Monitoring imprinting behaviour in goose and chicken chicks

Green-headed ducks are an example of sexual imprinting. Before the chicks leave their mothers, they know that their mates will resemble their mothers in appearance. Males of mallard ducks are imprinted on females of their own species between the 6th and 8th week (critical period) before reaching sexual maturity (Şahin and Biricik, 1997; Irwin and Price, 1999). Thus, these species learn to recognise individuals of their own species throughout their lives.

In a study conducted in chicken chicks, it was determined that the most critical period was between the 12th and 18th hours after hatching and a weak process in their education started after the 4th day (Aoki et all., 2022). During this period, they are sensitive to all kinds of stimuli from the environment. If they are left in the dark for a long time during this period and fed by hand, they may not be able to take a food on the ground when they are released because pecking behaviour has not been learned. In addition, this critical period is a time for the newly hatched chick to recognise its mother's voice and learn the song of its species (Batista et all., 2016). In this process, lifelong exposure to behaviours is guided.

4. RESULT

The science of ethology, the foundations of which were first laid with Aristotle's (384-322 BC) *Animal Stories*, has trained many scientists until today. Each of these scientists has both enabled us to get to know animals better and shed light on many information that will make our lives easier. From being able to fly in the sky to being able to live underground, we owe many things that make our lives easier to the study and adaptation of animal behaviour to our lives. We think that the animals we share this world with will continue to be studied and better recognised from today to the future.

Animals such as turkeys, ostriches, quails, ducks and chickens, which have been domesticated and live in close proximity to humans, belong to the group of poultry farm animals. There is a mutual relationship between these animals and humans. This relationship can sometimes be in a commercial dimension or sometimes in the form of family poultry, hobby animal husbandry. Under all circumstances, whether it is a carer or a family member, he/she should know his/her animal well.

What are the genetic behaviours of these animals that we take out of wildlife and domesticate? What is the gender-related behaviours? How do they perform behaviours such as reproduction and offspring care? What can we teach our animals? The answers to many questions such as these were tried to be given in this study. In addition, different perspectives have been brought to researchers who will plan new studies on this subject.

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Chapter 9

Behavioral Characteristics in Poultry

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1. INTRODUCTION

The domestication of chicken has been an interesting research topic in many wide raange disciplines from the times of Charles Darwin (Miao et al., 2012). It is widely accepted that chickens were domesticated from the red jungle fowl living in India and Southeast Asia (Marino, 2017; Knginakudru et al., 2008; Al-Nasser et al., 2007). Although scientists mostly agree that chickens were domesticated from the red jungle fowl, there are some conflicts regarding the date of domestication. While some researchers claim that these animals were domesticated 8000 years ago (Marino, 2017; Göger and Yenice, 2018), others report that they were domesticated approximately 2000-2500 years ago (West and Zhou, 1988; Tixier-Boichard et al., 2011). In addition to this information, there is also some molecular evidence that the domestication process began 58,000 years ago (Morino, 2017). Although much information has been obtained about the history of the domestication process, it is still open to debate.

Primarily chickens domesticated for entertainment or as a pet. Afterwards they are reared for their egg and meat. While they are domesticated by humans their production and behavioural traits are changed. During this domestication process, changes occurred in the productivity and behavioral characteristics of poultry. Selections made to obtain more products caused changes in some of the appearance characteristics and behaviors of chickens. Some researchers reported that although there were significant changes in some of the production and morphological characteristics of chickens, there were no major changes in their behavioral and cognitive characteristics (Marino, 2017; Göger and Yenice, 2018). The most important behavioral change was observed as a decrease in escape and coop behavior and an increase in feed consumption and aggressive behavior (Göger and Yenice, 2018). In addition, Marino (2017) reported that domestic chickens were more aggressive than their ancestors. Briefly, the behaviors, body weights and growth characteristics, appearance of poultry like feather colour animals have undergone some changes with selection.

Throughout the entire domestication process, the welfare of animals has been a neglected issue. Later, under the leadership of the organization known as the Society for Applied Ethology (ISAE), researchers have conducted studies to understand the relationship between animal behavior and welfare (Millman et al., 2004). The scope of applied ethology is particularly concerned with describing the behavior of farm animals. On the other hand, animal welfare can be defined as the provision of health, happiness and well-being, free from pain and suffering during the care, feeding, housing, reproduction, transportation, slaughter, treatment or use in scientific research of animals (Akbaş, 2013).

Animal behaviors can provide information about the welfare level of animals, so welfare and behavior are closely related to each other. While determining animal welfare there are two aspects; one of them is animals' health and the other one is whether animals behave like in their natural habitat (Akbaş, 2013). Behaviors play an important role in determining the welfare and performance of animals (Akbaş, 2013). Therefore, welfare is an important for producers not only from an ethical perspective but also its effect on production performence (Rushen et al., 1999; Arnaud et al., 2010).

At the present time, most of the poultry species used in commercial production are raised in very intensive and fully automated farms due to the increase in intensive production. In these farm systems, environmental conditions are regulated according to the needs of the animals. In these intensive and fully controlled environmental rearing systems, animals cannot exhibit their natural behaviors, which leads to declines in animal welfare. In addition, in recent years, a significant portion of consumers, especially in societies with high culture and welfare, are more conscious and sensitive about animal welfare. In this context, interest in research on animal behavior and welfare has increased.

The aim of this study is to describe the behavioral characteristics of chickens from the beginning of the domestication process to the present day and to reveal the relationships between these behavioral characteristics and their productivity and welfare status.

2. BEHAVIORAL PHYSIOLOGY

There are many factors such as environmental and breeding conditions, genetic infrastructure, and nutrition that affect this profit in broiler chickens raised for profit. However, as this intensive production system grows day by day, producers have begun to experience problems with animal welfare along with the increasing awareness of consumers. Because in this intensive production system, issues such as animal health and living conditions have begun to be ignored. For this reason, animal welfare has become an ethical problem. In addition, it has been understood that animal welfare also affects efficiency in production, and many researchers have begun to work on animal welfare.

Broiler chickens have been subjected to selection in order to produce more meat. These intensive selection programs continue today. With these applications, growth rates in broiler chickens increased by 400% from 1957 to 2005 (Zuidhof, Schneider, Carney, Korver, & Robinson, 2014, p. 11), and the time it took to reach 1500 g live weight in 1957 was 120 days, while it was reduced to 30 days in 2005 (Sarı & Saatcı, 2020). This high growth rate obtained with the selections applied to broiler chickens causes certain genetic problems such as some diseases, contact dermatitis, skeletal problems (Sarı & Saatcı, 2020), tibial dyschondroplasia, valgus-varus deformation (Karaaslan, 2015). These animals have difficulty moving due to the foot and leg problems they encounter and cannot reach the feeder and waterer (Karaaslan, 2015). As a result, live weight gain is negatively affected (Julian, 1986; Karaaslan, 2015), and thus economic losses occur.

Broilers spend 76-86% of their time lying down, depending on the severity of lameness they experience (Karaaslan, 2015). Since they lie down for a long time, in addition to foot and leg problems, burns and bruising occur in the chest area. These defects cause negative effects on carcass quality and also cause deaths at a rate of 0.5-5% (Karaaslan, 2015). In a study, it was reported that deaths caused by leg defects constituted 16.75% of total deaths (Mısırlıoğlu et al., 2001; Karaaslan, 2015). Whitehead et al. (2003) reported that valgus-varus deformation in broilers is related to rapid live weight gain and continuous lighting programs, Shim et al. (2012) also reported that valgus-varus deformation has a positive relationship with growth rate (Karaslan, 2015). Contact dermatitis can be expressed as burns on the soles of the feet, knee joints and chest area in broiler chickens and constitutes an important production and welfare problem in broiler chickens (Sarı and Saatcı, 2020). Bessei (2006) reports that it reduces profitability in production by revealing factors such as breast blisters and knee burns in broiler chickens with high amounts and severe foot problems. One of the most important elements used to define animal welfare is the determination of animal behavior. Animal welfare can be defined by observing the behavior of animals as well as by looking at some physiological parameters (amounts of some hormones in the blood; corticosterone (CORT), adrenocorticotropic hormone (ACTH), thyroid hormones (T3, T4)). For example, corticosterone, known as the stress hormone, occurs in poultry in certain stress situations such as high stocking density, low or high environmental temperature, moving from the brooder to the coop or from the coop to the slaughterhouse, interaction with humans, and sudden changes in their environment. Corticosterone is secreted from the adrenal glands in response to the activation of the hypothalamic-pituitary-adrenal (HHA) axis and is among the stress parameters in poultry (Dayıoğlu (Gür), 2018). Özkan et al., (2012a), in a study investigating the effects of cyclical lighting (16A:8K) on incubation, created three groups as the control group, the group to which cyclical lighting was applied throughout the entire incubation period, and the group to which cyclical lighting was applied during the last week of incubation. They reported that in the groups to which cyclical lighting was applied, the concentration of corticosterone in the blood was lower than in the control group after the stress encountered by the chicks during routine procedures applied in the hatchery on the day they hatched and during holding. They found that the group that used cyclic lighting throughout the entire incubation period (21 days) had a lower increase in blood corticosterone levels 8 hours after hatching than the other groups. They reported that this low corticosterone level was an indication that the chicks were less responsive to stress brought on by changing environmental conditions after hatching.

There are many behavioral characteristics related to welfare in broiler chickens such as sitting, standing, walking, jumping, feed consumption, drinking, wing stretching, sand bathing, feather pecking and aggression. In order to understand and define all these behaviors, it is necessary to know the physiology of these behaviors well. Behaviors in all vertebrate animals are regulated by the hypothalamus. Some hormones secreted from the hypothalamus stimulate the display of certain behaviors. The presence or absence of some hormones affects the display of certain behaviors and therefore may cause a decrease in animal welfare and production performance. In this section, information will be given about the physiology of some behaviors that are important in terms of production performance.

2.1. Reproduction and Sexual Behavior

In many birds, reproductive behavior includes courtship, mating, nesting, incubation, and care of the chicks (Ball and Balthazard, 2009). In poultry species, the hypothalamus governs the reproductive system and reproductive behavior. The hypothalamus, pituitary gland, and gonads (ovaries and testicles) are the three main elements of the reproductive system. A successful production system depends on the simultaneous and synchronous functioning of these three elements (Ottinger and Bakst, 1995). The avian reproductive system is regulated by the hypothalamic-pituitary-gonadal axis (Ottinger and Bakst, 1995) and gonadal hormones (Ottinger, 1993; Adkins and Adler, 1972). Gonadotropin-releasing hormone (GnRH), secreted by the pituitary gland, stimulates the release of luteinizing hormone (LH) and follicle-stimulating hormone (FSH), which regulate ovarian and testicular functions. Gonadal hormones, mainly testosterone, estradiol and progesterone, are carried to the central nervous system via the blood and provide feedback to the hypothalamus to initiate GnRH secretion (Ottinger and Bakst, 1995). However, GnRH exists in two forms in birds, GnRH-I (GnRH-I) and GnRH-II (cGnRH-II) (King and Millar, 1982; Miyamoto et al., 1984), and since this discovery, both forms have been observed in some poultry species (Sherwood et al., 1988; Milliam et al., 1993). There are several studies on the effects of some GnRH forms on the central nervous system. Beach and Inman (1965) found that castration abolished all sexual behaviors within 8 days and that testosterone pellet implantation restored all sexual behaviors. This supports the idea that male sexual behavior is dependent on the presence of testosterone. Again, Adkins and Adler (1972) conducted a study with adult Japanese quail castrated by subjecting them to a short photoperiod and observed the behavior of the Japanese quail by injecting them with either estardiol benzoate (EB) or testosterone propionate (TP). The EB-injected females displayed normal sexual behavior again, while no males displayed courtship behavior, but both males and females displayed copulatory behavior. The TP-injected females displayed very little of some sexual behavior, while the males displayed male sexual behavior.

2.2. Aggressive Behavior

Aggressive behavior is a behavior that is inherently associated with survival and reproduction (Fraser and Rushen, 1987; Duncan, 1998; Cheng and Muir, 2007). According to Caliva et al. (2017), although aggression is a social behavior for all animals, it is an important behavior that affects both animal welfare and performance when considering farm animals. The frequency and intensity of aggressive behavior and some social adaptation and behavioral synchrony can also be a good indicator of animal welfare (Duncan, 1998). However, in intensive and controlled production systems, such as in poultry production, aggression causes increased social stress and cannibalism due to feather and body injuries (Cheng and Muir, 2007).

In order to perceive this behavior and take the necessary precautions, it is first necessary to understand the mechanism and physiological background of the behavior. In humans and mammals, it has been determined that some monoamines are associated with aggressive behavior (Berman and Coccaro, 1998; Cheng and Muir, 2007). The density of serotonin and its metabolites and even its receptors is considered as an indicator of some abnormal behaviors, including aggressive behavior (Valzelli, 1984; Bell and Hobson, 1994; Popova et al., 1997; Barak and Mashiach, 2003; Abumariam et al., 2006; Cheng and Muir, 2007). Another monoamine, dopamine, is also considered as an indicator participating in the control of some behaviors (Snider and Kuchel, 1983; Kudriavtseva et al., 1988; Miczek et al., 1994; Kuikka et al., 1998; Cheng and Muir, 2007). Catecholamines (Epinephrine (EP) and norepinephrine) and corticosterone (CORT), known as “stress hormones”, are functionally linked to controlling internal behaviors (Servo and Naumenko, 1990), mood control (fight or flight), and coping with stress as a sense of well-being (Cheng and Muir, 2007). There are studies on whether these hormones, which affect such behaviors in humans and mammals, have the same function in poultry. In a study conducted by Cheng and Muir (2007), they hypothesized that the neuroendocrine system has the same function in laying hens. In this study, two different groups with clearly distinguishable levels of aggression and productivity and different sensitivity to environmental stressors were used. They found that serotonin concentration was higher in the group with low viability, which caused high cannibalism, and reported that serotonin levels were positively correlated with aggressive behavior. As a result of the measurements obtained at the age of 21 weeks, they found that there was a higher dopamine and epinephrine concentration in the group with low productivity and vitality than in the group with high productivity and vitality, also called the calm group. These results are parallel to the results of the study by Edens (1997), in which more aggressive behaviors were detected in Japanese quails with high dopamine levels and prove that dopamine has effects on aggression.

3. GENETIC BASIS OF BEHAVIOR

The process of domestication is a major innovation for humans, with major effects on the development of agriculture and societies (Siegel, 1993) and is a process in which animals adapt to living conditions close to humans through selection (Price, 1999; Wiren, 2009). Darwin (1875) suggested that animals were changed due to the choices humans made for certain characteristics when they were domesticated (Siegel, 1979). Despite the fact that they made unconscious choices in this domestication process, Wiren (2009) stated that since animals are raised in larger groups than in their natural habitats under modern conditions, it should be considered natural that individuals with greater living capacity that can cope with this density are selected. Hyams (1972) defines domestication as an ongoing process that involves an infinite number of small changes in the behavior of an animal towards humans and vice versa. This definition is consistent with Eibl-Eibesfeldt's (1970) view that adaptations of certain characteristics to certain environments can be observed during the domestication process.

In poultry, the process has accelerated in the last few decades due to the development of specialized male and female lines in increased selection and breeding programs (Siegel, 1993). In this process, poultry have responded physiologically, genetically and behaviorally to cope with the environmental pressures they feel (Siegel, 1993). Here, it is necessary to investigate how different domestic chickens are from their ancestors, the red jungle fowl, how much genetic diversity there is among them and what changes this genetic diversity causes in the behavior of chickens.

According to the studies conducted in DNA studies (Siegel et al., 1992), the genetic distance between red jungle fowl and white leghorn layer hybrids was found to be similar to the genetic distance between commercial broiler hybrids (Siegel, 1993). Although most behaviors seem to be affected by polygenic systems, there is a lot of evidence that certain mutants change behavior (Siegel, 1993). The degree of effect of these mutants depends on the genetic background of the individual, the effect of the environment, or the relationship between the two. Kinney (1969), who estimated the heritability of some behaviors in chickens from genotypic and phenotypic correlations, reported that this genetic variation affects some behaviors themselves while indirectly affecting others (Siegel, 1993). Polymorphism can be the result of non-random matings, either directly or indirectly (Siegel, 1993). When indirect, polymorphisms that change physical appearance can cause social stratification in one sex and affect mate choice. Lill (1968) studied the effect of feather color on sexual isolation in domestic chickens, while Crawford and Smyth (1961), Sefton and Crawford (1967) and Crawford (1973) reported that polymorphisms in feather patterns affect social hierarchy and sexual behavior in Fayoumi chickens (Siegel, 1993). In another study by Crawford and Smyth (1965), it was found that single-crested males copulated more than rose-crested males and that males with the Rrpp genotype copulated more than those with the RRpp genotype. However, Petitjean and Cochez (1966) obtained the opposite result and reported that there was no difference in mating frequencies between males with the Rrpp and RRpp genotypes. The reasons for such different results may be due to the different genetic background of the flocks in which the experiment was conducted.

When all this information is taken into consideration, it is clearly seen that the genetic substructure that changes with selection has an effect on behavior. Despite the increasing interest and studies in recent years, the effect of genetics on behavior has not been adequately explained. Therefore, more studies are needed to explain the genetic substructure of behavior and to determine what effects the polymorphisms that occur have on behavior.

4. BEHAVIORAL CHARACTERISTICS IN POULTRY

It is possible to determine the behavioral characteristics of poultry and, accordingly, the welfare level of the flock. It is possible to evaluate each behavior as a different parameter. Accordingly, it is tried to explain which behavior is related to which parameters in the following sections.

4.1. Well-being-Related Behaviors

We can understand the welfare of animals by the fact that they can generally exhibit their behaviors in nature and live a life free of stress and disease. One of the most important factors affecting welfare in poultry is fear and stress. Poultry, which were developed to obtain high productivity through selection, have been provided with shelters and care-management systems that can meet the needs of the animals in order to increase this productivity. However, within these developed shelters and care-management systems, animals cannot exhibit their natural behaviors sufficiently and the fear behavior that is present in their instincts within this rapidly changing system could not be prevented (Akşit and Özdemir, 2002). Fear, defined as a psychophysiological reaction of the brain and nervous system, a disharmony that is felt during danger, a harmony-providing energy that can also disrupt harmony (Jones, 1987a,b; Gray 1987; Boissy, 1995), causes significant productivity losses in poultry (Akşit and Özdemir, 2002). The intensity of fear varies according to the animal's perception ability, previous experiences, hormonal status and the magnitude of the factor causing fear, and low-intensity fear factors increase the animal's adaptability. They give reactions such as running away, remaining motionless or resisting when they are in severe fear (Akşit and Özdemir, 2002). While short-term and low-intensity fear normally protects animals against external dangers, when it is long-term and severe, it disturbs the peace of the birds and affects performance (Jones, 1996; Akşit and Özdemir, 2002). Elrom (2001) reported that fear causes great economic losses in intensive production systems where the movements of animals are also restricted.

Among the natural behaviors of birds, behaviors such as sand bathing and feather trimming can be considered as welfare criteria. Since these behaviors are usually observed for a short time and in small numbers, they have been evaluated in different categories by various researchers. Feather trimming behavior was classified by Mohammed et al. (2018), Wei et al. (2020) and Li et al. (2019) alone and expressed as chickens gently trimming and combing their feathers with their beaks. On the other hand, some researchers have considered it under comfort behavior together with behaviors such as wing flapping, leg - wing stretching, feather flapping (Riber, 2015; Van Emous and Mens, 2021; De Los Mozos et al., 2017; Riber et al., 2021). In addition, Ross et al. (2019) evaluated behaviors such as feather trimming, leg - wing stretching, which included sand bathing, under the title of care behaviors. Many researchers have evaluated sand bathing as a behavior in itself, such as rubbing the head and body on the ground, scratching the beak, shaking the vertical wing, pecking and scratching while lying on the side, or shaking dirt from the feathers (Riber, 2015; Riber et al., 2021). Silva et al. (2021) defined sand bathing as a combination of feather grooming and stretching movements and, like Ross et al. (2019), described it as a grooming behavior. Silva et al. (2021) used 4000-day-old Cobb 500 male chicks in a study where they used straw bales, step platforms, and laser projectors as environmental enrichment tools. They used two groups, one without the same environmental enrichment as commercial chicken houses and one with an environment enriched with the mentioned materials, as the experimental group. The researchers reported that sand bathing behavior is a behavior associated with comfort and welfare for species for which feather care is important in their natural habitats and found that the frequency of sand bathing behavior was higher in the environmental enrichment group than in the non-enrichment group. Additionally, the frequency of sand bathing has been reported to decrease with increasing age and increasing settlement density (Meluzzi and Sirri 2009), and the inability to exhibit natural behaviors under restricted environmental conditions is a welfare issue (Ventura et al., 2010; Sánchez-Casanova et al., 2020).

The evaluation of such behaviors under different categories may vary depending on the studies planned by the researchers and their individual evaluations. However, no matter which group they are evaluated under, the basis of such behaviors is based on the behaviors they exhibit in their natural life. It is also possible to evaluate the behaviors they exhibit in their natural life as a measure of welfare.

4.2. Behaviors Related to Yield

Although poultry were domesticated for different purposes at the beginning of the domestication process, they are currently used for meat and egg production. Studies are still ongoing to increase the efficiency of these animals, whose efficiency has been increased with the selections applied. Studies on behavior have increased in recent years and efforts are being made to reveal its relationship with efficiency. The most important behaviors associated with efficiency are feed consumption and water drinking. Feed consumption is encouraged with care and management programs applied to chickens. In this way, important efficiency characteristics such as live weight and live weight gain are improved, and production is increased. All researchers agree on the definition of feed consumption and water drinking. Feed consumption is defined as the head being on the feeder or pecking at the feeder, and water drinking is defined as the beak being in contact with the water troughs (Mohammed et al., 2018; Riber, 2015; Van Emous and Mens, 2021; De Los Mozos et al., 2017; Riber et al., 2021; Siva et al., 2021; Wei et al., 2020; Ross et al., 2019; Li et al., 2019). Studies have shown that feed consumption and water drinking behavior vary according to the content of the feed, the structure of the feed, and the environmental conditions in which the animal is located. Mohammed et al. (2018) examined the effects of synbiotic supplementation on behavioral patterns and growth performance in 360 one-day-old Ross 708 chicks exposed to heat stress. As a result of the study, it was determined that chicks fed with synbiotic supplementation exhibited more feed consumption behavior. They also noted that the synbiotic-added group reached higher live weights on the 7th, 14th and 42nd days, provided higher live weight gains, consumed more feed, and had better feed utilization values on the 28th day. However, they reported that this application did not have a significant effect on water consumption. In a study investigating the behavior of two generations of broiler breeders fed with a balanced feed containing 25% reduced protein, it was determined that feed consumption was inhibited, and water consumption was significantly reduced (Li et al., 2019).

As a result, feed and water consumption behaviors are behaviors that are affected by many environmental factors such as feed content, feeding time, feeding program, light intensity, ambient temperature. By encouraging feed consumption with various regulations and programs, performance parameters such as live weight, live weight gain, feed utilization can be improved, and productivity can be increased.

4.3. Harmful Behaviors

The most common harmful behaviors in poultry can be defined as pecking, feather pecking, plucking, aggression, and cannibalism, which occurs as a result of these. While some researchers define feather pecking or plucking behavior as mild or severe on its own (Riber et al., 2021), some researchers examine it under object pecking (Li et al., 2019). Aggression or aggressive pecking has been defined as jumping, jumping, flapping, kicking, pecking at another animal from the front in a threatening manner (Riber, 2015; Riber et al., 2021) or directly pecking its head while walking, sitting or standing (Li et al., 2019). These behaviors are considered an indicator of animal welfare and are thought to be a reflection of emotional states (Silva et al., 2021). In addition, such behaviors negatively affect animal welfare as they can cause injuries or even deaths when they increase in the flock.

Pecking, feather pecking, plucking and aggressive behaviors can be controlled with various environmental arrangements and feed arrangements. Dawson et al (2021) reported that oral enrichment objects such as hanging ropes and straw bales increased the pecking opportunity and were also associated with walking scores. In a study conducted with slow-growing Delaware chickens, the animals were provided with an area consisting of plastic pipes or upper shade panels and curtained shelters placed away from the coop that did not receive environmental enrichment and provided an exit door for the animals as a control group. They reported that the behavior of the chickens was significantly affected by environmental conditions (indoors or outdoors). They found that the animals walked and grazed outside, while they consumed more feed, stood and sat inside. They observed that aggression behavior was generally higher outside than inside and noted that it was highest outside at 7 weeks of age (Fanatico et al., 2016). Another study on environmental enrichment was conducted by Silva et al. (2021). The study used straw bales, step platforms and laser projectors as environmental enrichment tools and observed behavioural and welfare parameters. They noted an increase in straw bale pecking, use of step platforms and climbing on straw bales, and reported that chickens raised in the enriched environment were calmer.

Kristensen et al. (2007), in a study investigating the effects of lighting sources used on behavior in commercially reared broiler chickens, noted that broilers exhibited less feather pecking behavior in warm white light than in biolux light. Similarly, Praytino et al. (1997) reported that broilers reared in red and white light were more active than those reared in green and blue light, and that those reared in red light were more aggressive. Considering all these studies, it is possible to say that the behavior of broiler chickens is affected by the wavelength and intensity of light, and accordingly, their welfare level is affected (Kristensen et al., 2007). There are also studies on feeding on pecking and aggression behavior. In a study conducted with two different feeding methods (everyday feeding and every other day feeding) and two different feed types (classic commercial feed and feed containing soybean hulls, fiber source and calcium propionate), it was recorded that chickens fed every other day exhibited more feather pecking behavior during feeding, while those in the control group exhibited more feather pecking behavior after feeding (Morissey et al., 2014).

4.4. Behaviors Related to Reproduction

In poultry, reproductive behaviors are typically observed following the attainment of sexual maturity. These behaviors encompass a series of innate and stereotyped actions, including courtship, copulation, nest building, incubation, and chick rearing (Ball and Balthazard, 2009). However, in the context of commercial poultry production, reproduction and mating are predominantly controlled through artificial insemination, thereby minimizing the relevance of natural reproductive behaviors. Instead, behaviors such as broodiness and nest utilization are of greater significance, as they directly influence production efficiency. Broodiness, in particular, represents a critical trait in commercial systems due to its negative impact on egg production. The prolactin gene has been identified as a key candidate gene associated with egg production in poultry. Broodiness behavior is strongly correlated with the activity of the prolactin gene, which regulates reproductive physiology through a negative feedback mechanism on the pituitary gland. This feedback suppresses the secretion of gonadotropin hormones, thereby inhibiting ovulation (Lea et al., 1996; Çebi and Akçay, 2010). Moreover, the initiation of brooding behavior is frequently accompanied by a reduction in egg production, a phenomenon linked to ovarian regression stimulated by increased secretion of prolactin hormone (Li et al., 2013). Empirical evidence indicates that plasma prolactin concentrations are significantly elevated in brooding hens compared to their non-brooding counterparts (Çebi and Akçay, 2010). Notably, in commercial poultry breeding programs, the prolactin gene, due to its direct and negative association with broodiness behavior, has been effectively eliminated through selective breeding practices. This genetic refinement has contributed to enhanced production efficiency in commercial poultry flocks.

5. CONCLUSION

Poultry animals have an important place in people's lives due to both their economic value and their role in food production. The behavioral characteristics of poultry animals vary according to their species, the environment they live in, and their social structure. Poultry animals are generally quite social creatures and form a certain hierarchy within the groups they live in. For example, there is a social hierarchy known as the "pecking order" in chickens. In this structure, more dominant chickens dominate other members of the group. Social interactions help such animals reduce their stress levels and establish social bonds. Poultry exhibit unique behaviors during their breeding season. Female birds usually choose a mate based on the showy behaviors exhibited by males. During this time, males show themselves by making sounds, dancing, or displaying their colorful feathers. Egg-laying and brood care are also behaviors specific to females; the female bird is very active in protecting the eggs and taking care of the brood. Feeding habits are one of the most important elements of the survival strategies of poultry animals. For example, chickens usually feed by mixing seeds, insects, and other foods on the ground. Ducks are usually found near water and feed on aquatic plants and underwater creatures. They can move in groups by exhibiting social behaviors while searching for food. Poultry use various communication methods. Sounds, calls and body language play an important role in the social interactions and mating behaviors of these animals. While chickens warn other members by making alarm sounds in times of danger, young ones make certain sounds to call their mothers. The behavioral characteristics of poultry are important elements that affect both interspecies differences and ecological balance. Poultry raised as farm animals are valuable creatures of our day, not only for their own species with their social structures and communication styles, but also in terms of their interactions with humans. Understanding the behavior of poultry contributes to the most efficient breeding of these animals, the creation of healthy living spaces and the increase of their productivity. In addition, this information is of critical importance in terms of animal welfare and sustainable agricultural practices.

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Chapter 10

Alternative Uses of Onion (*Allium cepa* L.)

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Introduction

The genus Allium and its close relatives, including the onion (*Allium cepa* L.), were classified in the family Liliaceae in the first taxonomic classifications. However, British and American botanists especially classify this genus in the Amaryllidaceae family due to its flower structure. There are more than 500 species of the genus Allium. Among these, the species that have been cultivated and gained economic importance over time are listed below (Rabinowitch and Brewster, 1990):

1.*Allium ampeloprasum* L.
  1.a. Leek group
    Allium porrum L.
    Allium ampeloprasum var. *porrum* (L.) J.Gay
  1.b. Kurrat group
    Allium kurrat Schweinf. ex *Krause*
    Allium porrum L. var. *aegyptiacum* Schweinf.
  1.c. Large-bulbed garlic group
    Allium ampeloprasum L. var. *holmense* (Mill.) Aschers. Et Graebn
    Allium ampeloprasum L. var. Ampeloprasum auct.
  1.d. Pearl onion group
    Allium ampeloprasum var. *sectivum* Lued.

2. *Allium cepa* L.
  2.Allium Bulb onion group
    Allium cepa var. *cepa*
    Allium cepa var. *typicum* Rgl.
  2.b. Shallot group (aggregatum)
    Allium ascalonicum auct. Non Strand
    Allium cepa var. *ascalonicum* Backer.
3. *Allium chinense* G. Don
    Allium bakeri Rgl.
  3.a.Allium Rakiyo group
    Allium exsertum (Lindl.) Baker non G. Don
4. *Allium fistulosum* L.
    Allium bouddhae Deb.
  4.aAllium Welsh onion group

5. Allium x *proliferum* (Moench)
    Allium cepa var. *viviparum* (Metzg.) Alef.
    Allium cepa var. *bulbiferum* Rgl
6. *Allium sativum* L.
  6.aAllium Garlic group

Allium sativum L. var. *sativum*
Allium sativum L. var. *typicum* Rgl.
6.b. Ophioscorodon group
Allium sativum L. var. *ophioscorodon* Doll.
Allium sativum L. var. *controversum* (Schrad.)
7. *Allium schoenoprasum* L.
Allium sibiricum L.
7.aAllium Chives group
Allium alpinum (DC.) Hegetschw.
8. Allium tuberosum Rottl. Ex spr.
Allium uliginosum G. Don
Allium chinense Maxim. Et auct. Non G. Don

Onion is a diploid vegetable and has 2n=16 chromosomes in the cell nucleus. Compared to other plant species, it has a much larger genome (C:16,415 Mbc) (Arumuganathan and Earle, 1991). Rabinowitch and Brewster (1990) reported that the main information on the evolutionary process and history of the onion is provided mainly through written sources and drawings. Based on this information, onion is defined as one of the oldest vegetable species cultivated today. There are no precise records on the geographical origin of the cultivation process, which dates back approximately 4,000 years. The temples and pyramids of Egypt's III and IV dynasties (2,700 BC) contain the first onion-related findings. In the same region, in the 1580s BC, it was found to be an object belonging to funeral ceremonies and left in graves (Täckholm and Drar, 1954). It is reported that onions are mentioned in records found in India dating back to the VI century BC and in the works of Homer and Juvenal in Roman and Greek culture. Some expressions of onion, which has an important historical background in the medical field, are found in the works of Hippocrates (V century BC) and Dioscorides (I century AD) (Helm, 1956; McCollum, 1976). Although some onion varieties are mentioned in the famous land management declaration “Capitulare de villis” written during the reign of the Roman Emperor Charlemagne (IXth century AD), it is reported that its spread to the entire European continent was only possible in the Middle Ages with the introduction of material through Russia (Kazakova, 1978). It is known to have been transported to the Americas by migration from Europe (McCollum, 1976).

Onion is a very important vegetable in terms of nutritional value. 100 g raw onion has an energy value of 40 kcal. The same amount of onion contains 9.34 g carbohydrate, 1.10 g protein, 4.24 g sugar, 0.10 g fat, 70 mg sulfur, 146 mg potassium, 24 mg phosphorus, 23 mg calcium, 10 mg magnesium, 7,4 mg vitamin C, 0.116 mg vitamin B3 and 0.046 mg vitamin B1 (Anonymous, 2024). Onion has been used for therapeutic purposes for many years. It is reported to be used in the regulation of the digestive system, and in the treatment of shortness of breath and mild burns; in addition to these, it is reported to be used in cases such as blood clotting, arteriosclerosis, cholesterol, rheumatic pains (Kawakishi and Morimutsu, 1994).

Onion is one of the most common culinary ingredients used in kitchens and various products such as pickles, onion oil and dried onion flakes are prepared commercially. Onion processing processes such as dry skining, chopping and slicing generate large amounts of onion waste, with onion dry skin accounting for about 60% of the total waste (Sagar and Pareek, 2021).

Onion dry skin and extract as a supplement to foods:

More than 0.6 million tons of onion dry skins are wasted every year in Europe and 300-500 kg of onion skins are wasted every day in India (Das and Mandal, 2015; Katsampa, 2015). Although onion dry skins are a potential source of biologically active compounds such as phenols and flavonoids, they decompose in soil, causing environmental damage (Shabir et al., 2022).

Onion dry skin protects the onion against external factors, so it is likely to contain high microbial load and mycotoxin residues (Katip, 2019). Therefore, onion dry skin, which is a by-product, needs to be reduced microbial load and free of mycotoxin residues to avoid risks in food processing.

Onion dry skin extracted as waste is a rich source of polyphenols, antioxidants, fructooligosaccharides and dietary fibers (Memon et al., 2020). In addition, onion dry skin extract has been found to have anticarcinogenic, hypocholesterolemic and antiasthmatic effects, and thanks to the flavonoids it contains, it has shown antiproliferative activity that can disrupt excessive polyamine concentration in the body (Sagar et al., 2021). Therefore, onion dry skin has the potential to be a promising source for improving the functional properties of foods. Onion dry skins, which pose a serious ecological and economic problem as waste in the food industry, especially due to their nutritional and phytochemical properties, are important in terms of sustainability by using them in various food products and processes and recovering valuable components such as phenolics and antioxidants (Celano et al., 2021). Onion dry skin contains various bioactive compounds such as organosulfur compounds, thiosulfinates, polyphenols including flavonoids and fructooligosaccharides (FOS). In comparison to edible onion flesh, onion dry skin/skin had the highest phenolic and flavonoid contents (Sagar et al., 2022).

Onion dry skin had higher total phenolics (52.7 mg GAE/g), total flavonoids (43.1 QE/g) and total flavanols (7.89 mg/g) on a dry matter basis than inner flakes (9.4 mg GAE/g; 7.0 mg QE/g; 6.19 mg/g) and whole onion (17.3 9.4 mg GAE/g; 10.3 mg QE/g; 8.84 mg/g), respectively (Benitez et al., 2011). The two main subgroups of flavonoids are anthocyanins and quercetin. Quercetin derivatives, which give onion skins different colors from yellow to purple, are present in high amounts in onion skins to protect the onion from soil microbes (Sagar et al., 2022).

Many researchers have shown that the addition of onion dry skin to food products has an impact on the quality and nutritional properties of the product. Gawlik-Dziki et al. (2013) found that thanks to its high antioxidant capacity, onion dry skins can prolong the shelf life of products by slowing down lipid oxidation. It was noted that the introduction of onion dry skin caused an increase in antioxidant activity, flavonoid and phenolic content in pizza dough (Sagar and Pareek, 2020). In another study, it was concluded that 3% onion dry skin added to bread dough provided a significant increase in the total phenol, dietary fiber, antioxidant activity and total flavonoid content of the product and did not cause a change in the sensory properties of the bread (Prokopov et al., 2018).

Onion is rich in polyphenols such as flavonoids and anthocyanins, as well as antioxidant, antibacterial and anti-inflammatory effects (Corzo-Martinez et al., 2007). The efficacy of onion juice in improving the storage life of meat and fish products is being investigated by researchers and the food industry. Onion dry skin solutions were helpful over various Gram-negative and Gram-positive bacteria (Whitemore and Naidu 2000). The application of onion juice was found to effectively retard lipid oxidation and extend the shelf life of minced sardine (*Sardina pilchardus*) stored at -20°C (Serdaroğlu and Felekoğlu, 2005). Zolfaghari et al. (2009) reported that onion extract treatment effectively extended the shelf life and preserved the quality of vacuum-packed Rutilus frisii fillet samples. Most of the flavonoids and anthocyanins in onion accumulate in the skins due to cell senescence. Onion skins contain 90% of the total flavanols, the main flavonoid group in onions, and about 60% of the total anthocyanins in onions (Mogren et al., 2006).

Studies on the characterization of phytochemical functional properties have shown high antioxidant and antibacterial properties of onion dry skins (Choi et al., 2015; Güner et al., 2021).For these reasons, recently, research on the use of Onion Skin Extracts (SKEs) as natural preservatives in the food industry has increased. Onion Skin Extracts have been integrated with other preservation techniques and used at different concentrations to retard lipid oxidation and bacterial spoilage and to preserve fish quality.

Umeda and Jorge (2021) investigated the effects of purple onion skin extract (100 and 200 mg/kg oil) on the resistance to oxidation of soybean oil after oven-accelerated preservation at 60°C for 21 days. After seven days of rapid storage, the soybean oil subjected to purple onion skin extract had a peroxide index of 7.56 meq/kg, which was lower than the peroxide index of the control soybean oil (10.56 meq/kg) and the legislative threshold. This suggests that peroxide formation was slowed down. Although the efficacy of the purple onion skin extract treatment on soybean oil was not as high as that of synthetic tert-butylhydroquinone (TBHQ), it was nevertheless able to inhibit the oxidation of the oil (Umeda & Jorge, 2021).

Sayed et al. (2014) reported utilizing onion skin powder (2, 4, 6%) to fortify both fried and dried noodles in a prior investigation. The researchers found that adding onion skin powder to both dried and fried noodles elevated the contents of dietary fiber (dry: 3.7−7.98%; baked: 3.64−8.08%), while decreasing the contents of protein (dry: 9.86−9.30%; baked: 9.24−8.89%) and carbohydrates (dried: 84.2−79.92%; fried: 73.78−68.35%).

According to Shim et al. (2012), a 50% ethanol extract of onion skin can prevent lipid peroxidation in uncooked pig meat, acting as a natural antioxidant. In a study conducted by Shim et al. (2012), the antioxidant capacity of treating uncooked ground pig meat with onion skin extract at varying doses (0.05, 0.1, and 0.2%) for 16 days at 4°C in a refrigerator was compared to control and ascorbic acid (0.05%)-treated meat. The findings showed that after 16 days, the Thio barbituric acid reagents value in the pork treated with onion skin extracts (0.5−0.58 mg malondialdehyde/kg meat) was significantly lower than in the control group (0.95 mg malondialdehyde/kg meat). This suggests that onion skin extracts inhibited lipid peroxidation, shielding the pork from the rancid flavor that develops during storage. Additionally, the researcher claimed that onion skin had dose-dependent bacteriostatic effects. After nine consecutive days of storage, the number of bacteria per gram log (colony forming units (cfu)/g) results for Bacillus cereus, E. coli, S. aure-us, Proteus vulgaris, as well as B. subtilis (2.7 mg: 101.0, 33.0, 8.0, 26.0, and 200.0 cfu/g; 5.4 mg: 19.0, 14.0, 24.0, 36.0, and 127.0 cfu/g; and 10.8 mg: 9.0, 10.0, 10.0, 12.0, as well as 18.0 cfu/g) were below the values for the control group (229.0, 142.0, 221.0, 84.0, and 217.0 cfu/g).

The pectinase efficiency of six fungi (Aspergillus niger, Penicillium loliense, Trichoderma harzianum, Trichoderma longibrachiatum, Trichoderma viride, & Ulocladium botrytis) was measured at two distinct culture ages (four and seven days), with onion skin as the sole carbon source. After four days, pectinase (0.334 U/mg culture filtrate) was generated among all strains of T. virides. The pretreatment of onion skins with skin milling, sodium chlorite, and glacial acetic acid resulted in the highest pectinase production. According to the scientists (Ismail et al., 2016), fungal pectinase can be produced on onion skin as a substrate.

Tea can be extracted from the skin of an onion. Otieno et al. (2020) used 160.82 ml of water to maximize the brewing of tea from onion skin (0.5 g) at 180 minutes (the ideal period). The main components found in onion skin tea were quercetin, isoquercetin, and protocatechuic acid. According to Matsunaga et al. (2013), supplementing high-fat diet-induced obese male rats with 5% onion skin tea and 1.15 mg/g quercetin reduced serum levels of leptin, glucose, and total cholesterol in comparison to the control group, thereby validating the tea's anti-obesity effect.

Ali et al. (2016) studied the effects of various extraction techniques (Acidified methanol, ethanol, acidified distilled water, and distilled water) on the red pigments (anthocyanins) found in onion skins. Acidified ethanol was shown to extract anthocyanins more than acidified methanol, with distilled water extract exhibiting the lowest amount of anthocyanin extraction. It is evident that the anthocyanins (methanol and ethanol extracts) were most stable and retained at 2.0 pH, 40°C to 80°C, and 60 minutes of incubation. The anthocyanins deteriorated more quickly as the temperature.

Yellow OPE (0.3%, 0.5%, and 1.0%) was recommended by Ju and Song (2020) for use as an antioxidant in funoran-based biodegradable packaging materials. The incorporation of yellow OPE at varying percentages enhanced the funoran-based films' total phenolic (31.92−61.31 mg GAE/g) and TF (21.80−79.22 mg QE/g) contents, hence bestowing antioxidant potential onto them.

Uçak (2019) reported that pretreatment of onion dry skin extracts effectively delayed Thiobarbituric Acid (TBARS) and Total Volatile Basic Nitrogen (TVBN) formation, retarded bacterial growth, and ultimately extended the shelf life of shrimps. The effect of SKEs added to gelatin edible films on retarding lipid oxidation and microbial spoilage of cold-stored rainbow trout fillets was studied (Uçak et al., 2019). Bedrníçek et al. (2020)

observed that the addition of 1-2% onion dry skin powder to fish sausages improved sensory properties and slowed down PV and TBAR accumulation. Güner et al. (2021) found that the treatment of minced salmon with red onion dry skin extracts was effective in reducing the formation of hydroperoxides (PV) and thiobarbituric acid reagents (TBARS) during cold storage.

In breads, onion dry skin, which contains high levels of flavonoids, was intended to improve the antioxidant potential of bread by increasing the bioavailable quercetin content. The addition of 2-3% dried onions resulted in a significant improvement in antioxidant capabilities and functional properties (Gawlik-Dziki, et al., 2013). It was also reported that substitution of wheat pasta flour with onion skin powder (2.5-7.5%) dose-dependently improved the dietary fiber, phenolic and flavonoid contents and antioxidant properties of pasta samples (Michalak-Majewska, et al., 2020).

In a study, the weight, volume, moisture, water activity (aw) and color of pan bread with onion skin powder were examined and significant differences were observed from the results. A significant ($p<0.05$) increase in weight values between the control and other samples was observed with increasing onion dry skin powder. In all the bread samples containing onion skin powder, the volume decreased with increasing substitution level. On the other hand, the specific gravity of the bread samples increased compared to the control (Omran, et al., 2020).

It was noticed that substitution of wheat flour with onion skins in bread formulation affected the color of pan bread. The results showed that substitution of wheat flour with onion dry skins significantly reduced the lightness (L*) values of bread crumb in the pan with increasing level of substitution, where the control pan bread recorded the highest value and the bread crumb became darker. Regarding a* and b* values, the a* and b* values of onion dry skin pan bread were higher due to the pigment content of these onion dry skin powders. Prokopov, et al. (2018) reported that onion waste powder tended to make the color of the bread interior darker with increasing levels of onion waste powder compared to the control bread.

Kırkın et al. (2021) examined the sensory aspects of peanut butter and chocolate truffles that had onion dry skin powder added. Samples with 3% onion dry skin powder and peanut butter were just as accepted as the control group; however, examples containing 6% onion dry skin powder were not. Chocolate samples containing onion dry skin powder were deemed unacceptable at both the 5% and 10% concentrations. To ensure sensory acceptance, the quantity of onion dry skin powder applied to the chocolate truffle samples may be lowered to the same levels as in the peanut butter samples. On the other hand, to assess the level of onion dry skin powder's efficiency, each sample's antioxidant characteristics should be examined. For protection any industrial application of onion dry skin powder should wait until mycotoxin and pesticide residue levels are under control.

Raddatz et colleagues (2022) designed a functional strawberry pulp that incorporates Lactobacillus casei and bioactive components from red onion peel extract into microparticle compositions to promote bacterial survivability during store and ingestion. The encapsulation efficiency of both probiotics and chemicals was good across every option. The findings showed ranges that varied from 77.77 to 92.11% for probiotic bacteria, 28.88 to 50.18% for reducing chemicals, 35.72 to 69.01% for flavonoids, and 25.39 to 60.0% for total monomeric anthocyanins. To summarize, red onion peel extract at low concentrations can aid in the continued existence of the probiotic L. casei under various environments.

Onions as a tool of alternative medicine:

According to the definition of the National Center for Complementary and Alternative Medicine of the National Institute of Health in the United States and the World Health Organization; " In a given nation or culture at a given time, complementary alternative medicine is a vast field of medicine that includes health services, approaches, practices, and related theories and beliefs that are not part of the politically dominant health system (Dokken and Sydnor-Greenberg, 2000; NIH, 2024; WHO, 2024).

Among the reasons why people benefit from complementary/alternative medicine practices are that they are compatible with their culture, cost less, can be accessed in a simpler way, have no or fewer interventional procedures, and are seen as hope for chronic, psychiatric and terminal diseases (Biçer and Yalçın Balık, 2019). The neurophysiological use of the effect of Allium species sheds light on the different uses of these plants. It has been observed that extracts obtained from Allium species exhibit analgesic and antipyretic effects and can be used in the treatment of diseases such as inflammation, ulcer, viral infection, cancer, eczema, diabetes, gangrene due to aging, shingles, AIDS (acquired immune deficiency syndrome) (Bhandari et al. 2017).

Onion plays an important role on fertility (Shokoohi et al., 2018). It has been emphasized that onion improves sperm quality and causes a significant increase in testosterone levels (Ige and Aghigbe, 2012; Shokoohi et al., 2018;

Banihani, 2019). A study reveals that Onion juice has protective effects against Escherichia coli bacteria, improves fertility, testicular tissue and antioxidants and significantly reduces the effects of bacteria (Shahverdi et al., 2017).

It is stated that onion is important for human health and its regular consumption improves health status and reduces the risk of disease, especially reduces the risk of cancer in various tissues, prevents cardiovascular diseases, neurodegenerative diseases and cataract formation (Albishia et al., 2013; Yang et al., 2013; Taşçı and Koca, 2019; Atik and Dıraman, 2019). In addition, regular consumption of onion, which has anthelminthic, anti-inflammatory, antiseptic, antispasmodic, carminative, diuretic, expectorant, hypoglycemic, hypotensive effects, is reported to reduce the risk of angina, arteriosclerosis and heart attack (Kumar et al., 2010; Teshika et al., 2019). Onion contains high levels of phenolic compounds, especially flavonoids, which have antioxidant properties as well as other pharmacological effects such as antibiotic, antidiabetic, antiatherogenic and anticancer activities (Helen et al. 2000; Insani et al., 2016; Beretta et al. 2017; Liguori et al. 2017; Marefatia et al., 2021). Flavones, flavanones, flavonols, isoflavones, flavanonols, chalcones and anthocyanins, which are subclasses of flavonoids and flavonols, are the most abundant flavonoids in Onion (Liguori et al., 2017; Marefati et al., 2021).

Onion polyphenolics and flavonoids, especially components such as quercetin, exert cardiovascular inflammatory effects (Albishi et al., 2013; Zhang et al., 2015; Vazquez-Prieto et al., 2015; Hashemzaei et al., 2017; Marefatia et al., 2021). Onion contains several flavonoids that may be helpful in the treatment of oxidative stress-mediated diseases as well as diseases associated with inflammation, thermal and mechanical hyperalgesia (Vazhappilly et al., 2019; Marefatia et al., 2021). Quercetin, a well-known constituent of Onion, shows various biological activities, including lung compression and reduction of cholesterol and sugar levels in the blood (Hashemzaei et al., 2017; Marefatia et al., 2021). Studies have shown that Onion can reduce inflammation and vascular inflammation (Alpsoy et al., 2011; Umoh et al., 2019).

Bernas et al. (2021) utilized onion juice for melting to evaluate its usefulness in maintaining the strength and form of mushroom fruiting bodies to the widely approved blanching method in a sodium metabisulfite (SM) solution. Pretreatment with onion juice and extracts (5% waste (tunic) and 25% fleshy scale plants) may be an option in addition to SM (0.3%), with fleshy scale leaf juice or extract being among the most efficient blanching treatments. L-Phenylalanine may indicate enzymatic activity in frozen button mushrooms after eight months of keeping. Monophenolase and, to a lesser extent, diphenolase were the enzymes that caused the color changes in fruiting bodies. An increase in L-tyrosine was related to undesirable color alterations.

Onion also contains Ca, Fe, Mg, P and K. Onion ensures that the body gets enough vitamin C with its high antioxidant properties. Vitamin C is an effective vitamin in preventing cancer. At the same time, vitamin C influences strengthening the immune system (Elshaboury, and Sakara, 2021). In scientific studies, the biological activities of flavonoids have been determined and it has been stated that these compounds have antiviral, antimicrobial, anti-inflammatory, antiproliferative, antiallergic antithrombotic, antioxidant, antineoplastic, cytoprotective and proapoptotic effects (Michaud Levesque et al., 2012).

Quercetin, allicin and kaempferol, which are found at high rates in onion, are bioactive compounds that are extremely important for human health. Taking these compounds into the body has a positive effect on the immune system of humans and has a positive effect on the treatment of various diseases. In addition, the high free radical inhibitory activity (342.17-842.13 µg/ml) and total antioxidant capacity (32.01-87.25 mg ascorbic acid equivalents/g extract) of these plants increase the importance of these products even more (Atik and Dıraman, 2019). Onion is also used in the treatment of other common ailments such as cold complaints (flu, cough, flu, etc.), burns, toothache, prostate hypertrophy, intestinal and kidney infections and heart failure, and as a blood purifier to remove microbes in the body (Kumar et al., 2010; Kaur et al., 2017; Saraçoğlu, 2018; Atik and Dıraman, 2019; Marefatia et al., 2021).

Raw onion functions as a good cleaning agent for the mouth and throat (Efe et al., 2012; Kaur et al., 2017; Saraçoğlu, 2018; Atik and Dıraman, 2019). In addition, onion has been shown to have healing effects on blood clotting, cholesterol, and vascular diseases. Due to its phenolic and sulfur compounds content, onion has strong antioxidant properties (Aksoy, 2010; Ergenoğlu et al., 2015). Studies have shown that onion juice can prevent both acute and chronic pain, inflammation and has a stronger effect against inflammation (Ozougwu and Eyo, 2014; Ghorani et al. 2018; Memarzia et al., 2019; Marefatia et al., 2021).

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Chapter 11

Wet Meadow Management During Major Construction Activities: Zamantı River Crossing Experience at the Turkish Section of the BTC Crude Oil Pipeline Project

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Introduction

Purpose and scope

This paper aims to explain the wet meadow management activities implemented during the Zamantı River crossing of the BTC P/L Project construction, and to suggest improvements for better wet meadow management during major construction activities.

The proposed BTC P/L Project involves a pipeline that transports crude oil from the oil fields of the Caspian Sea region through Azerbaijan, Georgia, and Turkey to a crude oil storage and export terminal constructed at Ceyhan on the Mediterranean coast of Türkiye. The Turkish section of the BTC P/L Project spans 1,076 km, extending from the Georgian border to the Mediterranean coast, including a marine terminal at Ceyhan. The pipeline construction was completed in September 2007, and the ecological monitoring during the operational phase was completed.

The Zamantı River, one of the most significant watercourses along the BTC Pipeline route, is characterized by an expansive floodplain comprising orchid-rich wet meadows that serve as critical habitats for avian species, including those categorized as threatened. The river itself also supports vital fish habitats, while the wet meadows exhibit distinctive wetland attributes. Consequently, a specialized river-crossing methodology was necessitated during the BTC Pipeline Project to address the ecological sensitivities of both the river and its extensive floodplain. This study details the wet meadow reinstatement method implemented, alongside an overview of the construction phase and subsequent monitoring activities informed by field observations. Based on these experiences, the study provides insights and formulates recommendations in enhancing wet meadow management for large-scale construction projects.

Wetlands are among the most threatened ecosystems in the world because they have traditionally been regarded as wastelands and invariably offered opportunities for alternative use, especially agriculture. Increasingly, however wetlands have come to be regarded as valuable resources, providing many goods and services critical to environmentally sustainable development; they are also of crucial importance to conserving the world's biodiversity (The World Bank 2002; Sousa 2004;Tooth & McCarthy 2007; Mitsch et al., 2015).

The benefits of wetlands are particularly evident in drylands, as they typically represent the only reliable sources of water in otherwise largely dry settings. (Silvius et al., 2000, Tooth & McCarthy 2007). Zamantı River wet meadow, being an ecologically sensitive area of the BTC P/L Project, localized in an arid region of Turkey. So that, a particular attention was paid to that area during project construction.

Roles and responsibilities in BTC P/L Project

BTC Pipeline Company: The BTC P/L Project was developed by a group of petroleum companies (BTC Pipeline Company [BTC Co]) formed in July 2002 (BTC P/L Project EIA 2002). BTC Co maintained the monitoring, auditing and reviewing role to ensure that the Project was undertaken in compliance with the project agreements and applicable health, safety, quality, social and environmental standards (ÇINAR 2003). BOTAŞ: BTC Co has contracted with BOTAŞ, the state-owned Turkish Petroleum Pipeline Corporation, as the turnkey contractor responsible for performing all works and services required for design, engineering, procurement, construction, inspection, start-up, demonstration and testing of the facilities, in compliance with the project agreements and applicable health, safety, social and environmental standards (BTC P/L Project EIA 2002).

Engineering, Procurement and Construction (EPC) Contractors: BOTAŞ management is responsible for ensuring that all BOTAŞ commitments in the EIA and Environmental Management and Monitoring Plans (EMMPs) were translated into EPC Contractors requirements and these requirements were implemented to the full intent and extent of the BOTAŞ original commitment. BOTAŞ EPC Contractors were responsible for implementation of, and adherence to, all the mitigation measures outlined in the EIA and EMMPs (ÇINAR 2003).

ÇINAR- Third Party: In addition to the management structure established for day-to-day oversight of the EPC Contractor's environmental performance, independent construction and environmental monitoring activities were conducted by a third party consulting company, ÇINAR, by which the experiences discussed in this paper were gained. ÇINAR was directly responsible for reporting any compliance and non-compliance situations to BOTAŞ (ÇINAR 2003).

The responsibilities of the Third Party monitors in their assessment of ecological parameters, that were described in an official document of the BTC P/L Project, are as follows (ÇINAR 2003): (i) Check the methodologies for pre-construction vegetation mapping surveys, verify survey techniques being carried out, check reports, site specific plans and method statements and monitor activities against the requirements of the EIA, (ii) Monitor reinstatement of Ecologically Sensitive Areas (ESAs) on a daily basis and document their situations regarding compliance with the EIA, the site-specific plans and method statements, (iii) Ensure that all environmental non-compliance situations at site are documented and reported, (iv) Provide advice to BOTAŞ' Lead Environmental Monitor and his/her staff regarding environmental matters, (v) Assist BOTAŞ's and EPC Contractor's construction staff in resolving non-compliance situations in the field, (vi) Monitor the performance of the contractors at site with respect to their arrangements and performance related to the Environment, and (vii) To participate in interface meetings at construction site as required. Within that scope the wet meadow management of Zamantı River crossing were developed and implemented.

The ecological monitoring is a part of the Reinstatement Plan (RP) of EMMP within the content of BTC P/L Project EIA. This plan specifies the minimum technical requirements for reinstatement and restoration of areas affected by construction activities. The primary aim of the RP is that all such areas shall be returned to their pre-construction state (BTC P/L Project EIA 2002). The reinstatement methodology for the Zamantı River and wet meadow crossing was suggested and monitored by Third Party experts specializing in the ecology of the Project. The author contributed as the ecological monitor for this specific project section, ensuring adherence to ecological standards and monitoring protocols.

Material and method

Characteristics of Zamantı River wet meadow

Wetlands adjacent to rivers take on the characteristics of the riparian and riverine conditions (Lyon 2001). Wet meadow occurs in floodplain areas along rivers and streams (Delaney et al 2000) and in poorly drained areas. Wet meadows depend on precipitation or ground water for a water source, so that they are often dry in the summer (EPA 2001; LCOSI 2003).

Zamantı River floodplain as a wet meadow which occurs between KP (Kilometre Point) 796.36 and 797.02 was defined as a special area (Ecologically Sensitive Area - ESA 36) by EIA of BTC P/L Project. This ESA 36 stretch is located on Uzun Plateau at Kayseri Province (PLL 2004a). The alignment traverses through a broad, flat, orchid-rich, marshy grass floodplain (Fig.1). No trees and shrub cover present at the meadow crossing.

The river channel is irregular and meandering with a rectangular cross-section at the meander inflection part. Crossing width is 25 m and the bank-full width is between 15 and 21 m, although the floodplain (wet meadow) is about 750 m wide. The Zamantı riverbed consists of silt and river flow is perennial of a uniform and tranquil. The soil type of the wet meadow is sandy silty clay (Table 1). Bank side vegetation comprises reeds and sedges, land cover is native grasses being used for grazing (PLL 2004b). Zamantı River forms upstream part of the Seyhan River which is one of the greatest rivers in Turkey.

Fig. 1 Zamantı River landscape

Table 1 Soil characteristics of Zamantı River wet meadow (PLL 2004c)

Depth (m)	Soil Description	Sieve Analysis		Soil Class
		> 2mm (%)	< 0.075mm (%)	
0.00 - 0.30	Top Soil			
0.30 - 0.90	Green to greenish grey, sandy silty CLAY. Moist, high plasticity.	5	82	CL
0.90 - 1.35	Light brown GRAVEL with clay, silt, sand and cobble. Dry, with a max. dimension of 75 cm.	41	12	GW
1.35 - 3.80	Light brown, sandy clayey SILT. Dry to moist, containing 3-35 % fine grained sand.	18	75	ML
3.80 - 5.00	Greenish gray GRAVEL with sand and clay. Wet, fine to coarse grained.	46	9	GW

Zamantı River supports breeding of migratory fish species of high commercial value, which are Brown Trout (*Salmo trutta magrosligma*), breeding between December to February, and European Eel (*Anguilla anguilla*), breeding from April to August and migrating between September and March. Zamantı River wet meadow is important for birds including three nationally-threatened species, which are Common Crane (*Grus grus*), Whinchat (*Saxicola rubetra*) and Icterine Warbler (*Hippolais icteriana*) (PLL 2004b). Table 2 shows the seasonal sensitivity and constraints for working in Zamantı River, which has led to consider March and/or August as the suitable time for construction.

Table 2 Seasonal constraints regarding flora and wild life (BTC P/L Project EIA 2002)

ECOLOGICAL CONCERN	MONTH J	F	M	A	M	J	J	A	S	O	N	D
Important Flora	■	■	■	■	■	■	■	■	■	■	■	■
Breeding birds				▓	▓	▓	▓					
Breeding fish	▓	▓	░	░	░							▓
Migrating fish	░	░	░						▓	▓	▓	▓

■ Construction completion in three weeks
▓ Absolute seasonal constraints
░ Seasonal constraints but amenable to mitigation

The plants shown in Table 3 were defined by EPC Contractor with the field survey of the area in 2003. *Dactylorhiza osmanica var. osmanica* is under conservation concern by CITES (Convention on International Trade in Endangered Species of Wild Fauna and Flora).

Table 3 Dominant Plants and Abundance Scale in ESA 36 (PLL 2004b)

Taxon	Endemism	Abundance (Braun - Blanquet)	English name	Risk Category (IUCN)
Ranunculus constantinopolitanus (DC.) Urv.	-	+	Crowfoot	LR(lc)
Alopecurus arundinacea Poiret	-	+	Foxtail grass	LR(lc)
Poa trivialis L.	-	+	Bluegrass	LR(lc)
Plantago major L.	-	+	Plantain	LR(lc)
Pedicularis comosa L.	-	+	-	LR(lc)
Cirsium alatum (Gmelin) Bobrov	-	+	Thistle	LR(lc)
Triglochin palustris L.	-	+	Marsh arrowgrass	LR(lc)

Taxon	Endemism	Abundance (Braun - Blanquet)	English name	Risk Category (IUCN)
Eleocharis palustris (L.) Roemer & Schultes	-	+	Spikerush	LR(lc)
Carex divisa Hudson	-	+	Sedge	LR(lc)
Dactlorhiza osmanica (Kl.) Soo var. *osmanica*	-	+	-	LR(lc)

IUCN : The International Union for Conservation of Nature

+ : Taxon sparse coverage < 1 %

LR(lc) : least concern

Construction techniques at Zamantı River wet meadow

Effectively, the construction of the pipeline through wetland areas are specifically designed to minimize impact within these hydrologically and ecologically sensitive areas. The objective of the development and implementation of these techniques is to ensure that the actual construction process incorporates the required measures to ensure that the integrity of the wetland habitats along the route is maintained. It should also be noted that additional ecological mitigation techniques should be utilized, where practical, during construction (SEIC 2005, Price & Martz, 2008)

The soil bearing capacity calculations were considered in defining the construction technique for the section of Zamantı river crossing of BTC P/L Project by EPC Contractor (Table 4). As it is seen from the table, soil bearing capacity is about 1.3 kg/cm^2, and this capacity is not enough for the operation of heavy machines like side booms. Expected bearing capacity failure type such a soil is punching shear failure (PLL 2004c). Each machine use causes soil deformation followed by changes in soil aggregation and physical as well as chemical and biological soil properties if the internal soil strength is exceeded (Vossbrink & Horn 2004). Therefore the surface improvements were required for the safe and proper operations of the equipment in one hand, and the specific measures were necessitated to protect the higher landscape value of the wet meadow in the other hand. The topsoil stripping which was implemented as a generic reinstatement procedure of BTC P/L Project construction was not suggested at Zamantı River crossing from the view point of the following ecological reasons considering wet meadow characteristics as well as seasonal constraints shown in Table 2:

- Tremendous sub soil destruction would be occurred during construction
- Biological reinstatement of wet meadow via both topsoil re-placing and also seeding would be impossible within expected period of time due to improper soil conditions

Table 4 Bearing Capacity Calculations (PLL 2004c)

Depth	Description	q all (Kpa)	Kg/cm2
0.00-0.30	Top Soil		
0.30-0.90	Sandy Silty Clay	123,36	1,25
0.90-1.35	Gravel Clay Silt Sand and Cobble	160	1,6
1.35-3.80	Sandy Clayey Silt	130	1,3
3.80-5.00	Gravel with Sand and Clay	194	2,0

Therefore a specific technique was required both for construction and also ecological reinstatement. As it can be seen from Table 4, the soil bearing capacity calculations of EPC Contractor of BTC P/L Project haven't been cover the topsoil with meadow as it was expected to strip it. However, plant roots in topsoil if it is not stripped, is able to create a strong surface layer which permits the circulation of the heavy machines without causing a punching shear stress. For this reason turf (with topsoil) removal at whole working strip was not suggested by Project's Third Party monitors on ecology, although it was being conducted as a generic procedure of topsoil management. Turf stripping, stockpiling and re-laying were suggested for ecological concerns only at trench line where the pipe is settled down. Additional protection and management activities (Sec. 4.1) to protect un-stripped turf cover from construction circulation and activities was conducted. Through the implementation, the meadow was protected with minimum disturbance and the stripped meadow along the pipeline trench was reinstated successfully.

With regard to the construction method, EPC Contractor implemented the push&pull technique to settle down the pipe. This technique involves the construction of a platform at each end of the wetland section to be crossed on which all of the equipment required to place the pipe in the trench would be positioned. Floats is fixed on the pipe, which is, then, pushed on rollers into the trench full of water. When the entire pipeline length is pushed into the trench of the section the straps on the floats is cut in order to sink the pipe in bottom of the trench (SEIC 2005). Fig. 2 shows the construction procedures at Zamantı River crossing.

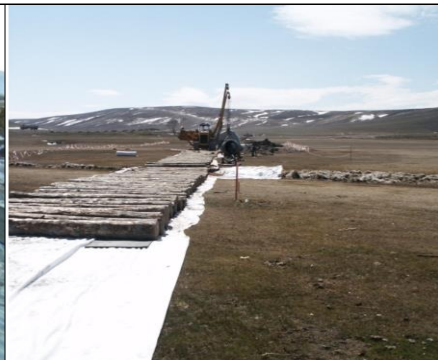
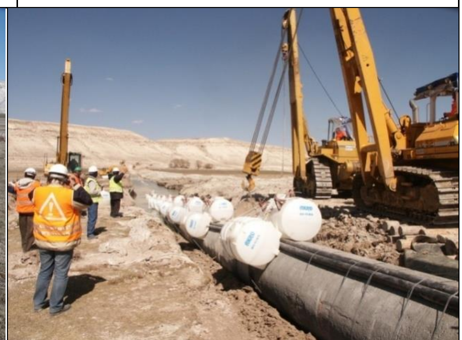
	
Turf protection: Wooden platform installation (March 2004)	Turf protection: Wooden platform installation (from BOTAŞ archive, March 2004)
	
Turf protection: Wooden platform installation (form BOTAŞ archive, March 2004)	Settling down the pipe, floats is fixed on the pipe (from BOTAŞ archive, March 2004)
	
Pipeline trench and excavated subsoil (from BOTAŞ archive, March 2004)	Zamantı River, subsoil stockpiling and pipe downloading (from BTC Co. archive, March 2004)

Fig. 2 Construction technique at Zamantı River crossing

Wet meadow landscape management and monitoring

The management and monitoring techniques described below was designed and implemented to minimize negative effects of pipeline construction over Zamantı River wet meadow (ESA 36) by means of changing the ecological processes and the geobotanical structure of vegetation and associated fauna.

Fig. 3 illustrates main components of reinstatement plan accordingly executed ecological monitoring activities regarding different implementation phases of the project.

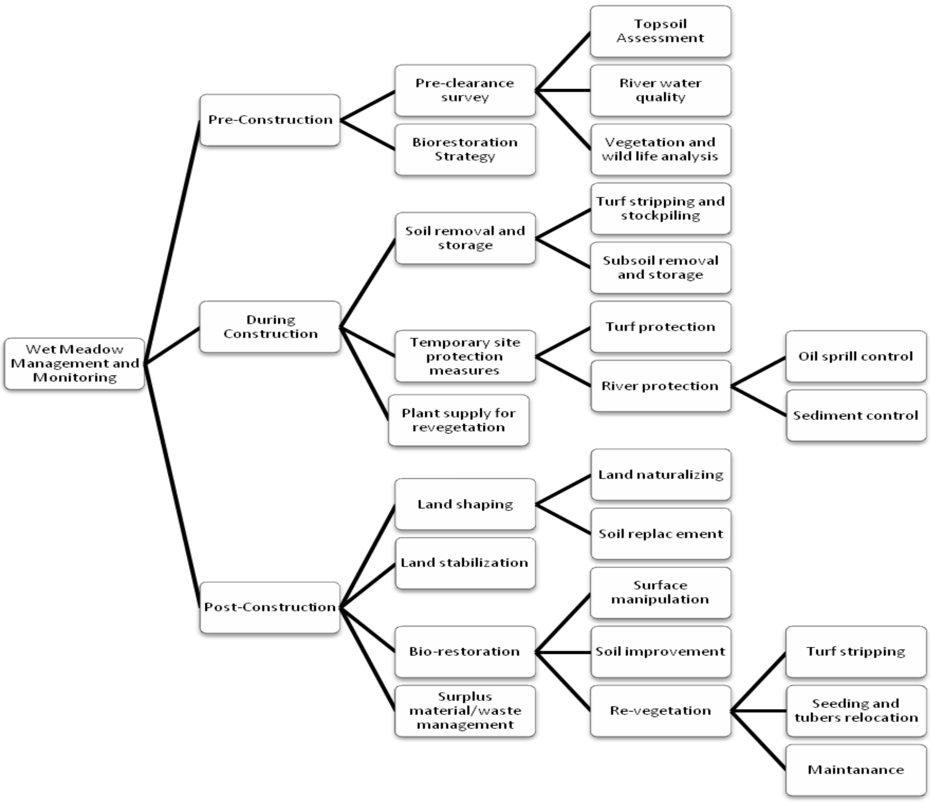


Fig. 3 The components of reinstatement plan

The reinstatement of ESA 36 consists of Reinstatement of the wet meadow together with Reinstatement of Zamantı River. In that scope the ecological monitoring for ESA 36 was covered the following issues.

Document Reviewing: Reinstatement Method Statement for Zamantı River Crossing

The special area method statements for all special areas reviewing that includes for ESA 36 as well was reviewed by landscape architects together with a soil scientist considering a checklist that was recommended by Third Party and approved by BOTAŞ (Table 5). All items with respect to reference in document were evaluated with comments about its deficiencies, non-compliance status and suggestions for revision.

Table 5 Special Areas Method statements reviewing checklist

CHECK LIST FOR REVIEWING

General

A. Introduction

1. SARMS definition and locations
2. References from EIA and other related documents prepared by contractor and approved by BOTAŞ
3. Definitions and abbreviations

B. Purpose

4. Target plants and animals' identification, their threatened status, and their location in area
5. Population abundance of these target species
6. Mitigation measures to restore the habitat and the population of these plants following construction
7. Habitats in the vicinity of RoW, which could be impacted by the project, and possible mitigation measures
8. Erosion control practices
9. Land reencountering for the reconstruction of landscape and original drainage basin topography, and visual impact mitigation

C. Scope

Scope means whether these titles between 11-15 were covered in any section of the Document WITHOUT giving attention to the quality and quantity of the information.

10. Protection of target species and bio-restoration of the area after construction
11. Erosion control (temporary and permanent) in the ESA
12. Soil management (soil removal, stockpiling and re-laying)
13. Landscape restoration (surface manipulation, re-contouring, revegetation)
14. Schedule for Mitigation and Reinstatement Activities
15. Follow-up monitoring program

D. Baseline Conditions and Constraints

16. Landscape description technique and results (the altitude (ASL), land use &vegetation cover and quality, existing problems, etc.)
17. Target plant species (characteristics, definition technique and results)
18. Target animal species (characteristics, definition technique and results)
19. Soil sampling (technique characteristics, erosion class, and assessment*
20. Constraints for reinstatement (seasonal constraints for fauna, climate for topsoil striping, constructional etc.)
21. 21 days limitation between RoW clearance and topsoil relaying.

E. Mitigation Measures and Reinstatement Activities

22. Topsoil and overburden stripping and stockpiling*

CHECK LIST FOR REVIEWING
23. Soil erosion control (temporary and permanent)*
24. Reinstatement of Landscape (Landscaping, re-contouring)
25. Redistribution of topsoil (where available) and surface manipulation*
26. Bio-restoration of the target species - Fauna protection - Revegetation (seeding, translocation, maintenance of translocated plants, seed storage, planting, etc
27. Aftercare (fertilizing, watering etc)
28. Schedule for mitigation and reinstatement activities
29. Follow-up monitoring

Revegetation Strategy:

The climate of the area is characterized by dry summers, cold winters and low rainfall. Table 6 indicates the temperature and precipitation records for March and August (when the seasonal constraints present) at the nearest meteorological station in Pınarbaşı settlement.

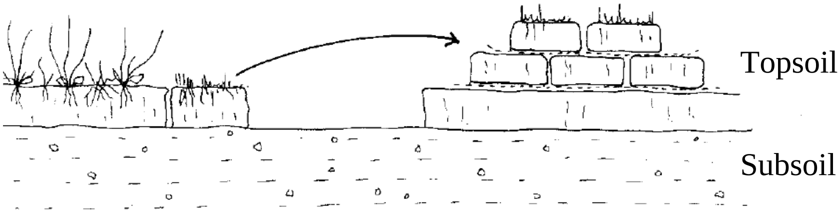
Table 6 The temperature and precipitation records for the periods of ecological window (PLL 2004b)

Months	**Temperature (°C)**			**Precipitation (mm) ***
	Average monthly	*Average high*	*Average lowest*	
March	1.6	7.4	-3.5	77.5 (mainly as snowfall)
August	18.8	27.5	9.1	6.7

*: Total annual precipitation is 630.3 mm, mainly as snowfall

The soil's sandy silty clay composition presents a challenge for successful revegetation through seeding, in addition to the unfavorable climatic conditions mentioned previously. Consequently, while the existing vegetation cover is relatively stable, seeding is not a viable option for revegetation under the prevailing post-construction conditions. Instead, the most effective management technique for this type of area involves the stripping and re-laying of turfs, where the topsoil containing the grass cover is removed in layers and placed in a designated storage area. The turfs can be stripped and stored on permeable geotextile sheets for up to three months. During storage, the turfs should be oriented with the vegetation facing inwards and shaded or watered periodically to prevent desiccation. Importantly, the turfs must be replaced at the same level, as any protruding edges will dry out and die. Additionally, the gaps between the re-laid turfs should be filled with subsoil and seeded with an appropriate grass mixture (Fig. 4) (The Highways Agency 2009).

1. Trim vegetation to 5-10 cm
2. Slice surface with disc harrow at about 0,3 m centres
3. Stack on porous geotextile sheet. Keep moist. Cut turves 20 cm deep, up to 5 m long, with excavator, or smaller lenghts by hand



4. Re-lay level, without protruding edges. Fill the gaps with topsoil. Water well.

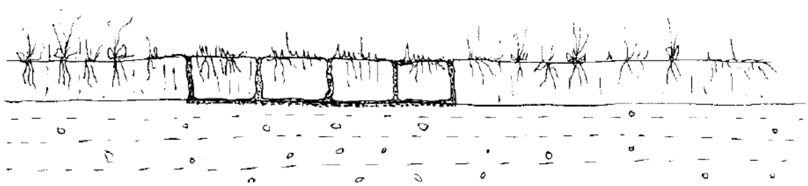


Fig. 4 A sequence for stripping and re-laying of turf (The Highways Agency 2009)

Densmore et al. (2000) describes methods to revegetate subarctic sites with native plants, and recommends striping, transporting, storing, and transplanting turf (vegetation mats) as follow: the turf is precut with a pulaski tool to the desired size which can be the size of a tractor loader bucket, or, if a tractor is not available the turf is cut into smaller pieces that one or two workers can handle. It should be attempted to cut the turf in such a way that the roots on the most valued plants remain intact.

With regard to Zamantı wet meadow crossing of BTC P/J Project, the following procedures were implemented for turf stripping and management:

- ✓ Turf was stripped using excavator. Since ESA 36 consists of orchids, the topsoil up to a depth of 30 cm was suggested to strip considering the tuber depth.
- ✓ Subsoil taken from the trench was stockpiled aside after underlying geotextile with suitable thickness quality over the grass cover.
- ✓ The heavy machines that excavate trench, lay down the pipe, and backfill the subsoil were provided to move over the settled wooden platform on the grass up to open trench.
- ✓ River was protected from sedimentation using silt fences.

- ✓ River banks were stabilized by installing gabions.
- ✓ Turf was re-laid and the gaps between turfs were filled with subsoil by man-power.
- ✓ Additional seeding with native plants were implemented where the disturbances to turf were high
- ✓ Grass cover maintained by cleaning from surplus clay after backfilling of subsoil and removal of geotextile and improved by soil aeration works and additional seeding.

Periodic monitoring at field and reporting

The monitoring activities cover daily base field inspections and daily reporting with regard to the compliance with the environmental conditions and requirements of the EIA. According to seasonal sensitivity constraint (Table 2), the construction at river crossing was started in March and completed in one month. Fig. 5 shows some pictures from monitoring activities during Zamantı River wet meadow crossing.

Variance Request Program

Such variance request program also was required for the impacts occurred at site specific circumstances which were not predicted during the preparation EIA report and Reinstatement Method Statement for Zamantı River Crossing, but affected construction in a daily basis and required applying an alternative management method integrated with alternative mitigation measures. Third party monitoring minimized the time required for review and approval of variance requests while providing high level of environmental quality (Şahin & Kurum 2008).

Turf protection: Wooden platform installation (March 2004)

Turf protection using geotextile during subsoil stockpiling (March 2004)

Turf protection during subsoil stoc-king (March 2004)

Soil improvement by organic manure spreading (March 2004)

Turf re-laying (March 2004

Turf re-laying (March 2004)

Fig. 5. Some samples from monitoring activities at field

Turf re-laying (March 2004)

Turf re-laying (March 2004)

Zamantı River meadow during construction (March 2004)

Zamantı River meadow after reinstatement (July 2004)

Zamantı River meadow after reinstatement (July 2007)

Zamantı River meadow after reinstatement (July 2007)

Fig. 5 Some samples from monitoring activities at field

Training

Environmental/ecological problems could arise simply from ignorance and lack of training during major project construction activities. This issue carries much more importance during major constructions that effects ecologically sensitive areas like wet meadows. Therefore, trainings about ecological reinstatement were given as EIA requirement as well as following EMMP, particularly by the monitors. The target groups were range from lay person to the construction staff that is not sufficiently aware of environmental responsibilities of the project (Şahin & Kurum 2008). There are several reasons for training employees about the wetlands sensitivity, ecological reinstatement process and monitoring plan for them: (1) Every employee should feel that he/she has a certain degree of 'ownership' of the process and that he/she is an effective and forceful part of the whole environmental/ecological management plan; (2) Any employee can have good ideas about how to improve environmental/ecological management efforts; (3) Every employee should be informed about the applicable rules and responsibilities; (4) Capacity-development training on operational issues will result in overall better management of ecological resources; (5) Communications training between different parties (construction, environment, management, public, etc.) will foster both improved awareness of ecological concerns and a higher level of information exchange.

Results :*from lessons learned to possible improvements for better wet meadow management*

During monitoring of the wet meadow reinstatement implementations some weaknesses or insufficiencies where possible improvements could be applied that would enhance the overall success of wet meadow management. The suggestions for improved monitoring, that should be considered within above mentioned approaches and techniques of wet meadow landscape management and monitoring were given below.

Definition of wetland types within the landscape typologies along the RoW in association with construction purposes

Although mostly the vegetation associations and communities are analyzed for the purposes of describing and classifying wetland types, as it was in BTC P/L, it is not enough for wetland management purposes when a construction to be conducted over the wetland. In a pipeline project of Sakhalin II (Phase 2) Oil Project Piltun-Astokhskoye and Lunskoye fields in Russia, wetlands firstly were defined in the base of vegetation analysis and geobotanical units, then for the construction purposes, the wetlands were divided into distinguished groups based upon the load bearing capacity of the soil (SEIC 2005). On the other hand, this classification is based on only load bearing capacity and does not include any landscape criteria. Therefore, before classifying or defining the wetlands along the pipeline corridor, landscape typology definition might be conducted to understand the typology of wetlands in wider scale.

Tooth & McCarthy (2007) suggests following questions to diverse one wetland from the other for dry lands where the wet meadows exist: (1) what are the general characteristics of wetlands in drylands? (2) are wetlands in drylands different from wetlands in other climatic settings? (3) are there any features distinctive or even unique to wetlands in drylands? Similar questions can be produced for landscape characterization of wet meadows. GIS and remotely sensed data can greatly facilitate landscape characterization studies of wetlands (Lyon 2001). On the other hand, as wetlands are so diverse, it could be argued that generalizations regarding their characteristics are misleading or meaningless, as numerous exceptions will always be found. So that, each wetland likely to be affected by the construction, can be classified considering (1) relationship among ecological components (e.g. soil texture, climate and vegetation cover for wet meadows in particular) and processes, and the ecosystem services (ecological, economical, recreational, etc.) they deliver, as an evaluation process of wetlands (2) ecological constraints for construction (e.g. ecological windows when the construction is possible, etc.), and (3) engineering (soil) properties such as load bearing capacity of wet meadow surface as well as soil layers. The landscaping strategies associated with construction technique, then, should be prepared according to the mentioned wetland classification.

Documentation of landscaping strategies

The documents related to the landscaping strategies should include each pre-, during- and post-activity phase (Table 7). Those procedures should be described within the strategy documents for each project phase, and the documents should be used as a guide for development of the monitoring program (Şahin & Kurum 2008).

Table 7 Landscaping procedures

Phase	Landscaping Procedures	Content
Before Activity	Landscaping strategies in EIA	Landscaping strategies should be included in the environmental management plan of any EIA with the objective of land-shaping that will be in harmony visually with surrounding landscape, re-stabilizing the soil, and re-establishing a vegetative cover that is compatible with the surrounding environment.
	Procedures during field clearance	On field records before disturbances regarding: - soil characteristics - vegetation survey - natural drainage system - visual survey, etc. Documenting requirements related to revegetation - availability of plants from existing stocks - seed collection requirement and scheduling - seed bank needs - propagation requirement and infrastructure - equipment and man-power requirement
During Activity	Soil/turf management	- topsoil/turf stripping, stockpiling - subsoil stripping, stockpiling
	Temporary erosion control measures	- standard drawings for erosion control structures - implementation
	Plant supply for revegetation	- landscaping specifications for planting material, planting technique, etc. - stock availability - seed collection
After Activity	Land-shaping/recontouring	- land naturalizing - soil replacement
	Land stabilization	- permanent erosion control
	Revegetation	Protect landscape integrity and biodiversity, and also to support erosion control implementations - surface manipulation - soil improvement - re-vegetation
	Surplus material management	waste management

Preparatory works to be needed for ecological reinstatement

The activities related to ecological reinstatement of each project phase, (1) pre-construction, (2) during construction, (3) post-construction and (4) operation, will necessitate certain management and monitoring activities that may be specific to that project phase or may overlap with other phases. Success at each step can be ensured only through adequate preparatory work during earlier stages of project implementation. Preparatory activities can be divided into: (1) cost considerations and (2) material, equipment and personnel considerations. It is suggested that there be an increased effort towards understanding and monitoring of any necessary preliminary actions that may be needed to ensure successful landscape restoration activities later in the project (Şahin and Kurum 2008).

Although the experience of Zamantı River wet meadow reinstatement showed that turf stripping and re-lay minimize plant material requirements at wet meadows depending the wetland characteristics, this issue is still of utmost concern. For the wet meadow types of Zamantı River, seed supply is likely to be required considering possible unexpected loss of meadow due to the construction disturbances. The sufficient seed material should be supplied before the construction start as a risk management and/or contingency plan. Regarding with the any plant material supply a decision making chart is suggested by this paper which reduces the possible risks (Fig. 6).

Manual seed collection can be useful, when native seed is required, and which is not commercially available, and when time and cost are not significantly limiting. The viability of collected seed is highly variable and therefore, seed production using this method can be erratic. Timing of seed collection is also an issue, since collection can only be undertaken for a short period of time (i.e., when seed is mature and suitable for harvest). For some species, seed maturity may vary considerably on the same plant. These factors typically result in costs and time frames which are very restrictive (AMEC Earth & Environmental Limited 2001). In this end seed supply difficulties and limitations for wet meadow restoration, in addition to the ecological constraints such as infertile soil, unfavourable climate, and biodiversity concerns, turf stripping planed together with proper pipeline/or other major construction techniques is a good practice.

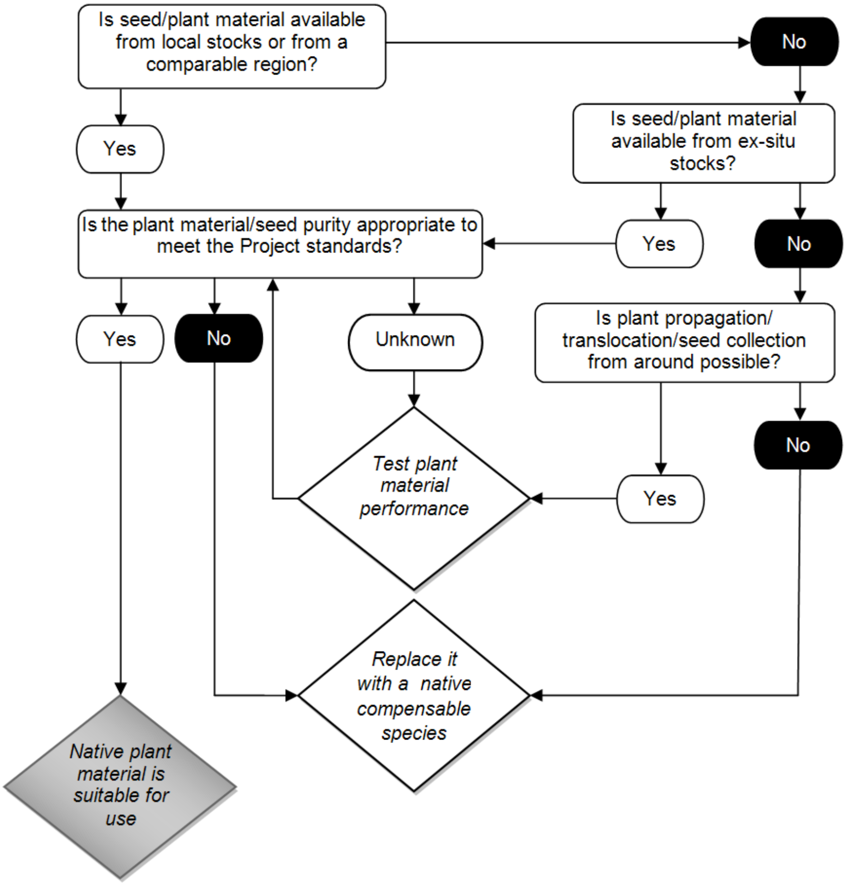


Fig. 6 Decision-Making Chart: Sourcing Native Plant Material (Adapted from Cole et al 2002)

Public participation

Taylor & O'Riordan (2002) indicates that it is neither sensible nor practicable to regard monitoring as purely a scientific process. It is of the utmost consequence for local people, who continually demonstrate that they are immensely effective in guiding the implementation of wetland management schemes. On the other hand, although public participation has become popular, widespread and effective in environmental management activities, it still tends to be used when the information sought is of a social nature. While public participation may contribute to increased knowledge of the state of the environment, it also promotes citizens' involvement in environmental protection (Pharcharuen, 2021). The main step to overcome the public participation, which was intended in BTC P/L project, is to provide running required mechanism to motivate close collaboration between

Department/Team of Community Relations with Department/Team of Environment which is responsible for management and monitoring of natural landscapes.

Discussion

A number of pipeline installed for the economic transport of natural gas, oil and chemicals has increased substantially in last decades. Because of their particular linear form, the construction work associated with a large-scale corridor can have significant effects upon both terrestrial and aquatic ecology, exerting influence on the landscape at a variety of different scales (Um & Wright 1996; Porter et al., 2016). With regard to waterbody and wetland crossings often require the completion of relatively advanced studies and assessments, which may ultimately indicate the need for extensive mitigative measures. From an ecological standpoint, these aquatic and/or bottom land areas are often the most productive and sensitive segments of a given pipeline route (Trow Consulting Engineers Ltd 1996) and are the most susceptible to impact from pipeline construction (Um and Wright 1996).

More attention is now being paid to wetland restoration and management as the consciousness on their value is more understood. Although, considerable literature exists about wetland restoration, wet meadows are less studied. On the other hand each wetland as landscape has its own structure and function changing temporally and spatially. Tooth & McCarthy (2007) states that at a general level, it is clear that there are some characteristics common to many wetlands. But at site specific conditions each wetland is unique being characterized by a range of geomorphological and sedimentological features, and by various biophysical interactions that are the product of catchment specific conditions such as local climatology, flow regime, sediment supply, lithology and structure, tectonic setting, geomorphic history, and vegetation type. In that end any wetland restoration methods should be site specific (Baird & Klumpp, 2012; Wilcox & Whillans, 1999).

In practice and literature, the recommendations about wet meadow restoration, wetlands in general, is concentrated on seeding or plant translocations (Gandy & Tucker 2000). The success of seeding, however, in ecologically sensitive areas like Zamantı River wet meadow, strongly depends upon natural conditions since the usage of chemical fertilizers, herbicides and pesticides to improve soil and/or soil transportation is not desired. This condition reduces success performance of the restoration in the wet meadows where the limiting factors are considerable. In addition to that, the technical specification related to major constructions such as pipeline engineering makes the restoration more difficult. Considering all those, turf stripping provides numerous advantageous in landscape restoration. Topsoil as a seed bank is stripped, stockpiled and re-layed/re-used in major construction projects as an environmental management requirement in major project, and it is increasingly implemented in practice. The turf/grass cover stripping, stockpiling and re-laying together with topsoil layer, however, is particularly implemented in urban parks and other green areas as well as sport layouts. It is not common in use for ecological restoration during major constructions. The paper presents a success implementation in that sense.

Novel pipeline construction methods using trenchless technology that have been developed over recent years might be seen as an alternative to conventional open-cut techniques for underground pipeline installation at ecologically sensitive areas in particular. On the other hand, Chapman et al (2007) states that although there has been considerable research into the area of trenchless pipeline construction, there is still a strong message from industry that further work is required.

Wet meadow management was succeeded in BTC P/L Project Zamantı River crossing by the implementation of turf stripping, stockpiling and re-laying techniques with additional protection efforts with wooden platform installation for machine circulation, geotextile spreading over grassland before subsoil stocking over it as well as time restrictions for construction and restoration process. By this way, the most significant impacts on hydrological regime and ecology of wetlands via pipeline construction could be minimized and kept under control.

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Chapter 12

Suitable Plant Selection for Field Cultivation in Saline Conditions

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1. INTRODUCTION

There has been an increase in agricultural areas to meet the rapidly increasing food demand since the mid-twentieth century, but this increase has stopped since the beginning of the 21st century (Figure 1). Since there is no longer any suitable land for agriculture without harming nature and the environment, humanity can no longer find new agricultural land. For this reason, areas that are not suitable for agriculture are also used for agricultural purposes and obtaining the highest possible yield from the unit area is followed as the most important production policy.

Salinity resulting from the accumulation in the soil (secondary salinity) due to the high amount of dissolved salt in the water applied for irrigation purposes or salinity resulting from the natural structure of the soil (primary salinity) is an abiotic stress factor for plants. Salt stress is a factor that causes significant yield losses in the cultivation of plants other than halophytes, which are highly tolerant to salinity. Despite this, agricultural crop cultivation continues in many primary or secondary saline areas for the purpose of food production.

Today, in many countries, due to necessity agriculture is carried out also in salty areas. However, in these salty areas, the yield for most plants is considerably lower than normal yields. For this reason, in order to be able to farm in salty conditions, certain precautions are taken depending on the salinity level and characteristics of the agricultural area and cultivation is carried out by accepting a slight decrease in productivity. In some agricultural areas, farmers continue cultivation with low production without knowing that their land is salty. Thousands of studies have been conducted around the world for decades examining the relationships between salinity and plant yield. Based on these studies, data on the tolerance of most plants to saline conditions have been obtained. Since the response of plants to salinity has been determined, it is possible to calculate in advance how much yield can be obtained for any plant at a certain salinity level. In this way, it is possible to make economic calculations for the plant planned to be grown at a certain salinity level.

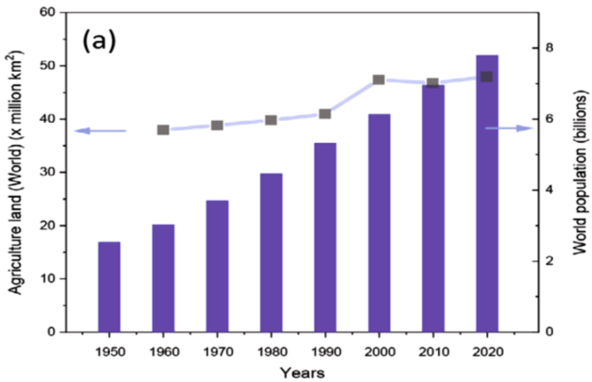

Figure 1. Change in agricultural area and population in the world (Lifei et al. 2021)

Salt tolerance of plants can vary significantly among species and varieties. Field crops are generally more salt tolerant than other plants. Most field crops can produce adequate yields without being affected by saline conditions. However, when salinity reaches high levels, it is not possible to obtain sufficient yield except for a few field crops.

In this study, the interactions between salinity and plant yield were explained, the yield potentials of 10 different field crops were compared for 10 different salinity levels, and the situations to be taken into consideration in deciding on the appropriate plant selection for each salinity level were examined.

2. SALTY CONDITIONS AND THEIR EFFECTS ON PLANT

The term electrical conductivity is used as a measure of the amount of dissolved solids in the water used for irrigation, that is, the salt content of the water. Electrical conductivity is expressed as the inverse of the resistance in ohms of a column of 1 cm length and 1 cm^2 cross-sectional area of the solution at a certain temperature, usually 25 °C. The more dissolved solids (salt) water contains, the better it conducts electricity and the higher its electrical conductivity value. In other words, water with high electrical conductivity means low quality water because it contains too much salt.

Since the water used for irrigation is not pure water, it definitely contains dissolved salt. Therefore, water applied to the soil for irrigation causes salt to be carried to the root zone. These salts first spread to the plant root zone. Some of the water in the root zone is taken up by the plant while some of it evaporates from the soil surface. As the water lost from the soil surface evaporates as pure water, salts accumulate on the soil surface. If this process is repeated many times for an arid region, the soil surface will be completely covered with salts. On the other hand, the uptake of salt along with water from the root area of the plants is limited due to the roots acting as a semi-permeable membrane. However, if the salinity is high, the amount of salt taken in can be toxic to the plant. Since a certain amount of salt will be added to the root zone with each irrigation, it is possible to encounter significant amounts of salt accumulation in the soil, especially towards the end of the growing season. In order for the plant not to be affected by salinity, these salts accumulated in the root zone must be leached away. For this, the most appropriate solution is to apply additional leaching water to the irrigation water. If the salts accumulated in the root zone during the growing season do not reach a level that threatens plant productivity, then the leaching out of the salts can be left to winter rains. Rainfall during the winter season can wash the root zone and remove salts. However, in regions where winter rainfall is not sufficient, it would be appropriate to take soil samples before planting and to perform an effective leaching before cultivation if the salinity level is high as a result of the analysis. Because the period when plants are most sensitive to salty conditions is generally the young period at the beginning of the growing season. Even if soil salinity is low at the beginning of the growing season, re-salinization of the root zone is possible in the middle of the season, depending on water quality.

Salts accumulating in the root zone have two important effects on the plant. The first of these is the toxic effect of salt ions. Salts entering the plant body with irrigation water cause negative physiological effects on the plant. The toxic effect is on the plant itself and this effect is not caused by lack of water or the water not being available. In general, toxicity occurs when toxic ions taken from the soil-water environment accumulate in the leaves as a result of transpiration in the plant, causing damage to the plant. The level of this damage depends on time, salt concentration in the plant organ, plant resistance and water use. Toxic effects on the plant will reduce the development of the plant and also cause a decrease in yield. Sodium, chlorine and boron are examples of ions that cause toxic effects in irrigation water (Yurtseven, 2024).

The second effect of salts on the plant is the osmotic effect. High salinity in the root zone creates an osmotic suction pressure, making it difficult for the plant to take water from the soil. In high salinity conditions, even if there is enough water in the soil, the plant cannot take the water from the soil and suffers from drought. This is why this event is called physiological drought (Öztürk, 2004). The plant's inability to extract water from the soil not only means the plant is dehydrated, but also deprived of nutrients. Because plants take in nutrients in dissolved form in the water they take in with their roots. Therefore, not being able to take in water means not being able to take in nutrients. This is the main reason for the decrease in yield seen for plants that do not receive enough water. In the absence of sufficient water, the plant will not be able to transport nutrients and photosynthesis products, resulting in shrinkage in fruits and empty grains in cereals (Collier & Cummins, 1992).

In physiological drought, the plant begins to wilt, showing signs of dehydration. Wilting at high salinity levels can occur not only as a result of water deprivation but also as a result of sap loss into the soil. The fluid movement between the salt concentration of plant sap and the salt concentration of soil solution occurs from the less concentrated environment to the more concentrated environment, that is, the less salty solution flows towards the more salty solution. If root zone salinity is not diluted with irrigation, rainfall or additional leaching water, it can lead to death of the plant that cannot take in water despite losing water.

3. SALT TOLERANCE OF PLANTS

Negative changes that occur in the plant under the influence of some factors are called stress. Stress factors are divided into two groups: biotic and abiotic stress factors. One of the most important abiotic stress factors is salt stress. Although plants are affected by saline conditions in two ways, toxic and osmotic, not every plant is affected by a certain salinity at the same level. While some plants are very sensitive to salty conditions, some tolerant varieties show very good resistance. Therefore, the degree to which plants are affected by saline conditions depends entirely on the plant's response to salinity, that is, its tolerance.

Understanding the response of field crops to salinity stress, including resistance mechanisms, may support the propagation of adapted varieties with high productivity even under adverse environmental factors. Additionally, in seed cultivation, it should be kept in mind that the plant is more sensitive to osmotic stress during the germination phase than during the vegetative development phase. Today, biotechnological approaches are used to accelerate the propagation and development of salt-adapted crops. Additionally, hormones and osmolyte application can reduce the toxicity effect of salts in cereal products. Studies are being conducted on many management strategies to cope with the detrimental negative effects of salt stress on the physiology, development and yield of cereal crops (Alkharabsheh vd. 2021).

In very general terms, although many field crops are salinity-tolerant, a few species are in the salinity-sensitive group. The tolerance of plants to saline conditions is expressed by two terms. One of them is the threshold value (A) and the other is the proportional yield slope (B) (Figure 2).

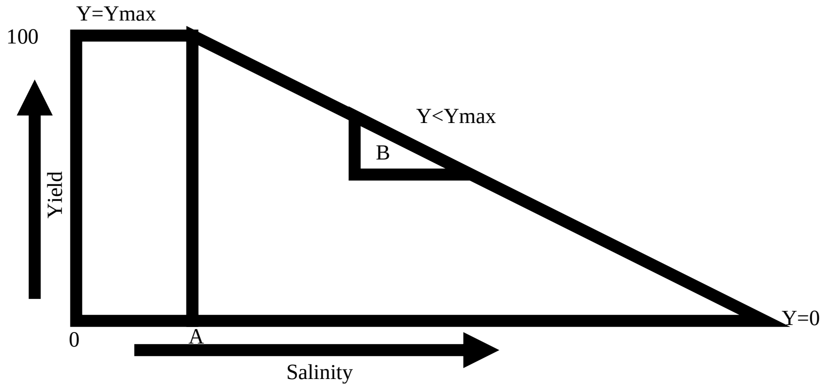

Figure 2. Theoretical relationship between soil salinity and yield

The threshold value is the salinity level at which the plant can withstand the increase in salinity without causing a decrease in yield and at which the first decrease in yield begins. The proportional yield slope is the rate of decrease in plant yield per unit increase in salinity from the threshold value. When these two terms are known for a plant, the yield to be obtained from that plant at any salinity value can be calculated. The ratio of the yield obtained under saline conditions to the yield obtained under optimum conditions is called proportional yield. The high threshold value and the low proportional yield slope are indicators that positively affect the plant's resistance to salty conditions. But these two terms are completely independent of each other. In other words, it would be wrong to say that a plant with a high threshold value is salt tolerant or that a plant with a low proportional yield slope is salt tolerant. It would be correct to evaluate both values together and comment on the result. When commenting on the salt tolerance of a plant, the salinity level must be specified and the proportional yield of the plant at that salinity level must be taken into account. Although plant a produces higher proportional yields than plant b at a given salinity level, it is possible that plant b may produce higher proportional yields than plant a at a higher salinity level. Therefore, the tolerance of plants to salinity must be evaluated with the expression of proportional yield corresponding to the salinity level.

4. PLANT SELECTION FOR FIELD CROPS IN SALINE CONDITIONS

In this section, information about plant yields and plant salinity tolerances for different salinity levels is given and field crops are compared with each other. When choosing the plant to be grown in salty conditions, the plant that will provide the highest profitability should be grown. For this purpose, the yield amounts to be obtained for each plant at a certain salinity level must be determined and the profit calculation must be made according to the yield. However, since it is not clear how much the plant to be grown will be sold for at the end of the season, in this study, comparisons were made in terms of the proportional yield to be obtained according to different salinity levels and the plants that provide the highest proportional yield for that salinity level were suggested.

In the study, interpretations were made by taking into account 10 different salinity levels: 2, 4, 6, 8, 10, 12, 16, 20, 25, 30 dS/m. Barley, wheat, rye, sugar beet, sunflower, soybean, corn, cotton, alfalfa and peanut plants were taken into consideration in the study.

The threshold and proportional yield slope values, which are the tolerance parameters required for calculating the proportional yield for the plants considered, are given in Table 1 (FAO, 2024).

Table 1. Threshold and proportional yield slope values for the plants considered

Plant	Threshold value (dS/m)	Proportional yield slope (%)
Barley	8	5
Wheat	6	7.1
Rye	11.4	10.8
Sugar Beet	7	5.9
Sunflower	4.8	5
Soybean	5	20
Corn	1.7	12
Cotton	7.7	5.2
Alfalfa	2	7.3
Peanut	3.2	29

Proportional yield curves were drawn for the plants considered and yield evaluation was made according to these curves. Figure 3 shows the proportional yield curves for alfalfa and wheat as examples.

By using the obtained proportional yield graphs, a proportional yield table was prepared for each plant and the salinity levels taken into account (Table 2).

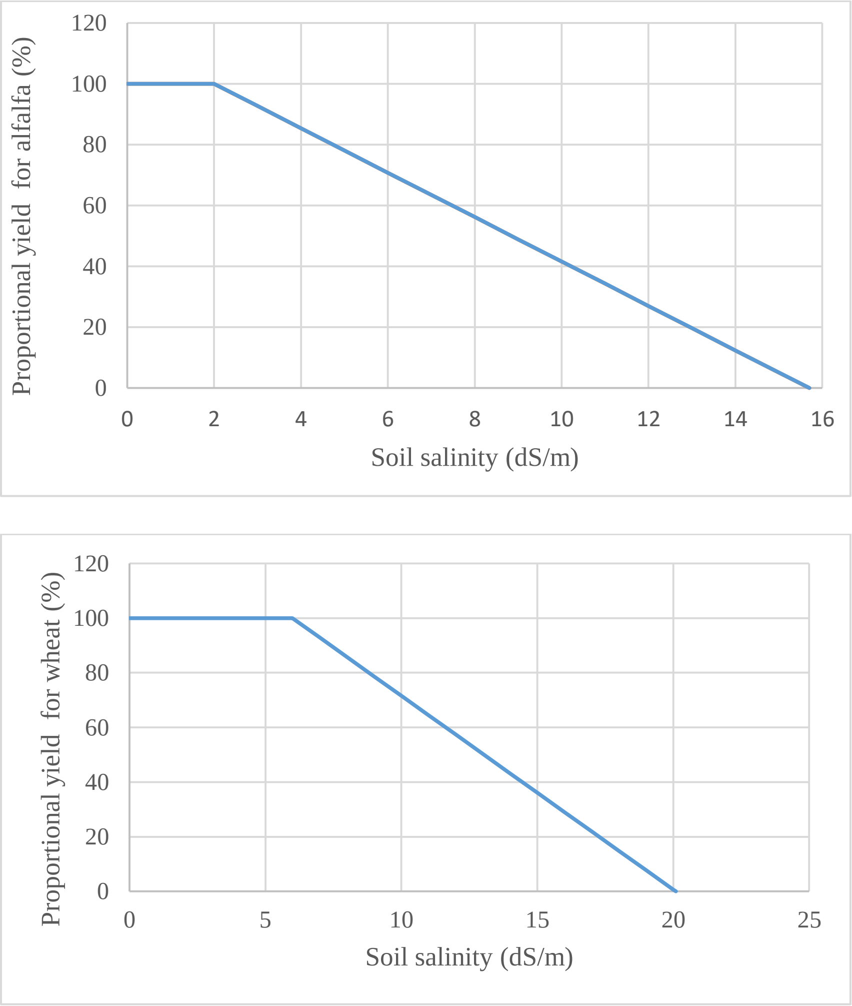

Figure 3. Proportional yield curves for alfalfa and wheat

Table 2. Proportional yield values according to salinity level (%)

Bitki	Tuzluluk düzeyleri (dS/m)									
	2	4	6	8	10	12	16	20	25	30
Arpa	100	100	100	100	90	80	60	40	15	0
Buğday	100	100	100	85.8	71.6	57.4	29	0.6	0	0
Çavdar	100	100	100	100	100	93,52	50,32	7,12	0	0
Şeker Pancarı	100	100	100	94,1	82,3	70,5	46,9	23,3	0	0
Ayçiçeği	100	100	94	84	74	64	44	24	0	0
Soya Fasulyesi	100	100	80	40	0	0	0	0	0	0
Mısır	96,4	72,4	48,4	24,4	0,4	0	0	0	0	0
Pamuk	100	100	100	98,44	88,04	77,64	56,84	36,04	10,04	0
Yonca	100	85,4	70,8	56,2	41,6	27	0	0	0	0
Yer Fıstığı	100	76,8	18,8	0	0	0	0	0	0	0

As seen in the table, plants show some resistance to rising salinity levels and give 100% yield, but they show a decrease in yield after the threshold value is exceeded. When the table is examined from the lowest salinity level of 2 dS/m, it shows that the corn plant is affected by even very low salinity in an environment that is essentially salt-free, such as 2 dS/m, causing a yield decrease of around 5%. From 10 dS/m salinity onwards, the corn plant dies and the yield becomes zero. With this data alone, it can be said that corn is a salt-sensitive plant and should not be grown in saline soils.

The salinity level of 4 dS/m is the limit value at which salinity just begins. At this value, 72.4% yield can be obtained from corn, 76.8% from peanuts and 85.4% from alfalfa. When growing in an area with 4 dS/m salinity, full yield will be obtained from other plants considered except these three plants. When salinity reaches 6 dS/m, there are changes in the ranking and yield decreases occur in also some other plants. At 6 dS/m salinity, peanuts can only produce 18.8% yield, while corn can produce 48.4%, alfalfa 70.8%, soybeans 80% and sunflowers 94% yield. Accordingly, it will not be appropriate to grow these plants at 6 dS/m salinity level, and plant selection will need to be made from other plants.

At salinity levels reaching 8 dS/m, peanut yield becomes zero. At this level, corn will produce 24.4%, soybeans 40%, alfalfa 56.2%, sunflower 84%, wheat 85.8%, sugar beet 94.1%, cotton 98.44%, while barley and rye will provide full yield. Although 8 dS/m is the starting point of high salinity, yield loss is observed in eight out of ten plants considered. Even though the cotton plant is mentioned as one of the most salt-resistant plants, it still suffers from a small amount of yield loss. Therefore, rye, barley and cotton appear to be cultivable at a salinity level of 8 dS/m.

It is pointless to grow peanuts, soybeans and corn as yields cannot be achieved when salinity reaches 10 dS/m. At 10 dS/m salinity level, alfalfa will yield 41.6%, wheat 71.6%, sunflower 74%, sugar beet 82.3%, cotton 88.04%, barley 90% and rye will yield full yield. As can be seen, only rye, barley, cotton and sugar beet have the potential to be profitable at this salinity level. At 10 dS/m salinity level, the cultivation of other plants considered will not be suitable.

Yield loss occurred for all plants considered at a salinity level of 12 dS/m. At this salinity level, plants that yield 75% and above were rye 93.52%, barley 80% and cotton 77.64%.

16 dS/m is the beginning of severe salinity. Although it is not logical to farm in areas with this level of salinity, it is possible to grow some field crops by accepting significant yield losses, that is, by accepting low production. At 16 dS/m salinity, the highest yield can be achieved as 60% when barley is grown. It is possible to get a yield of 56.84% when cotton is grown and 50.32% when rye is grown. As can be seen, even in rye, which seemed to be quite tolerant up to this point, there is a loss of up to fifty percent under excessive salinity conditions.

If salinity increases further and reaches 25 dS/m, then there is only a possibility of getting 10.04% yield from cotton and 15% from barley. From this point on, it is not possible to obtain yield from all the plants considered in more saline conditions.

5. CONCLUSION

In the yield calculations made by considering that 10 different field crops were grown under 10 different salinity conditions, high yield loss values were observed in some plants due to the increase in salinity. Even at 4 dS/m, where salinity has just begun, there was a yield loss of 27.6% in corn, 23.2% in peanuts and 14.6% in alfalfa.

At 6 dS/m salinity level, full yields were obtained from barley, rye-sorghum, cotton, sugar beet and wheat. In order to avoid any loss of yield when growing field crops in an area with a salinity of around 6 dS/m, it would be appropriate to grow these plants.

At 8 dS/m salinity level, only rye and barley were able to achieve full yield, while cotton suffered a small loss.

In high salinity conditions such as 10 dS/m, only rye, barley and cotton can be grown among the plants considered. There is no possibility of profitable production above 12 dS/m. Because yields remained at 50-60% even for the most tolerant plants such as barley, rye and cotton at this salinity level.

As a result, in order to make a profitable production of field crops, it does not seem possible to grow above 12 dS/m salinity level without soil reclamation due to yield losses. In areas with salinity between 8 and 12 dS/m, only rye, barley and cotton plants will be suitable for cultivation. At salinity levels between 4 and 8 dS/m, it is possible to grow rye, barley, cotton, sugar beet and wheat from high to low yield.

Corn and peanut crops were identified as the most sensitive to salinity and were found to be suitable for cultivation in areas with low salinity (<2 dS/m) whenever possible.

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Chapter 13

Integrated Innovations in Modern Tractor Technologies: Autonomy, Electrification and Data-Driven Applications

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1. Introduction

Agriculture, one of humanity's oldest practices, has always been a dynamic process incorporating changes and new technologies. In this sector, every process is done with the help of machines and modern equipment. Tractors, in particular, have played a crucial role in the mechanization of agricultural production, evolving from simple mechanical vehicles to connected mobile hubs. Their role in the evolution of the agricultural sector is a testament to the pride we can take in our technological advancements.

While tractors were used in the last century as simple mechanical vehicles used only for pulling and pushing, they have evolved into connected mobile hubs, including autonomous tractors with sensors, software, and digital communication systems. (Mocera et al., 2023). In this transformation process, agricultural production performance has been enhanced, and the sustainability and profitability of agricultural production have also been guaranteed. Technological developments have also presented new possibilities, threats, and requirements for the agricultural ecosystem. Therefore, “smart” tractor designs are becoming the norm in today’s agriculture, with electric or hybrid models run by renewable energy, autonomous driving systems, and management and decision-making tools incorporating big data analysis (Chen et al., 2022).

Agriculture 4. 0, the Fourth Industrial Revolution in Agriculture, integrates advanced artificial intelligence technologies in the agricultural sector and implements Industry 4. 0 concepts. These concepts include machine learning, the Internet of Things (IoT), robotics, and cloud computing. In the modern context, tractors are not only the power units or means of transportation. However, they are transforming into the ‘smart nodes’ of the overall production system capable of adjusting their work rate, responding to environmental changes, and coordinating with other agricultural machinery (Bracanović et al.,2018).

These changes can also contribute to improving tractors to be more eco-friendly. Issues such as high carbon emissions and ever-rising fuel costs due to traditional internal combustion engine technologies have forced manufacturers and large companies in the sector to look for alternatives (Troncon et al., 2019). Due to the research in this area, using electric or hybrid tractors and hydrogen-based power units or biofuels have become topics of interest (Amelchenko et al., 2014).

While modern tractor technologies offer numerous benefits, they also present challenges and limitations. For instance, the transition to electric or hybrid tractors may require significant investment in infrastructure and training. The increasing use of autonomous and high-tech tractors may reduce the need for manual labor, potentially impacting rural employment. However, this situation also enhances the stability and efficiency of production and the need to address the issue of professional preparation and digital literacy of the workers in the agricultural sector (Santos et al., 2023). This paper aims to explore the overall architecture of contemporary tractor technologies and review the possible changes that may occur in the sector's future. Many topics, such as electrification and autonomy, are discussed in detail, focusing on the key features of modern tractor technologies and their effects on agricultural production systems). Therefore, the issues concerning the electric or hybrid tractor design and the use of hydrogen-based power units or biofuels have been identified during studies in this field.

2. Electrification and Alternative Energy Sources

Traditional agricultural tractors have been widely used to operate agricultural machinery with the help of an internal combustion diesel engine. Nevertheless, the current approach should be reconsidered due to the increasing fuel costs, the scarcity of fossil fuel supplies, environmental issues, and the necessity of addressing climate change (Mocera et al., 2023; Troncon et al., 2019). More specifically, the following has been identified as a high-priority issue: reducing carbon emissions and achieving sustainability on a global scale (Amelchenko et al., 2014). Thus, energy conversion units, which use alternative energy sources like electric, hybrid, and hydrogen, are predicted to capture more and more interest from tractor manufacturers. The shift towards electrification and alternative energy sources in the agricultural sector could significantly reduce carbon emissions, lower operational costs, and contribute to a more sustainable and environmentally friendly farming industry (Chen et al., 2022).

2.1. Development of Electric and Hybrid Tractor Technologies

The electric tractor concepts visible in the present agricultural sector result from the electric vehicle revolution in the automotive and agricultural sectors (Sun, 2019). Those tractors with electric or hybrid options have their power transmitted through energy management systems and electric motors with battery packs (Brenna et al., 2018).

Electric motors are more efficient than internal combustion engines because they store and use electrical energy with minimum loss. Thus, energy storage and utilization can be effectively managed, while energy can be recovered during braking or when the vehicle decelerates (Kim et al., 2003). This can significantly decrease the overall costs of operation and fuel (Liu et al., 2021).

Direct-drive motors have fewer parts, so they are easier to maintain, last longer, and have a low tendency to fail. Removing traditional maintenance tasks like oil changes benefits the business financially and operationally (Didmanidze et al., 2020).

These vehicles are powered by electricity, making them run silently and enhancing the comfort of the operators and onlookers. The low noise level is a significant benefit and particularly important for urban farming applications or companies with environmental concerns (Buning, 2010).

2.2. Battery Technology and Charging Infrastructure

Battery technology is one of the most important factors defining the efficiency of electric tractors. According to Sangeetha et al. (2023), lithium-ion batteries are the most commonly used due to their high energy density, long life, and relatively low cost. However, when it comes to agricultural enterprises where operational continuity and seasonal intensity are key, it is crucial to consider the need for fast charging points, swap battery systems, and energy storage facilities near the farms (Bezerra, 2017).

Using portable solar panels for power supply or incorporating wind turbines and bio-gas sources can be crucial in developing an energy base in rural areas (Faraz & Azad, 2012; Khadkikar et al., 2009). Photovoltaic energy systems enhance environmental friendliness and offer cheap power options in rural areas (Hachim et al., 2018).

2.3. Hybrid Systems: Key to Transition

Hybrid solutions are a beacon of hope, offering a possible way to solve the logistical and cost-related issues associated with the transition to fully electric tractors. These hybrid tractors, including an internal combustion engine and an electric motor, provide high energy from fossil fuel and the benefits of electric systems, respectively. This approach enhances energy efficiency and reduces the carbon footprint, making it suitable for current and future operation conditions.

The internal combustion engine is left on, especially in tasks that require high power for a long time, while the electric motor is engaged only to conserve fuel when doing light work or when accuracy is needed (Walkowicz et al., 2012; Jia et al., 2018). This flexibility also helps conserve energy and aligns with the agricultural sector's sustainable development goals (Xiao et al., 2018).

2.4. Hydrogen Fuel and Other Innovative Energy Sources

In addition to electrification, hydrogen-fueled tractors are also being developed. Hydrogen is an energy resource that various techniques can produce. Hydrogen can be made through multiple methods, including water electrolysis or biomass conversion and the energy generated from renewables (Demirbas, 2006; Wang et al., 2019). Hydrogen-fueled batteries are a system that provides zero emission of power using chemical energy to electrical energy. It is characterized by high energy density and long-term work capabilities, which make this technology unique (Joo, 2011). However, current challenges hindering the adoption of this technology include limited hydrogen infrastructure and high production and storage costs (Logan, 2004). Other biofuels such as bioethanol and biodiesel, methane, and ammonia-based fuels are also among the topics under study (Narnaware et al., 2022).

2.5. Environmental and Sustainability Goals

Using electricity and other energy sources in energy distribution also creates economic benefits, minimizes the impact of joyous noise and environmental pollution, and reduces carbon emissions. Protection also enhances resources and air quality, which is a crucial aim (Liu et al., 2023; Robinah et al., 2021). Remarkably, considering the agricultural sector's enhanced position in combating climate change, applying green technologies is a significant question of social responsibility (Anggarani et al., 2020).

3. Autonomous and Semi-Autonomous Systems

One of the most significant changes that is seen in the context of agricultural machinery is the use of autonomous and semi-autonomous tractors. The operation of previously based tractors depends on the skills and directions given by the operators, and now they are slowly being operated without the need for a driver by using artificial intelligence and positioning systems (Joseph et al., 2020). This change has excellent potential to increase efficiency in the production process and tackle labor shortages, cost impact, and safety problems (Auat Cheein & Carelli, 2013).

3.1 Main composition elements of autonomous systems

Some of the most essential elements of an autonomous tractor are the high-precision positioning systems; simultaneously, it should contain advanced sensors and powerful processing units. However, it is also important not to forget about AI-based control algorithms and integrated decision-making mechanisms (Alberto-Rodríguez et al., 2020; Wang & Noguchi, 2016).

GPS (Global Positioning System), RTK (Real-Time Kinematics), and satellite-assisted high-accuracy positioning systems facilitate the movement of tractors within a field with an accuracy of a few centimeters. This enables accurate planting and positioning for fertilization and spraying while conserving fuel and material and optimizing time (Yang et al., 2017).

Equipping tractors with sensing systems and sensors allows them to observe the environment and understand where it is and what is around it. These data are significant for autonomous driving and may contribute to the prevention of collisions (Nguyen et al., 2022; Fei et al., 2019).

Due to technologies such as image processing and object recognition, tractors can now respond to changes in field and weather conditions in real-time. This plays an active role in developing tractors capable of learning processes and does not follow a predetermined course (Yang et al., 2023).

3.2. Semi-Autonomous Systems: Gradual Transition Approach

Complete autonomous systems have some technical and legal issues in their implementation, so semi-autonomous systems are used in the agricultural sector. These solutions enable the operator to set a particular path or speed for the tractor and control it in the field; however, monotonous operations can be automated (D'Antonio et al., 2023).

The driver must choose the starting point and path he wants to follow, and the tractor determines the location on this path and manages the steering. During the harvesting, fertilizing, and spraying processes, tractors control their speed with the help of sensors. They can manage the equipment's height or the application's intensity. The result is an efficient use of resources, leading to better outcomes using inputs (Bi & Liu, 2023).

Semi-autonomous approaches provide a way to engage users increasingly with new technologies while gradually enhancing safety, productivity, and quality (Lavrov & Zubina, 2021).

3.3. Security and Regulatory Frameworks

This is why the issue of the safety of autonomous tractors is considered one of the most important when it comes to their deployment. This way, the human factor can be eliminated or minimized to avoid mistakes caused by misuse. However, autonomous systems have to be designed so they do not develop systematic errors. There are two significant ideas: Environmental sensors and artificial intelligence. The tractor should be able to identify an object in the field and deal with it in the sense that if it is a threat, the tractor should stop, and if it is not a threat, the tractor should avoid it, as per Stählin and Hartmann (2012).

Since autonomous tractors work with the data crucial for agribusinesses' performance, cybersecurity, data privacy, and the system's resilience to manipulation must be addressed (Gaggero et al., 2022; Khan & Quadri, 2021). Hence, the security of the remote-control systems of the vehicles and the GPS networks is crucial.

Since the technology of the autonomous agricultural vehicle is still being developed internationally, there is a need for a legal and/or regulatory framework to govern its use. These include accidents, vehicle ownership, and even data ownership, which means that producers and decision-makers must make and implement new laws (Kohler & Colbert-Taylor, 2015; Kim, 2021).

3.4. Economic Impacts, Productivity and Labor Dynamics

Autonomous and semi-autonomous tractors enhance businesses' efficiency as they help cut costs and improve time utilization. This eliminates the need for operators, and production can be carried on at a constant and high rate, especially in areas of labor shortage (Prokopov et al., 2020). However, the application of these high-tech systems stimulates the growth of digital competencies of farmers and technical personnel (Vorozhtsov et al., 2022).

In the future, autonomous tractors will minimize the human factor and improve the accuracy of work, enhance the quality of the products, and optimize the use of resources, which will increase the economic profit and improve environmental sustainability (Mimra et al., 2017; Chen et al., 2022).

3.5. Future Vision

With technological advancements, it is anticipated that autonomous tractors will be used for certain functions and all the production processes. Thus, autonomous tractors will provide the data to other advanced agricultural machinery and realize the whole crop production process from seeding to harvesting (Wang & Sun, 2023). Several companies in an area can also cut costs and enhance resource utilization by using autonomous tractors jointly. This will alter rural development and ownership patterns, as Li et al. (2023) explain.

Self-learning capabilities, which are through machine learning and deep learning algorithms, allow autonomous tractors to learn from the experiences in the field and become better, reduce errors, and be able to handle the dynamic environment (Sahatun & Yamin, 2023).

Autonomous and semi-autonomous tractor technology improves the agricultural production system's safety, effectiveness, and adaptability. This transformation shows a shift from the mechanisms of vehicles made of mechanical parts to the concept of intelligent robotic systems capable of learning, analyzing, and deciding. The operator's role is evolving from the control of the vehicles in the classical sense to management, inspection, planning, and optimization. This way, the agricultural sector will quickly become more digital, sustain itself, and adapt to climate and resource management shifts.

4. Data-Driven Decision Support Systems and IoT Integration

Among the most significant changes in modern tractor technologies, one can identify the appearance of the so-called "decision support systems," which have been made possible by enhanced data collection, analysis, and processing capabilities. While the initial tractors provide mechanical power and accomplish a particular function, the modern ones are sophisticated systems that are capable of perceiving the field conditions, the condition of the equipment, and the environment conditions through multiple data flows, process such information in real-time and make recommendations to the operator or make the decisions on their own using artificial intelligence (Kaparthi et al., 2021).

The Internet of Things (IoT), cloud computing, big data analytics, and artificial intelligence-based software are at the heart of this change. For instance, IoTs based on cloud systems offers a strong platform for tracking the conditions of agricultural vehicles and enhancing decision-making. These systems not only improve the productivity of machinery but also enable better management of farming activities to be more effective, sustainable, and cohesive (Mocanu et al., 2015).

4.1. Data Collection and Sensor Integration

The advanced tractor models available in the market are fitted with various sensors. The following are some of the data that these sensors offer: engine performance data, fuel consumption data, soil moisture, and temperature data, plant growth data, and global positioning system data that provides information on the location of the farm and weather data (Torres et al., 2017). The parameters, which include the engine speed, torque, temperature, pressure, and vibration, are monitored to enable data analysis for fuel savings, fault detection, and condition-based maintenance (Fan et al., 2022).

The sourced data include soil moisture, pH level, nutrients in the soil, and temperature of the plant leaves, which help optimize fertilization, irrigation, and pesticide application. This increases the output while reducing the input (Singh et al., 2015). Thus, environmental conditions, including wind speed, rainfall, humidity, light intensity, etc., can be effectively managed to ensure proper operation timing (Chen et al., 2023).

4.2. IoT Integration and Connected Ecosystems

Using tractors in the IoT-based infrastructure means the machine is now integral to a more extensive agricultural system. The tractor can relay information to planters, fertilizers, or spraying equipment. This integration makes it possible for each piece of equipment to adapt to each other and work simultaneously and efficiently (Kundu et al., 2020). The collected data is stored on cloud-based servers and analyzed using advanced analytics tools. This way, the farmers will be provided with a flexible data analytics framework that can be accessed anytime (Jadhav, 2019).

Cell phones or tablets can monitor tractor performance, location, operation phases, and equipment status. Operators, managers, or advisors can make decisions, give instructions, and implement them in the field without being present. Internet of Things-based systems have been instrumental in modern agriculture as they help improve resource production and efficiency (Sakthi & Rose, 2020).

4.3. Big Data Analysis and Artificial Intelligence-Based Decision Support Systems

The real value of the collected data depends on its proper analysis. Through machine learning, deep learning, and data mining techniques, past performance records, sensor readings, and failure data can be analyzed to predict which part of the tractor will require maintenance and under which conditions it may fail (Mistry et al., 2023). This prevents unexpected downtime and production losses.

By combining plant growth data, climate information, and soil properties, yield and quality estimates can be made for different production scenarios (Veeragandham & Santhi, 2020). Thus, production decisions such as fertilizer or pesticide dosage, irrigation amount, and harvest time are shaped in the light of objective data. Decision support software integrated with autonomous systems calculates the optimal route that the tractor should follow in the field, reducing time, fuel, and labor (Liakos et al., 2018).

4.4. Farmer-Friendly Interfaces and User Experience

Advanced data analytics and IoT integration can only be of real value if the farmer or operator uses the technology effectively. User-friendly interfaces are, therefore, key to the success of decision support systems. By making complex data understandable through graphs, maps, color coding, and icons, dashboards present the situation on the field (Carvalho et al., 2019).

Each farm has its specific conditions. Systems enrich the experience by providing personalized recommendations based on user profiles, historical records, and specific parameters (Hargrave, 2008). Scenario simulations that solve problems like “What would I do if this happened?” enable the farmers to try different approaches and mitigate against certain risks, as Saleem et al. (2020) pointed out.

4.5. Data Security, Privacy and Property Rights

The use of data-driven approaches has also raised concerns about data security and privacy. Production strategies, productivity information, or economic data of agricultural enterprises are valuable information for competition. All necessary precautions should be taken so that the data is not accessed, attacked, or altered in an undesired manner (Kotal et al., 2023). Some of the issues that law collected needs include who the farmers are, the down legal or owner of farms, the data, to what kind end of the data it will allow me to put, and with what frequency it will be shared with third parties (Song et al., 2021).

Hence, it is essential to identify and manage risks in agricultural data to ensure the effective implementation of new-age agricultural systems. Farmers’ concerns about the privacy of their business data can be addressed by ensuring that data is anonymized and protected by the law (Wu et al., 2023; Bergstrom et al., 2022).

4.6. Sustainability, Resource Management and Environmental Benefits

The data-driven decision support systems are meant to be efficient, economically, and environmentally friendly. Appropriate input management, water and energy conservation, and optimal practices help reduce greenhouse gas emissions and optimize water and nutrient utilization (Comania et al., 2018). This thus strikes a balance that is advantageous to the producer and society in the long run. Furthermore, multicriteria decision support approaches that seek to achieve the right balance between economic efficiency and environmental sustainability enhance the efficiency of decision-making in this area (Lee & Park, 2017).

Implementing decision support systems to achieve environmental sustainability objectives is anchored on techniques that ensure effective resource management to meet economic and ecological goals (Fathi et al., 2009).

4.7. Future Perspective

Advancements in sensor technology, AI algorithms, and IoT integration transform tractors from simple production tools to management platforms. In the future, AI will enable tractors to process data and improve working strategies with each passing year (Balan et al., 2020). In the next few years, AI will help tractors generate data and use it to enhance production strategies accordingly (Balan et al., 2020).

Finally, data-enabled innovation will enhance every domain of agricultural production and will improve competitiveness, profitability, and sustainability to an unprecedented extent (Kodati & Jeeva, 2019; Patil & Jadhav, 2023).

5. Standardization, Regulatory Frameworks and Future Perspectives

Due to the advancement in tractor technologies, the agricultural sector is changing rapidly, which depicts the dynamics of a complex transformation process. Electrification, autonomy, data-enabled decision-making, improved ergonomics and safety, and social and economic effects of these technologies will be achieved sustainably and equitably if regulations, standards, collaborations between sectors, and research and development activities are well coordinated (Liu et al., 2021; Savin & Matveev, 2020).

Electrification reduces energy costs and carbon emissions, while autonomy and data-driven technologies make agricultural processes more efficient and sustainable. This transformation needs technological advancement, policy measures, and multi-stakeholder partnerships (Amongo et al., 2020; Jamal, 2023).

Therefore, the following measures are recommended to ensure that this transformation process is sustained: Standards should be developed, and research and development activities should be encouraged. For instance, the formulation of policies by public institutions and the coordination of policies across sectors are key in increasing technology adoption in the agricultural sector (Olmstead & Rhode, 2000; Akram et al., 2020).

5.1. Standards and Certification Processes

Specific technical standards, certification schemes, and quality control mechanisms are necessary to accept and spread agricultural equipment in the international market. The advancement and conformity of these standards aid in the competitiveness of manufacturers and enhanced performance of agricultural equipment (Kostomakhin & Kazakova, 2020). Hence, international standards for the safety, environmental impact, data accuracy, and security of electric, autonomous, or complex sensor tractors should be set up (Ayala Garay et al., 2018).

Standard protocols are needed for tractors and other intelligent agricultural machinery, sensor systems, and cloud-based platforms to interoperate with each other and share data. Standardization activities enhance the interoperability of the various brands and models, accelerating the adoption of technology (Kim, 2014).

Hence, certification helps the producers enhance the quality of the product, which in turn creates confidence among the consumers. OCIMA in Mexico, for instance, is important in ensuring that agricultural equipment meets set global standards by improving the efficiency of certification processes (Ayala Garay et al., 2012).

5.2. Regulatory Frameworks and Public Policies

Some major players in integrating new technologies in the field include governments and their subsidiaries, international organizations, and regional administrations. Financial mechanisms like tax incentives, credits, grants, and R&D incentives help farmers and producers acquire high-tech tractors. These supports accelerate technology adoption, especially for small and medium enterprises (SMEs), as evidenced by Bogomolova et al. (2020) and Strizhkova et al. (2020).

Public institutions, professional associations, and civil society organizations can also shape the transformation of the human factor by providing programs that help enhance the digital skills of operators, technicians, and managers. Of particular importance is the issue of training and capacity building for the effective implementation of digital agricultural technologies (Kolmykova et al., 2021; Singh et al., 2023).

Due to the issues of data ownership, privacy, and accountability of AI-enabled decisions, as well as the status of autonomous cars, the legal frameworks need to be updated. Defining specific rules in these areas helps to gain society's approval and builds trust in the sphere (Elmaghraoui et al., 2019; Buklagin, 2021).

5.3. Multidisciplinary and Cross-Sectoral Collaborations

The development of modern tractor technologies involves several fields, including engineering, informatics, biotechnology, economics, sociology, and environmental sciences. Integrating academic knowledge with industrial practices in R&D projects leads to the creation of new ideas (Freimann, 2003). Besides, collaboration between universities and industries helps partner organizations achieve economic gains and improve the probability of success of research collaborations (Fiaz et al., 2011; Raffaelle, 2009).

Startups dedicated to developing the next generation of agricultural solutions can do so quickly and with a relatively short and adaptable business model. Cooperation with international producers, investors, and government structures supports these startups and helps them achieve global impact (Vaidya, 2019).

The exchange of knowledge and best practices from around the world and cooperative research initiatives are key to advancing agricultural technologies. Therefore, multidisciplinary management models must play a significant role in the design and quality control of modern tractors (Vaidya, 2019).

5.4. Continuous R&D and Innovation Culture

Technological change is not a fixed process. Further research, development, testing, pilot implementation, and feedback loops ensure that the progress of the tractor technologies is more effective, efficient, and sustainable. This includes using more lightweight composite materials, advancing higher energy density battery systems, and employing hydrogen or ammonia-based fuels for the energy system of tractors. With artificial intelligence applications like deep learning, image processing, object recognition, and predictive modeling, the tractors can handle more challenging conditions and learn and carry out more complicated functions within a shorter time and with minimal human input.

5.5. Raising Ecological and Climate Awareness

The main factors that influence the design and use of the modern tractor include climate change, availability of natural resources, and environmental sustainability. Using green energy sources, auto adaption, and precision helps conserve inputs and reduce wastage. This, in turn, helps the agriculture sector to adapt and enhance its contribution to the fight against climate change (Balafoutis et al., 2017; D'Antonio et al., 2023).

Some of the techniques used in precision agriculture and data-driven decision-support systems include avoiding soil over-tilling, supporting biodiversity, and promoting sustainable production cycles. Modern tractors play a significant role in enhancing the sustainability of the environment, as they help conserve fuel and reduce greenhouse gases (Amelchenko et al., 2018; Mandloi et al., 2018).

Using electric and hybrid tractors is another way of addressing the problem of sustainable agriculture by reducing dependence on fossil fuels. These technologies enhance the effectiveness of agricultural production without negatively affecting the environment (Didmanidze et al., 2020).

5.6. Social Acceptance and Inclusion

The success of technological transformation is not only based on technical factors but also social factors, such as acceptance, equity, and inclusion. Farmers, consumers, politicians, and other societal actors must share their information and concerns about new technologies. Such approaches to communication help to address the issues surrounding technology adoption properly. Technological changes that are versatile enough to work with the regions' various social, economic, and ecological systems in the modernization process are effective without neglecting the local knowledge and practices.

Conclusion

The future of modern tractor technologies shows that multiple-dimensional adaptations will continue. Advancements in electrification, autonomy, data analytics, ergonomics, safety, and the system exist. Resultant In the effects of this transformation, the process, economy, and society are important; coupled with close standardization cooperation between regulatory public frameworks authorities, the industry creates sustainable agricultural academia, civil society organizations, and farmers. The general objective should be achieving a sustainable agricultural future with improved production, food security, environmental stability, economic profitability, and societal well-being. Therefore, the sustainable modern agricultural tractor system technologies will still address pivotal place challenges in developing the future more sophisticated well and as the requirements. present

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Chapter 14

The Environmental Impacts and Sustainability of No-Tillage Agriculture

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1. Introduction to No-Tillage Agriculture

Since its inception in the mid-20th century, no-tillage agriculture has become a globally practiced farming system. It refers to disrupting the soil as minimally and seldom as possible. Instead of mixing the entire soil profile, no-tillage agriculture implements a slot less than the seeding depth. A seed is planted in this slot, which is then sealed. Developing over the years, agricultural engineers have designed equipment that is not only capable of precision planting but is also able to handle the residues that remain on the soil surface. This has led to the development of various systems that can be categorized into three main approaches: no-till, which refers to a direct planting system in which the crop is sown in a permanent soil slot with the least disturbance to the soil; minimum tillage, which reduces the implements used to cultivate the soil; and reduced tillage, which reduces the number of field operations. Conservation agriculture, with no-till as one of its key aspects, is the internationally recognized term for these surface tillage practices. Importantly, no-tillage offers environmental benefits and significant economic advantages, making it a promising choice for farmers interested in sustainable practices.

The fundamentals and methods of adopting no-till management developed when tillage practices were observed to cause soil organic matter and structure loss, soil erosion following wet tillage/dry fallow systems, and the release of stored carbon back into the atmosphere. Its growth has been spurred on by other disadvantages of tillage, including dust formation, compaction, and air and water pollution. It demands alleviating soil cultivation's labor, time, and cost requirements in semi-arid regions. Interest in no-till has also been stimulated to address climate change and ensure food security and soil and water conservation. Soil management is a key component of environmental strategy in semi-arid and temperate regions, where no-tillage can play a significant role. The dominance of the intensified agroecosystem may necessitate specific management options for rooted crops requiring minimal tillage, nutrient recycling, or cover crop retention to meet the sustainability and ecosystem functioning restoration challenge. (Liu et al.2021; Jayaraman et al.2024)

2. Environmental Impacts of No-Tillage

Adopting no-tillage has helped mitigate many of the adverse sustainability outcomes traditionally associated with intensive tillage agriculture, mainly due to reduced soil erosion. Adopting no-tillage also helps conserve moisture through decreased evaporation rates and improved water infiltration, which can enhance soil moisture levels in high and low rainfall seasons. No-tillage systems have provided many positive benefits for soil habitat and structure. Earthworms and microbial communities increase in no-tillage systems, which is reflected in improved soil quality, as the outcomes of the greater levels of biological activity lead to organic matter improvements, which contribute to improved soil structure, water, and nutrient holding capacities (Shakoor et al., 2021). Some reports suggest that no-tillage cropping can increase soil acidity due to the accumulation of nutrients in the rhizosphere. However, this problem generally occurs in high residue retention cropping systems, which can be corrected by increasing lime application (Yue et al., 2023).

The slowing down and maximizing water infiltration at the plant root zone are due to the improved soil structure associated with no-tillage. By improving the amount of time that water percolates through the soil and by reducing the quantity of water running off eroded landscapes, a reduction in pollutants in runoff can occur, thus improving water quality. No-tillage systems incorporating cover crops and organic mulch reduce leaching and runoff into waterways. Biodiversity in no-tillage systems is highly influenced by the amount and type of crop rotation, the type of no-tillage system, and the amount of plant litter left on the soil surface. However, it is important to note how an ecosystem will respond to management changes in tillage intensity is unpredictable. It depends on various factors, particularly the weather, and is region and land management system-specific. This unpredictability underscores the need for adaptive management strategies in no-tillage systems. In a study comparing grasslands of differing soil fertility, there was more excellent species diversity in the more fertile soil receiving no-tillage practices than conventional tillage in the early stages. Some reports have suggested that some no-tillage systems may result in species loss, particularly earthworms, due to the removal of a 'food base' in thatch removal systems (Li et al., 2023; Li et al., 2023; Hashimi et al., 2023).

2.1. Soil Health and Quality

Soil health and quality are critical factors for sustainable agriculture. Plowing or other tillage operations profoundly disrupt the soil by destroying its structure, organic matter content, and the communities of organisms living in it. No-tillage, on the other hand, contributes to the reduction of soil disturbance and preservation, thus ensuring the vitality and health of the soil. In soils, organic matter, mainly derived from plant residues, is critical in stimulating and maintaining the activity and biodiversity of soil microbial communities. The more organic matter is returned to the soil, the more microbial activity will increase. The high soil microbial diversity in no-tillage systems, especially fungi, is mainly due to the accumulation of organic matter caused by reduced or absent plowing. Moreover, organic matter improves nutrient cycling and increases soil fertility. This ultimately results in higher farm productivity. In contrast to the more compacted plowed soil, no-tilled soil is less compacted, thus reducing mechanization damage. Compacted soil can reduce water infiltration, leading to surface runoff and erosion. Compacted soil will lead to resisted penetration towards root growth, causing compaction problems in the root zone of plants and ultimately reducing crop productivity.

If the amount of microorganisms is high, soil health is optimum, improving crop resilience in dry or drought conditions. These facts are evidenced in various sites in scientific studies conducted in different locations from long-term experiments. Nowadays, many kinds of research have been conducted considering various cropping patterns and environmental conditions worldwide, and the results are overwhelmingly in favor of no-tillage. This ongoing research is crucial in improving no-tillage practices and addressing the challenges it may face. However, it is important to note that using reduced or no-tillage systems is inappropriate in all contexts. In some situations, such as where infestations are very high or where long-term rotations are challenging to implement if, for example, mechanical or chemical weeding is not available or affordable, no-tillage systems may face challenges. High weeds and pests can reduce crop productivity in no-tillage systems. This balanced view of the effectiveness of no-tillage systems is important for farmers and policymakers to consider when implementing sustainable agriculture practices.

Agriculture must adopt sustainable and productive practices to ensure good soil quality and enhance farmer incentives in fragile environments. Implementing no-tillage systems can significantly improve soil quality while concurrently fulfilling vital environmental functions by conserving residue rather than traditional plowing methods. Adopting no-tillage agriculture can lead to positive environmental outcomes by enriching soil organic matter, optimizing pH levels, and mitigating acidity compared to clear-cutting practices.

For this transition to be successful, engaging farmers and providing them with the necessary information to enhance management practices related to no-tillage adoption is important. Reducing soil disturbance during seeding and crop growth can result in a more stable, fertile top layer, even under heavy rainfall conditions, due to decreased external influences. This approach minimizes erosion risks, as the absence of frequent human or tractor interaction lessens the compaction typically caused by machinery. Consequently, the soil becomes more porous and resilient.

With improved aeration and effective water management strategies, farmers can significantly contribute to the sustainability of agricultural systems. (Yue et al. 2023; Hashimi et al. 2023; Li et al. 2023)

2.2. Water Conservation and Quality

For water resources management, water conservation in soils is as important as any other component of the hydrological cycle. In no-tillage systems, there is more water available for plants, and water infiltrates into the soil faster than in conventional systems, which reduces surface water flows and, thus, the danger of erosion. About 50% of the precipitation runs over its surface in a conventional moldboard plow system. Thus, it is considered a squander for half the yearly precipitation. In no-tillage, most of the precipitation infiltrates into the soil. This promotes the recharge of the aquifers underneath, mainly recharging the shallow aquifers, which is a noteworthy process for improving agriculture in arid and semi-arid regions. (Mondal et al.2023; Teixeira & Basch, 2022; Ofstehage and Nehring2021)

In this way, the farmer relies less on irrigation, particularly for crops growing in dry seasons. Along with saving water in agricultural fields, soil moisture conservation mitigates the severe effects of future drought events on crop productivity. Overall, the water content in no-tillage systems using crop residues helps farmers to adapt to current and forecast droughts. The quantity of runoff also significantly influences water quality. In no-tillage agriculture, surface runoff is minimized by the structural and physical properties of the soil, which promote the infiltration of rainfall into the soil. When erosion occurs due to mechanical or water forces, no-tillage fields are reported to produce several times less soil erosion or sediment. The reduction of soil erosion through no-tillage systems also decreases the loss of potentially adsorbed phosphorus through the loss of surface soil. Long-term runoff water quality results from no-tillage systems show a decrease in nutrient loads at the edge of no-tillage fields. While these studies show short-term local nutrient losses during no-tillage adoption or transition, they also demonstrate a long-term improvement in nutrient conservation in no-tillage watersheds. Note, however, that no-tillage does not necessarily reduce pesticide runoff in regions with heavy rainfall, and carryover of pesticides in subsurface waters can occur. (Li et al.2023; Li et al.2023; Wang et al.2024)

2.3. Biodiversity Preservation

Preserving biodiversity is an important aspect of ecological soil sustainability. Biodiversity in organisms and taxa is closely related to ecosystem functions, crucial factors in ecological sustainability. Reducing soil disturbance at the farm level is favorable for preserving biodiversity because less soil is moved and disturbed, which leaves more diverse habitats for animals or microorganisms. On the one hand, earthworm and microbial biodiversity, as indicators, can be increased by continuous no-tillage. Reduced or direct seed drilling or placement of fertilizers used in no-tillage systems directly supplies food for fauna, whereas, in plowed fields, wild microorganisms use plant residues and organic matter. Decreased pesticide residue is easily broken down through an increased amount and enormous diversity of aerobic microorganisms in soils under no-tillage. The abundance of secondary soil biota (micro-, meso, and macrofauna) increased in no-tillage fields. Reduced disease losses because of continuous no-tillage, degraded predators and plant-parasitic nematodes, and additional nutrients appear to be leached from the soil, which boosts soil biota. These processes enable (degrading) no-tillage agriculture to be categorized as sustainable. (Mondal & Chakraborty, 2022; Li et al.2023; Tian et al., 2023)

Maintaining and manipulating biodiversity through specifically designed crop rotation and diverse cover crops result in higher soil organic carbon content, suppressive disease, and mixture rates, thus enhancing crop yields and resistance to environmental stress. Growing mixed cover crops is one of the primary indicators in a no-tillage cropping system, resulting in a healthy and diverse plant community in conventional and organic agriculture. It is possible to select cover crops that do not favor established weed populations, which includes the reduced seeding rate of the previous crop that can result in an estimated increase in the number of weed seeds deposited in the soil. Studies have confirmed the elevated presence of beneficial organisms and their enhanced diversity, accelerating the slow build-up of pest levels in no-tillage systems. Enhanced populations of predators, carabid beetles, spiders, and beneficial organisms were reported in many agricultural landscapes with a proportion of no-tillage fields. However, they are frequently associated with no-tillage, crop rotation, and other farming practices. On the other hand, there is a risk of decreased crop yield because of the acceleration of the detrimental effects of pests, diseases, and weeds, which cannot be controlled effectively.

A declining pest population cannot be associated with the suppression of pests by indigenous predators and parasites in a continuous no-tillage system. In an integrated pest management program, they are important in reproducing weed seed predators and disrupting the life cycle of pests, which depend on other pest types. These ecological networks of pests and pest natural enemies can be damaged severely. (Ofstehage and Nehring2021; Yue et al.2023; Teixeira & Basch, 2022)

3. Sustainability Dimension of No-Tillage

Economically, no-till agriculture may save labor, fuel, and equipment. Depending on the system's functionality, no-till agriculture may also provide a similar or improved yield compared with other systems. No-till practices can also affect the externalities associated with crop production and provide sub-marketable benefits such as improved water conservation and soil structure. In areas where marginal improvements in soil biomass and soil water conservation occur, no-tillage may help to create more resilient farming systems. From a social dimension, no-tillage may be a driver toward social goals by enhancing farmer engagement in the decision-making process and through deep engagement with rural communities in the field. Some potential challenges include farmer training to manage weeds and other issues repaired by tillage with alternative systems, such as reduced or non-chemical management. (Shakoor et al.2021; Li et al.2023; Li et al.2023)

Although researchers continue to study the short-term economic, social, and environmental benefits of no-tillage, considering its role in sustainable agriculture and policy objectives requires a longer view. This often gets framed as the ability of no-tillage to contribute to economic and environmental sustainability. Farmers may be most concerned about soil health and how that transfers into increased yield and reduced input costs. Similarly, while research often separates the three dimensions of sustainability, farmers often evaluate decisions based on all three factors together. For example, if no-tillage were to increase yield but decrease soil quality or environmental quality, it would not meet the criteria for long-term sustainability, acting only as a more environmentally damaging form of agriculture that uses the original soil. (Yue et al.2023; Hashimi et al.2023; Teixeira & Basch, 2022)

3.1. Economic Benefits

Proponents of no-tillage agriculture frequently assert that farmers should adopt this strategy over conventional and reduced-tillage alternatives because it is more cost-effective. Such claims are well-supported by numerous research studies and years of adoption trials. No-tillage farming operations are nearly always significantly more profitable than their conventional and reduced-tillage counterparts. For farm owners, no-tillage systems reduce the money farmers must invest in farming operations. An average of $50 reduces farmer-invested capital for every no-till land acre, and the change in annual operating debt is on the order of $5 to $8 lower per acre. The bulk of these savings is due to reduced operating expenses from reduced machine costs. The purchase of fuel and maintenance of machines also decreased significantly. (Ofstehage and Nehring2021; Daryanto et al., 2020)

The bulk of no-tillage savings are per-acre savings, but non-per-acre expenses have also decreased in no-tillage operations. Most of these macroeconomic benefits can be attributed to no-tillage farming practices being more sustainable than other tillage practices. No-tillage fields build up topsoil at an average of one inch every seventeen years. This is a significantly faster rate of development than fields in other tillage systems and is a sign that no-till fields are more fertile. No-tillage soils retain more moisture, are less subject to water and wind erosion, and have different and usually more minor wilderness encroachment problems than other tillage practices. Reduced soil erosion is associated with savings in land restoration and reduced weed control expenses. Substantial reductions in post-harvest residue treatment expenses are also possible. Corn producers using no-tillage farming methods or implementing agroforestry and agroecology practices can favorably differentiate their products from legitimately labeled 'conventionally grown' on this account. (Tian et al., 2023; Teixeira & Basch, 2022)

The adoption of no-tillage ranks near the top. One farm out of four is now using no-tillage or other somewhat vigorous forms of conservation tillage. Systematic adoption of no-tillage has also occurred in foreign countries. Farmers are not adopting no-tillage as fast as they might be because it can be challenging to start and maintain from an operational viewpoint. No-tillage farming does not fit well into the farming cycles it was designed for. Commensurate with this, the yields of infrequently tilled crops are often inconsistent, a consideration that makes it less attractive to farmers. Drought conditions mitigate these disadvantages since no-tillage operations affect soil moisture levels and enhance water management. Fields in no-tillage retain up to 15,000 gallons of water in the upper 1 to 1.5 feet of soil in a 40-acre no-tillage field each year. Farmers who use no-tillage methods save those quantities of water or more annually on all the no-till land they farm. (Daryanto et al., 2020; Yue et al.2023; Jayaraman et al.2024)

3.2. Social Implications

One reported advantage of no-tillage farming is the potential for building or strengthening communities. External costs, including those due to environmental damage, tend to be borne by the greater public, while the primary indications benefit. A community participating in no-tillage can choose to work together in local conservation groups, area committees, or regional projects or organizations. Involvement in local community groups allows for sharing knowledge, information, resources, machinery, and time. No-tillage also has social implications that farmers discover when they adopt a continuous no-tillage system. As one farmer said, moving large farms to no-tillage has the apparent result of changing job requirements, even though people and machinery are not replaced or added. Labor requirements changed, day-to-day work hours shifted, and the work-life balance was altered. These changes occur because of reduced machinery operating time and more excellent working time with environmental aspects. Social sustainability includes human health, education, and welfare; food security; economic progress, prosperity, and equity; and social diversity. Over the period, support services and research staff in the southern region of the project received the same responses about the perceived benefits of, impediments to, changes made by, and attitudes towards no-tillage farming. Potential obstacles to the possible spread of no-tillage practices identified by the project include ongoing sustainability of weed control and some aspects of finance. Not everyone will necessarily see value in converting from traditional forms of agricultural tillage management to no-tillage systems, mainly where investment support is unavailable and the initial change from traditional farming systems to no-tillage cropping (Daryanto et al., 2020; Ofstehage and Nehring2021).

3.3. Long-Term Viability

From a long-term perspective, it is argued that no-tillage agriculture has an advantage in incorporating sustainability into dominant farming practices. In order to maintain soil organic matter with decreased weed competition, herbicides can be used; however, this is assumed to cause imbalance and environmental damage. Instead, no-till can be effectively combined with well-established components of organic farming. However, some sustainability components, such as soil fertility cycles and pest control, are vulnerable in modern no-tillage systems. However, this is also the case when only implementing crop rotation without no-till, so practical solutions exist. Farmers tend to change the cropping system they adopt when climate changes, either due to climate change or in response to altered market conditions. They will also possibly do so when the full impact of climate change becomes apparent. (Teixeira & Basch, 2022)

Therefore, it could be argued that rather than sustainable practices or closed systems of agriculture that do not require outside inputs, it is the ability to be continuously adapted to an increasingly variable climate that characterizes a genuinely sustainable goal. Furthermore, some caution is required as the availability of conservation agriculture to produce food in the broadest sustainable sense obviously will decrease in a climate scenario of increasingly severe droughts. Over time, as no-till has realized beneficial effects on both soil organic matter, soil fertility, and water holding capacity unless more severe pest problems arise that are not well covered by crop rotation, there is no reason to believe that the fields fulfilling current low-weather dependency would be less likely to do so in the future (Li et al., 2023; Jayaraman et al., 2024).

4. Challenges and Limitations of No-Tillage Adoption

The adoption of NT agriculture as a sustainable farming system is of enormous interest, but barriers continue to impede farmers from fully adopting this. The most researched limitation is the financial constraints limiting farm adoption, but social and agronomic issues may also limit adoption. The limitation often mentioned is the lack of resources available for farmers to invest in no-tillage (NT). This can include such resources as time, expertise, machinery, and appropriate working capital. By definition, technical innovation requires a new learning curve. Therefore, not knowing enough about NT may limit the rate of adoption. Pooling machinery could reduce this financial constraint and provide a reasonable, cost-effective option for farmers uncertain about the system. Pooling with neighbors and hiring machinery may lower risks for farmers too small to undertake the risks involved with capital-intensive machinery. This is just another method to ensure improved capacity for sharing machinery. This is likely to change with an increased understanding of the NT system. Research on these and other barriers to NT research will enable further advances on this issue. The management of weeds is one of the main agronomic challenges in NT farming, especially when converting from conventional to NT. Other challenges include soil compaction, reducing input dependence, and potentially reducing crop yield. Labor is saved in the long term, but labor and resources are needed to change farming practices, especially if transitioning from conventional to NT farms and switching the systems on established farms can be constrained by current conceptions and personal knowledge. Some social limitations on change can include human resistance to new farming methods that go against currently established practices within the person's mind and the community within which the individual lives. The above examples can be mitigated through various means, such as increased education for the individual farmer, landholder, or management figure. In the case of community values and tradition, people who might otherwise adopt new technologies in farming can be discouraged by their community from doing so if the technology goes against the nature of the community. Farmers have even been ostracized by their committees or communities, who shun someone who adopts an alternative lifestyle. (Wang et al.2024; Hashimi et al.2023; Yue et al.2023)

5. Conclusion and Future Directions

We have reviewed some environmental impacts and the long-term sustainability of no-tillage agriculture. These environmental benefits make a compelling case for continued and expanded investment in NT system research and development. The emphasis of such investment would be to address some of the nutrient-related challenges of NT systems, the potential trade-offs in above- and below-ground biodiversity, and to further develop and disseminate cover crops and species with functional traits agronomically suited to NT systems. NT has excellent global potential to improve soil health and provide mechanisms for agriculture's sustainability of agriculture, and as such, is an agricultural practice that merits continued research investment at all appropriate scales. (Tian et al., 2023; Hashimi et al.2023)

Research and policy that support innovation and allow for farmer needs and circumstances to be integral in adopting NT will become increasingly important. Future directions should be considered to support farmers who have already started the adoption process and those in the earliest stages of considering these practices. An interdisciplinary kind of research and hands-on efforts will lead the way in sustainable farming, integrating biological, chemical, physical, social, psychological, and farm-transitioning understanding to help meet these objectives. Because the information is essential to farmers, it will be continually improved through the participation of numerous stakeholders. All of these people must continue to work as stewards of the planet to ensure our soil's safety and health sustainably. We hope policymakers, researchers, conservationists, and farmers will act similarly. (Daryanto et al., 2020; Somasundaram et al.2020)

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Chapter 15

Improvement of Flour Quality By Using Legumes: Chickpea Example

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Introduction

Climate change, food systems and food security are strongly linked. The food we consume, and the production methods of these foods are one of the most critical processes that determine human and planetary health. Today, the methods used to produce food cause an increase in greenhouse gas emissions, global warming, or the climate crisis, while agricultural food production is one of the systems most vulnerable to the effects of climate change. Every action that directly or indirectly contributes to greenhouse gas emissions (production, vital activities, etc.) has a carbon footprint, which is evaluated as the amount of carbon dioxide equivalents. The carbon footprint of a food refers to the total greenhouse gas emissions during the production, transportation, storage, processing, packaging, preparation for cooking and consumption stages of the food.

The amount of water used directly and indirectly for the production and consumption of products and services is referred to as “water footprint” or “virtual water”. The water footprint of a food consists of the sum of the water footprints of each food production stage per food unit (usually m^3 ton^{-1}). This footprint is grouped as green, blue and gray according to the consumed water quality. Food production has a significant share in water use. Almost 92% of all water used globally is used for food production. Additionally, one third (30%) of the water used in agriculture is used directly or indirectly for animal production. Animal products, in particular, require more water per unit of energy compared to plant-based products (Ding et al., 2024; Li, 2024).

Wheat, rye, oats and rice and the flour obtained from these cereals are the main grains. Grains are almost the most important source of energy for the human body. In a normal diet, we get 30% of our total calories from grains. Grains and grain products contain vitamins, minerals, carbohydrates and other nutrients. Since the quality of the protein, they contain is low, the protein quality of grains increases when consumed with high-quality proteins. The vitamins contained in grains are rich in vitamin E and are a very important source of vitamin B1. The fiber in grains reduces glucose release in the body and keeps blood sugar levels under control. Grains, which make you feel full for a long while, also acts important role on weight control (Feng et al., 2024; Petrović et al., 2024).

Since edible legumes are mature seeds of plants, their composition is very rich in carbohydrates and protein. Especially in winter months, legumes protect our body against diseases and are the food element with the most protein after meat. The reason for this is that they contain high levels of amino acids. It is also a reason for preference because they contain as much protein as meat and are cheaper than meat. Their protein content is high but their usability in the body is moderate. Especially in cases where meat and eggs are not available or a diet limited in fat and cholesterol is recommended, legumes are increased, and protein requirements are tried to be balanced. The protein content of legumes is 40-60% compared to egg protein. This rate reaches 70% when legumes such as lentils and chickpeas are added to cereal products and vegetable dishes. Therefore, just like other plants, it is essential to the scientific studies that are based on the genetic structure (Yıldırım et al., 2022), biodiversity and nutritional value of legumes and effects of various factors (Ciftci et al, 2021; Okumuş et al., 2024).

Whole grain foods are incorporated by a low risk on cardiovascular diseases besides some types of cancer, as well as improved control of blood glucose and lipids, improved insulin resistance, and greater dietary fiber and micronutrient provision, as reported by McKeown et al. (2002).

Chickpeas, which rank third in legumes production worldwide, are a widely consumed species with an extremely rich content in terms of nutrients. Chickpea (*Cicer arietinum* L.), an important species of the food grain legume family, is widely distributed in many parts of the world and has different consumption patterns and is important in terms of the concept of sustainability (Kahraman, 2020).

Seeds of chickpeas are a relatively inexpensive as a source of dietary fiber and bioactive compounds as well, coupled with their low glycemic index (a system of measuring the effect of carbohydrates on blood glucose levels), which may be beneficial to decrease in cardiovascular disease risk. Diets consuming fiber-rich chickpea-based legumes showed a decrease in total plasma cholesterol levels. Chickpeas, which are considered a “functional food” and are thus accepted by consumers (Jukanti et al., 2012), are a relatively inexpensive source of different minerals and vitamins that may potentially help decreasing of risk on chronic diseases. Chickpeas are used as main ingredient for many traditional foods and more recently, it has been used for increase in food nutritional value. They are included in the composition of cereal-based food items, such as pasta and ready-made products, as well as bakery products and gluten-free products as snacks and partial wheat flour substitutes (Kaur and Prasad, 2021).

Chickpea containing foods also exhibit acceptable sensory properties has increased scientific interest in the subject. Health benefits of chickpea based functional foods can sufficiently meet demands for consumers by acceptable sensory properties, such as some pasta and cracker snacks (de Lima et al., 2019). This work aims to evaluate the use of chickpea, an important food grain legume, as a flour additive and its contributions to sustainability.

Nutrition, Flour Quality and Industrial Status

Vegan products are gaining increasing attention in societies due to their lower environmental impact and contribution to sustainability compared to traditional animal products. Vegan diets have the potential to reduce high greenhouse gas emissions, water consumption and land use resulting from the production of animal products (Poore and Nemecek, 2018). As the demand for vegan products increases in the agricultural sector, farmers and producers are turning to the production of plant-based products, which provides an opportunity for agricultural production models to change. For example, the production of high-protein plant foods such as legumes, nuts and grains offer a more economical and sustainable alternative compared to traditional animal husbandry activities (Godfray et al., 2018).

Positive sides of vegetarian and vegan diets may be summarized by reduced risk of chronic disease, weight control, environmental sustainability, ethical concerns and nutritional diversity. Negative sides of vegetarian and vegan diets may be summarized by risk of nutrient deficiencies, social challenges, need for planning and preparation, increased processing of some foods, potential increased costs (Khaledi-Paveh et al., 2024; Mayrhofer et al., 2024).

In recent years, gluten-free diets have gained popularity. Gluten is a type of protein group that takes part in grains likewise barley, wheat and rye. A gluten-free based diet is vital primarily for celiac patients and individuals with gluten sensitivity. However, many people who want to improve their health and quality of life. Gluten sensitivity manifests itself with digestive problems such as bloating, abdominal pain, diarrhea, or constipation after consuming gluten. It has been reported that with a gluten-free diet; digestive health can be improved, energy levels increased, skin health, mental clarity, and the immune system can be improved. Many people choose to follow a vegetarian or vegan diet for ethical and health reasons. Combining a gluten-free diet with a vegetarian or vegan diet comes with its challenges, but it is not impossible. Essentially, a vegetarian gluten-free diet would be one that is based on gluten-free grains, fruits, vegetables, legumes, and nuts, as well as eggs and dairy products. A vegan gluten-free diet does not include eggs or dairy products. Studies show a positive relationship between a vegetarian/vegan diet and health. In general, some types of cancer, health problems such as cardiovascular, hypertension, diabetes, obesity, intestinal and stomach cancer, are less common in vegetarians/vegans than in non-vegetarians (Kamei et al., 2024; Menaka et al., 2024; Smeets et al., 2024; Wall and Semrad, 2024).

Cereals are the main source for energy for most people in many countries with low purchasing power. Foods produced from cereals such as bread, biscuits, etc. have limited dietary protein, and therefore their nutritional quality is low. Numerous studies have been carried out for a long time to enrich cereal flour with legume flour and other sources, because legume proteins have lysine content (Senya et al., 2021).

Wheat flour is the most commonly used type of flour in baking and comes in varieties such as whole wheat and all-purpose flour. Positive sides of wheat flour may be summarized by rich in essential vitamins and minerals, providing sustainable energy from complex carbohydrates, containing dietary fiber, and supporting a healthy metabolism. Negative sides of wheat flour may be summarized by weakening of the immune system, risk of obesity, risk of diabetes, oral health problems, and negative effects on heart health due to high sugar intake (Gumul et al., 2024; Koksel et al., 2024; Yasin et al., 2024).

The glycemic index is a term that is frequently used by those who want to have a balanced diet, lose weight healthily and by diabetics, especially in recent years. The glycemic index is a value given to foods based on how slowly or quickly they cause a rise in blood sugar levels after digestion. This index is a numerical value. The opposite happens in foods with a lower index. People's blood sugar increases slowly and decreases slowly. Therefore, the index has an effect on blood sugar. Foods with low index value can be given as beans, chickpeas, lentils, bulgur and yoghurt (Gerontiti et al., 2024; Pasqualoni et al., 2024).

The decrease in time spent on cooking and the increase in income levels due to people spending more time on work and travel are among the most important reasons for the increase in the consumption of biscuits among the "snack foods". Therefore, production is increasing all over the world in parallel with the increase in consumption. Previously considered a luxury consumer item, biscuits have now become a food that everyone can consume. The biscuit industry, which also tends to produce healthy foods in USA and Europe, is seeking to the products which are both delicious and appeal to consumers' palates and healthy. In particular, studies are underway in the USA to develop technologies that use low fat. When the biscuit sector is examined closely, it is seen that the fastest growing part consists of low-fat or fat-free products. Biscuits are carbohydrates and can be applied when you consume a biscuit containing carbohydrates during the day and eat a normal protein-containing meal for dinner, provided that it is not too long-term. However, this biscuit is not suitable if it is sugary and solid oily. However, if it is a biscuit with vegetable oil, oat bran, whole wheat flour and dried fruit, it can be used for dieting (Dangelico et al., 2024; Honrado et al., 2024; Kayode et al., 2024).

Daily bread consumption varies according to the characteristics, habits, lifestyle and work style of individuals and the composition of their diets. Those who do a lot of physical work consume more bread than those who do little physical work because they spend more energy. Especially in the summer months, those working in agriculture and construction work skip one or two meals with foods such as bread-fruit, bread-vegetables, bread-cheese instead of cooked meals. Bread has an important place in the fast-food system. Again, while watery meals increase bread consumption, the inclusion of waterless foods and dishes such as rice, pasta, pastry and desserts on the menu decreases bread consumption. In general, the raw material of bread is wheat flour. Additionally, the amount of pulp formed by carbohydrates that cannot be digested by enzymes in the body is also high in bread made from unrefined flour. On the other hand, energy value of wheat seed and rye-based breads is lower compared with white bread (Mesta-Corral et al., 2024; Norton et al., 2024; Rahmatjonovna, 2024).

Recently, a large group of cereal derivatives has been used for food purposes has emerged on the world food market. In addition to oats, barley, sorghum, millet and other products, cereals, wheat, rice and corn, which are used as the main source, special breeding programs are being carried out to target varieties that can be used for these new products. These breeding programs are essential to find and develop a wide range of healthy-friend dietary products that contribute to physical wellness of human (Loskutov and Khlestkina, 2021). Composite flour is defined that is mixture by various types of flour (tubers, roots, cereals and legumes) obtained with or without the addition of wheat flour (Shittu et al. 2007; Hasmadi et al., 2018; Emmanuel et al., 2019).

Use of Legumes as Flour

Filling, protein-rich and available in many varieties, legumes are an indispensable food for humans. Gluten-free legumes are used in recipes at the same rate as a substitute for flour. Legume flour can enrich foods and provide an excellent gluten-free alternative to all-purpose flour or cornstarch. They will also add fiber, protein, and a host of nutrients to foods, whether they're soups, stews, or baked goods.

Consumers' demands for healthy nutrition have led to the emergence of a new market based on functional breads produced by partially or completely adding different flours as an alternative to refined wheat flour, which contains low levels of nutrients, dietary fiber and phytochemical compounds. Long cooking and preparation times that do not comply with consumers' modern lifestyle habits negatively affect legume consumption. In order to increase consumption, it is recommended that legume flour be included in daily consumed staple foods such as bakery products. The addition of legume flour to breads prepared on the basis of wheat flour affects not only the nutritional content of the bread but also its physical, chemical, functional and sensory properties (Boukid et al., 2019; Torbica et al., 2019; Bojňanská et al., 2021; Mariscal-Moreno et al., 2021).

In the studies, it has been stated that the “grassy”, “green”, “earthy” and “bitter” structures that will emerge only in relation to the use of legume flours (Frohlich et al., 2021) may negatively affect the acceptability of the products by the consumer. Low-cost flour obtained by fortifying different legumes with grains contributes to the improvement of the nutritional quality of wheat products (Levent and Yeşil, 2019; Urigacha, 2020).

It's a versatile supplement for a powerful diet and gluten-free lifestyle. As the popularity of plant-based diets increases, so too do the high-protein, low-fat, fiber-rich legume flours. On the other hand, it has been stated that it is possible to improve both the functional and chemical properties of cereals and legumes by germinating the grain (Kılınçer and Demir, 2019).

Researchers Dhingra and Jood (2001) stated that wheat is considered poor in terms of nutrition and lacks the amino acids threonine and lysine like other cereal proteins. Therefore, supplementing wheat flour with legume flour or some other sources leads to an improvement in the nutritional value of wheat products (Kahraman, 2023; Torheim, L.E., Fadnes).

Some legumes (Zhao et al., 2019; Schmelter et al., 2021) and especially chickpeas, which are commonly preferred over the world, generally have a less glycemic-index compared with cereals (Cappa et al., 2020; Di Cairano et al., 2020). Legume-enriched products have been characterized by consumers as having a desirable "roasted-like" flavor (Young et al., 2020; Kotsiou et al., 2021).

Effects of Chickpeas on Flour Quality and Various Areas of Usage

Cereals are in the first place in the world field crops production areas, followed by food legumes. Food legumes are essential products owing to their rich nutritional value, their effectiveness in reducing fallow lands, their contribution to employment, and their export potential. Chickpeas have become an important part of human nutrition and are grown in more than 50 countries today. India is known as the largest producer of chickpeas. Per capita chickpea consumption has changed as 4.9-5.8 kg $year^{-1}$ for 5 years and was 5.1 kg $year^{-1}$ in 2020 year. For 2020/21 marketing years, sufficiency ratio decreased as 4.07% compared with the previous year and reached by 122.3% ratio (FAO, 2024).

The first thing that can be said about chickpea flour is that it is gluten-free, which makes it an ideal option for those who need to stay away from gluten. Being an extremely good source of fiber, it supports the regulation of the digestive system. This can improve bowel movements significantly. It is also used as a mask by many people. Chickpea flour mask also has beneficial properties for skin health. In addition to these, it is an important food because it makes humans feel full. For this reason, it finds its place in diet programs. Various recipes can be made with chickpea flour by people on a diet (Parenti et al., 2024; Suo et al., 2024).

Chickpea flour is quite good as a protein source, minerals, fiber and bioactive compounds and can be used to enhancement of nutritional value in the bakery products such as bread, biscuits, etc. foods. According to the results of studies conducted on the subject, the chickpea flour including pasta showed increase in stickiness, increased fat, protein and minerals, and decreased also the glycemic index (Padalino et al., 2015). In a cereal flour mixture made using chickpea flour, it was determined that all of fortified breads presented improved nutritional value depending on the level of chickpea inclusion. In previous studies, the additional 15% ratio by chickpea and 20% ratio by lupin flour to wheat breads also presented quite significant rise on estimated value of PDCAAS (Corrected Amino Acid Score) for final products (Guardado-Felix et al., 2020).

Chickpeas are quite rich by minerals and vitamins (Table 1), they contain choline, which helps the nervous system in the brain function smoothly. Chickpeas are high in fiber, so you may need to be careful when consuming them. Excessive fiber intake can cause stomach discomfort, diarrhea, and bloating. In addition, persistent stomach cramps can occur. Chickpeas, a relative of soybeans, can cause allergies. If you are allergic to a type of legume, you should definitely do the relevant tests before consuming chickpeas. Chickpea allergies can be seen on the skin and can bring symptoms such as nausea, diarrhea, itching, or coughing (Abu Risha et al., 2024; Kakaei et al., 2024).

Table 1. Composition per 100 g edible portion (Food Standards Agency, 2002: McCance and Widdowson's The Composition of Foods)

Components (units)	Chickpea (Dried, boiled in unsalted water)	Chickpea (Flour/ besan flour)	Wheat germ	Wheat (brown)	Wheat (white, plain)
Water (g)	65,8	10,00	11,7	14,0	14,0
Total nitrogen (g)	1,35	3,15	4,54	2,20	1,64
Protein (g)	8,4	19,7	26,7	12,6	9,4
Fat (g)	2,1	5,4	9,2	2,0	1,3
Carbohydrate (g)	18,2	49,6	44,7	68,5	77,7
Energy (kcal)	121	313	357	324	341
Energy (kJ)	512	1328	1509	1384	1450
Starch (g)	16,6	43,8	28,7	66,8	76,2
Total sugars (g)	1,0	2,6	16,0	1,7	1,5
Glucose (g)	Trace	Trace	0,7	Trace	Trace
Fructose (g)	0,1	0,2	0,5	Trace	Trace
Sucrose (g)	0,9	2,4	14,8	0,7	0,3
Maltose (g)	0	0	0	0	0,2
Lactose (g)	0	0	0	0	0
Dietary fiber (g)	4,3	10,7	15,6	6,4	3,1
Saturated fatty acids (g)	0,2	0,5	1,3	0,3	0,2
Monounsaturated fatty acids (g)	0,4	1,1	1,1	0,2	0,1
Poly-unsaturated fatty acids (g)	1,0	2,7	4,2	0,9	0,6

Cholesterol (mg)	0	0	0	0	0
Na (mg)	5	39	5	4	3
K (mg)	270	1000	950	250	150
Ca (mg)	46	180	55	130	140
Mg (mg)	37	120	270	80	20
P (mg)	83	340	1050	230	110
Fe (mg)	2,1	8,3	8,5	3,2	2,0
Cu (mg)	0,28	0,62	0,90	0,32	0,15
Zn (mg)	1,2	3,1	17,0	1,9	0,6
Cl (mg)	7	60	80	45	81
Mn (mg)	0,7	2,1	12,3	1,9	0,6
Se (µg)	1	2	3	4	2
Retinol (µg)	0	0	0	0	0
Carotene (µg)	23	60	0	0	0
Vitamin D (µg)	0	0	0	0	0
Vitamin E (µg)	1,10	2,88	22,00	0,60	0,30
Thiamin (µg)	0,10	0,39	2,01	0,39	0,31
Riboflavin (µg)	0,07	0,24	0,72	0,07	0,03
Niacin (µg)	0,7	1,9	4,5	4,0	1,7
Vitamin B_6 (µg)	0,14	0,53	3,30	0,30	0,15
Vitamin B_{12} (µg)	0	0	0	0	0
Folate (µg)	66	180	N	51	22
Pantothenate (µg)	0,29	1,59	1,9	0,4	0,3
Vitamin C (µg)	Trace	Trace	0	0	0

As it seen on Table 1, regular consumption of chickpea flour is one of the effective methods to reduce bad cholesterol and reduce the risk of heart disease. Chickpea flour, which is also high in iron, is beneficial in strengthening the immune system. Another beneficial active ingredient in its content is fiber and fatty acids (Augustin et al., 2024; Kaluzhskikh et al., 2024).

Starch is an important part of a healthy diet and has many benefits. However, excessive use can lead to some negative consequences. On the other hand, biscuit consumption is increasingly seen in society. Therefore, the starch in consumed biscuits should present slower digestion characteristics (Jia et al., 2020). The use of blends of whole grains and wheat flour with some legumes or other cereal grain flours in foods has improved functional and nutritional properties (Wang et al., 2020).

Chickpea starch has higher amylose and resistant starch (which aid in weight loss and heart health, provide blood sugar control, increase insulin sensitivity and support digestive health) content (Kaur and Prasad, 2021). Therefore, chickpeas are used in many various floury food types (Altaf et al., 2021). In addition, intensive studies are being focused on effects of germination as physicochemical, structural, techno-functional and digestive features of chickpea flour, and it has been emphasized that studies should be carried out to improve the sensory qualities in breads produced from gluten-free flours (Yıldırım and Nadeem, 2019). By removing endogenous non-starch components, a significant increase in starch digestibility has been achieved (Yang et al., 2021).

In recent years, due to the interest in the functional protein characteristics, the use of chickpea grains inside composited flour for several formulations has been increasing. As the proportion of chickpea flour increases in cereal-based products, the carbohydrate content decreases. In general, legumes and especially chickpeas increase the content of protein and can increase the nutritional quality in cereal including foods (Patane, 2006). In addition, various studies have been carried out on important issues such as the evaluation of chickpeas as a type of encapsulation technique, complex coacervation (Adal, 2022), and the evaluation of the protein extracted powder taken from stale breads and the participation of chickpea flour in wheat-based flour (Şişman et al., 2022).

Conclusions

Flour obtained by grinding is the raw material of bread, which is a basic foodstuff in human nutrition, and is a basic foodstuff with high nutritional value. In recent years, with changing environmental conditions, developing technology, increasing competition at national and international levels, and increasing consumer awareness, the search for alternatives to grains in flour production has become a necessity rather than a choice. In this respect, legumes stand out with their essential importance in many areas in terms of the concept of sustainability, and they are also of great importance in terms of their use in flour production.

Legumes are extremely rich by protein, lysine, dietary fiber, unsaturated type fatty (oleic and linoleic acid) acids. As an important legume, chickpea (*Cicer arietinum* L.) is widely consumed in nutrition in various forms around the world. Chickpeas are used in fast-food products as well such as pasta, biscuits, chips, grain-based foodstuffs, various snacks, partially the flour of wheat substitute and gluten-free product production. Chickpeas can also be evaluated by going through a number of processes (thermal, physical, biochemical) in order to increase its digestion ratio and elimination of various anti-nutritional compounds. With regards of the increase in request for consumers to alternative products, products with high chickpea content are being developed for developing of grain-based products with increased nutritional value, and various studies have also revealed that chickpeas have acceptable sensory properties. To promote the incorporation of wheat bread which includes chickpea flour with reformed nutritional amount, it is necessary to focus on what kind of effect the rheological qualities of doughs produced from composite flour and the physicochemical properties and storage life of the products produced in this way have. In this work, current scientific studies on chickpea flour are evaluated.

In the world agricultural product market, legumes have been the market that has gained the greatest advantage with the global pandemic. Due to their long shelf life and being a protein-rich food source, there has been a significant increase in demand for legume products during this period. In general, food grain legumes have lower unfavorable environmental effects by means of greenhouse gas output and carbon footprint, energy use, land use, eutrophication (damage to aquatic ecosystems) potential and acidification potential (loss of calcium from bone and decay) per serving. Legumes have long storage life and are year-round food sources. The multidimensional aspects of legumes, including chickpeas, in terms of sustainability contribute to a healthy planet and healthy people.

Legume flour is an appealing option because of its variety and simplicity, as well as its many health benefits, from antioxidants to plant-based protein. From chickpea flour to black bean flour and just about everything in between, this versatile ingredient is ready to give your meals a generous boost of nutrients and flavor.

Future research needs to focus on sustainability. The importance of food grain legumes in sustainable agricultural systems, tolerance to biotic and abiotic stress conditions, and breeding and agronomy issues in terms of bioactive components and sustainability of human health and security should be investigated more extensively.

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Chapter 16

Types of Nanoparticles Used in Hydroponic Systems

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1. Introduction

Nanoparticles exhibit unique physicochemical properties depending on their size, shape, and total surface area exposure (Raliya et al., 2015). These unique properties make them attractive in hydroponics by enhancing nutrition availability and having antimicrobial effects. Commonly used nanoparticles in hydroponics include copper nanoparticles, silver nanoparticles, and iron nanoparticles. Among these examples, silver nanoparticles are the most used due to their extraordinary chemical and biological properties and low environmental impacts (Sharma et al., 2019).

Copper nanoparticles work as an antimicrobial in hydroponics. They adhere to bacterial membranes and cause cell cluster damage (Santos et al., 2021). The damage to epiphytic lettuce bacteria causes a decrease in histamine levels. In another study, copper nanoparticles were used as a foliar fertilizer solution in a trial and suggested enhancing economic and nutritional benefits and increasing the market quality of baby leaf lettuce without a reduction in pathogen populations (Nawaz et al., 2020). Silver nanoparticles are used in hydroponic systems for their antimicrobial properties and nutritional benefits as antioxidants. The use of silver nanoparticles elevated redox proteins and increased microbial content in lettuce leaves (Patra et al., 2021).

1.1. Metal and Metal Oxide Nanoparticles

Since the use of nanomaterials started in agricultural research, which is not more than 15 years ago, the most common nanoparticles that have been tested are metal and metal oxide nanoparticles (Raliya et al., 2015). In order to attain these kinds of nanomaterials, nanoparticles are usually produced by the reduction or synthesis of components that are dissolved in solvents. Silver, gold, and iron dissolved and placed into a safe and sustainable solution can be consumed by plants without negative effects, also because the amount of nanostructures introduced to the media is very low (Rico et al., 2011).

Nanoparticles' broad selection of applications is due to their small size, large surface area, and improved chemical behavior in comparison with the same material in bulk. These nanoparticles are largely utilized to avoid ethylene during storage by penetrating *Lablab purpureus L.* seeds, because working at lower concentrations of ethylene than the reference intensifier is likely due to signal inhibition with several ethylene sensors and not by an increase in energy production (Li et al., 2013). The change of seed and fruit is achieved by downregulating ethylene and altering the cascade activity from sensor to the *cis*-transactivation element of inconsistency. Additionally, these nanoparticles penetrated IV and V tissues of *Lablab purpureus L.* seeds when absorption has been revealed.

In the case of plants, they assimilate the metal or metal oxide nanoparticles, which may change plants' metabolism and growth, with potential reinforcement that is positive under stress and negative under control conditions (Khodakovskaya et al., 2009). Due to their small dimensions, nanoparticles can infiltrate and transpire through roots and shoots. It has been revealed in many studies that nanoparticles can combine with roots and, afterwards, penetrate endodermal and cortical tissues. Whether nanoparticles can penetrate interior cell tissues has been revealed by passive adhesion-based extraction technologies and 3D projection microscopy, but it is still difficult to detect how rare this penetration is.

To some, metal and metal oxide nanoparticles are toxic or damaging to plants due to their diffusion to cells, causing oxidative stress and interacting with enzymes that may affect their activity (Rico et al., 2011). Oxidative stress may be due to metal ion release after nanoparticle oxidation. This idea came from the alteration of water plasma aggregation in the vicinity of hydroxyl gradient wells in hydrated titania nanoparticles under light. These nanoparticles are predominantly employed for their photocatalytic characteristics, breaking down pollutants and improving disinfection under ultraviolet light. Under this condition, it has been found that interest is reduced when it is applied to a hydroponic solution (Raliya et al., 2015). Some of the larger metal species might not work on plant roots in the short term when in a colloidal solution.

1.1.1 Applications of zinc oxide (ZnO), iron oxide (Fe_2O_3), and silver (Ag) nanoparticles.

Efforts for the applications of nanoparticle (NP) based Ag, ZnO, Fe_2O_3, and chitosan on seeds and seedlings in hydroponic systems for different stages of the crop life have been recently reported (Raliya et al., 2015; Singh et al., 2018). The utilized metal nanoparticles in factories are Ag, Cu, Au, and Zn, mainly the latter in nano-forms ZnO as antimicrobial content and also to protect the products. This makes it possible to work with these nanoparticles and their variants (metal NPs, doped or coated, 1-, 2-, 3-D, crystals, aggregates), not only in this type of dynamic experiment in plants on substrates such as hydroponic systems but also on soils, with their possible negative consequences for the soil (Shah & Belozerova, 2009).

These metals produce the required electron transfer capacity for photosynthesis and cellular respiration reactions due to their redox properties that characterize them (Prasad et al., 2012). The objective of this work was to detect any reaction variables with these nanoparticles prior to their utilization on crops such as radish plants.

1.2. Carbon-Based Nanomaterials

Over the past two decades, carbon-based nanomaterials have received much attention in various research areas, including environmental science and soil-crop interactions (Khodakovskaya et al., 2009). Additionally, the nanotechnology revolution has the potential to influence markets with new materials such as fullerenes, nanotubes, and graphene.

The appealing properties of carbon-based nanomaterials, such as high electrical and thermal conductivity, good chemical stability, large surface area, and high mechanical strength, have allowed them to be employed in several fields in recent years, including fuel cells, batteries, catalysis to increase the efficiency of numerous processes, capacitors, alloys, corrosion protection, biofabrication of scaffolds for tissue engineering, biosensors, and as a platform for drug delivery systems (Kumar et al., 2017).

The use of these carbon-based nanomaterials in hydroponic systems has preserved the nutrition of different plant species and helped to overcome issues in power hydrodynamics. Several studies have confirmed their effect on root hairs, growth hormone synthesis, root elongation, cell division, and food conductance, but the possible toxic properties of these nanoparticles may suppress stomatal conduction in plants and reduce mineral uptake, especially in radishes (Zhao et al., 2012).

Not much is known about the impact of fullerenes, nanotubes, and graphene on the soil ecosystem, biological variation, changes in composition, structure, metabolism, and function of the soil microbial population, plant growth, the diversity of soil-dwelling roundworms or earthworms, or the effect on soil biogeochemical processes. The complexities of studying the effects of carbon-based nanomaterials in hydroponic systems have led to conflicting results and different outcomes; it is not always clear whether they are influenced by surface property modifications or by changes in the physical, chemical, and colloidal characteristics of the nutrient solution (Rico et al., 2011).

1.3. Biopolymer and Hybrid Nanomaterials

Biopolymer and hydrogel-based nanomaterials are based on polymers that demonstrate a behavior similar to that found in nature (Ahmed & Ikram, 2015). In the first case, nanocomposites are obtained by specifically mixing a biopolymer with inorganic nanoparticles. In hydrogels, when the proportion of biopolymer increases, so does the overall mass of the hydrogel, with the inorganic nanoparticles filling up the empty spaces in the biopolymer framework (Thakur & Thakur, 2018). In both cases, the polymer network contributes to increased polymer density, particle aggregation, and better stability in water. This fascinating behavior opens up new possibilities for their use as a medium and fundamental component in biotechnological applications, from drug administration to a variety of polymers to biocatalysts, and even biotechnological treatments.

However, the main disadvantage of polymer or hydrogel-based nanomaterials in agriculture comes from their fast pore blocking capacity, which in turn means that the metal or ceramic nanoparticles used in their composition are the best compromise to ensure long-term use when mixed in soil or in granule formulations of slow-release fertilizer/pH controllers (Zulfiqar et al., 2019). This nanoparticle-based blocking effect becomes an advantage when such nanomaterials are used in hydroponic cultivation systems. The protection of the supplies' root zones from hydroponic system failure due to pathogens and the nutrition increased permanence are paramount for the full-scale operation of these types of plant cultivation industries. The use of nanoparticles for developing innovative nanomaterials with higher porosity and broader nutrient and water reabsorption has been widely explored.

2. Application Techniques

Application methods are a very supportive part of hydroponic technology for applying the nutrient solution to the root zone, including drip, ebb and flow, open and closed channel, floating raft, nutrient film technique, and aeroponic systems (Jones, 2021). While several factors are important for selecting the best method for growing plants in a hydroponic system, they are generally classified based on aggregate or occasionally on the solution culture. Some studies used very complex irrigation systems that depend on the method used inside the hydroponic system, like drip or ebb and flow, and also on the size of the solution.

Flat distribution irrigation processes are used for filling up level vessels or channels with thin solutions. Watering techniques include actions like irrigation of rows of pots that hold the crop, or fine spray or mist. Devices that form a pressurized mist, quantity, or aerosol droplets include mechanical stir, the particle neutralization chamber, or steam injection (Resh, 2012).

Traditional passive methodologies applied through the use of floats or capillary pads are easy and inexpensive to utilize, although they can generate root hypoxia and allow for the growth of algae and odoriferous bacteria under certain environmental conditions (Savvas et al., 2013). Passive systems with fixed emission flow, like capillarity, free drainage, and capillary flow barriers for copper and silver nanoparticles applied to the nutrient solution, were used in many previous studies, although they are only able to flow after returning to the original level. Systems with trays or horizontal channels immerse the roots in the nutrient solution, and when they are plunged, some roots grow in the air to absorb oxygen, where the thick-walled tubes were utilized as well.

However, they need aerators due to the high probability of root asphyxiation if the power supply is cut. The system with the booster pump assures uniformity without hydraulic head drop. The well-circulated solution enhanced gas permeability even in the absence of electric energy, maintaining the oxidation reduction potential between 330±20 mV and the idea of reduced nutrient solution costs (Resh, 2012).

2.1. Direct Addition to Nutrient Solution

Direct addition of nanoparticles or other nanoscale materials to the nutrient solution is a straightforward way to introduce NMs into a hydroponics-based plant study. However, direct addition may also result in the accumulation of NMs in the plant tissues or even transformation of NMs (or their byproducts) into a more phytotoxic form because of physicochemical and other biogeochemical processes occurring in the nutrient solution (Rico et al., 2011; Ma et al., 2010).

Nanoparticles, for example, were found to dissolve in nutrient solutions and subsequently release ions in the nutrient solution at concentration levels high enough to harm the plants. Testing of a specific concentration of nanoparticles in a nutrient solution found that they were taken up by plant roots and then accumulated in parts of the plant such as stems and leaves (Dimkpa et al., 2013). Uptake occurred as nanoparticles dissolved and released ions in the growth media.

The comparison of the usage of dry nano-sized materials in nutrient solution versus in fertilizer slurries on plant growth and acquisition revealed that the use of dry nanoparticles led to improved growth and higher content in the plant leaves compared to materials delivered in the form of a suspension (Zhao et al., 2012). However, certain elements can also possess the ability to generate nanoscale species and colloids in the nutrient solution when respective species were small-sized, which may alter the metal availability in solutions and the resulting bioavailability in the plant.

Overall, although direct addition provides advantages of straightforward concentration determination and less artificial manipulation, it is recommended to be cautious of physicochemical transformations that occur in the nutrient solution and the unexpected effects on the phytotoxicity study systems using this dosing route (Zulfiqar et al., 2019).

2.1.1. Homogeneous mixing of nanoparticles into the nutrient solution

The most common method reported to disperse nanoparticles in a nutritive solution is to add them directly. The addition must be accompanied by continuous shaking to induce the dispersion process and to guarantee a homogeneous nutrient solution (Nair et al., 2010). This method is used when the nutritive medicament must be manipulated outside the culture room, such as the reuse of nutrient solution between different production periods of vegetable seedlings, and is widely applied. When applied, the procedure minimizes the direct contact of small seedlings and nanoparticles at high concentrations, which could cause differing stress responses. Additionally, the direct contact of small seedlings with clumps of nanoparticles is minimized.

After the addition of nanoparticles, the nutrient solution is always kept holding sufficient turbulence to prevent the formation of aggregates in contact with the air, guaranteeing the useful suspension of the particles (Ma et al., 2010).

Another proposal is an alternative method of dispersal, which aims to promote a more uniform dispersion of the nanoparticles in the nutrient solution. This method consists of the use of a pre-dispersion, obtained by diluting the extract in the solution, and ultrasound, with shorter exposure for a homogenization process generating a more suitable nanoparticle suspension (Buzea et al., 2007). With the application of the pre-dispersion, a more homogeneous distribution of nanoparticles in hydroponic systems is obtained in multiple replicates, mainly avoiding prolonged direct contact between the nanoparticle-containing solution and the young seedlings, consequently reducing physiological stress.

With the application of sonification, lower exposure conditions increased the load/surface area ratio of the nanoparticles in a more homogeneous manner, without the need to directly add individual nanoparticles. The use of the pre-dispersion and sonification decreased contact with the nutrient solution and the integrity of nanoparticle dispersions (Khot et al., 2012). It is necessary to adequately disperse nanoparticles in nutrient solutions and responsibly introduce them into hydroponic systems to improve their production and stability and protect the health of biological systems.

2.1.2. Effects of nanoparticle concentrations on plant development

NPs have been used for various purposes in some studies because they may have a content-specific effect, i.e., they may react differently at different concentrations, either as a poison, a nutrient, or an enhancer, as growth promoters (Dimkpa et al., 2013; Tripathi et al., 2017). For instance, using a mixed suspension of CuO NPs at 0.1 g L^{-1} had a stimulatory effect on biomass production in sunflower plants, but any higher concentration inhibited growth. $CdSO_4$ and Cd NPs were used to evaluate their possible uptake by a number of vegetables, and it was found that although vegetable exposure to Cd NPs was less effective than that of $CdSO_4$, Cd was detectable in the plants. It had a severe inhibitory effect on root growth in lentil plants (Peralta-Videa et al., 2011). By contrast, SiO_2 NP amendments at 300 mg Si kg^{-1} soil could improve the shoot and root biomass of *Cucumis sativus* L. (Nair et al., 2010). The lowest and highest SiO_2 nanoparticle application concentrations were used as controls in the study.

3. Environmental and Ecological Impacts

Nanotechnology has been progressing rapidly, and many nanoproducts have been introduced for the benefits of agriculture. Despite the reported potential negative consequences of nanotechnology, ecological studies addressing the environmental and ecological implications are extremely rare (Rico et al., 2011; Schwab et al., 2016). The volatility of nanoparticles may lead them to move into the environment and induce adverse effects through direct contact, egestion of particles, contamination of food and water sources, or through contact with other plant cells or tissues.

The emergence of nanotechnology is introducing several new dimensions to managing plant nutrient and mineral element disorders. Ultimately, responsible use of these new tools will require a systems approach to nutrient management. Future studies investigating the environmental or ecological impacts of nanomaterials are clearly needed, and these should focus on areas where the potential for impact is greatest, such as variance of elemental or ion transformation (Khot et al., 2012).

Increased movement of nanoparticles to soils with soil amendment and off-target movement of nanoparticles in pesticide or synthetic hormone application is likely a phenomenon that could affect soil and aquatic life (Khot et al., 2012; Schwab et al., 2016). As nanotechnology develops, the amount of natural and newly generated nanoparticles will increase naturally. Innovative research will be critical to advance understanding of the environmental and economic impact of nanomaterial applications, to determine under which conditions, if any, the use of nanomaterials presents a risk to broad public and environmental health, and to advance the safe and responsible use of nanotechnology in agriculture (Rico et al., 2011).

Yields are urgently needed to narrow the scientific gaps to understand the exchanges and destiny of nanoparticles in the environment and determine the conditions that govern their movement among above-ground and below-ground compartments. The present scientific gaps significantly limit the ability to perform environmental and ecological risk assessments. Such concerns continue to grow, with far-reaching links between composition, soil microbes, and plant interactions (Tripathi et al., 2017; Wang et al., 2016).

Without consistent and accurate methodologies designed to address key scientific gaps, the ability to study nanoparticles and fully map the complex nano-biogeochemistry and effects in the environment will remain limited. If these gaps are bridged, many of the advantages and innovations that made nano-based materials attractive for agricultural and most other applications will become a reality and could prove transformational for society at large.

3.1. Impact of Nanoparticles on Soil and Water Ecosystems

The concept of the adverse effects of human activities on the environment forcing scientists to find new materials that can replace the existing ones provides a great impetus to the development of nanotechnologies. Nanoparticles and nanomaterials have found an increasing number of applications in different industries, leading to enhanced properties of various products and improving their quality (Klaine et al., 2008). On the other hand, one of their undesirable effects is their release into the environment and interaction with soil and water ecosystems as a result of their use.

Their effect on the life-supporting system is relatively unknown and requires continuous scientific investigation. In this line, many studies have been carried out in order to elucidate the behavior of different nanoparticles when they come into contact with terrestrial and aquatic organisms, their potential toxicological effects, and possible ways to reduce adverse environmental effects (Lowry et al., 2010). In the current work, the use of nanoparticles in hydroponics and their influence on the toxicity to organisms, establishment of microorganisms and plants, water quality, and ecological functions of the water were studied.

The environmental impact of nanoparticles has undergone a rapid assessment in recent years. It has been clarified that their release into the environment, in particular in different water streams, is an inevitable event because of their increasing uses (Gottschalk et al., 2013). It has been reported that the concentrations of manufactured nanoparticles in several products lead to the production of effluents containing them during the use and end of life of the final product. The incineration and landfilling of products containing different nanoparticles resulted in leaching and release of nanoparticles into soils and groundwater (Nowack & Bucheli, 2007).

However, other sources of nanoparticles in the environment include fertilization, and the flooding of rivers by contaminated soils leads to their dispersion (Bundschuh et al., 2018).

3.1.1. Potential environmental effects of nanoparticle leakage through hydroponic wastewater

A. Peyrot reviewed the emerging applications involving the use of nanoparticles in hydroponic systems. Although the released nanoparticles tend to aggregate and can be collected by the root system during the circulation process, the possible health and environmental risks deriving from nanoparticle leakage have also been analyzed (Gottschalk et al., 2013). Long-term toxic effects have yet to be elucidated correctly. Some metal oxide and Ag nanoparticles can accumulate in the plant, and unlike organic compounds, they do not mineralize, leading to phytotoxicity from the metallic ions concerned (Lowry et al., 2010). Others are generally adsorbed onto the root systems.

Furthermore, the intrinsic characteristics of hydroponics favor the aggregation of nanoparticles and therefore their potential to avoid release into the environment. Appropriate post-harvest management of both solution and roots is suitable for selecting and reducing the amount of nanoparticles loaded into the plants (Nowack & Bucheli, 2007).

A preliminary leaching test involving the pilot-scale hydroponics system allowed us to observe that the concentrations of nanoparticles in the wastewater after six months of continuous use are considerably lower than the values generally reported. An application modeling insight has indicated that the environmental fate of a synthetic nanoparticle inside a hydroponics experimental setting may differ from the environmental fate anticipated under equivalent treatment conditions without the wastewater (Bundschuh et al., 2018).

High stabilization media efficiency and hydroponics with encapsulated biofilter operation enabled a significant reduction of nanoparticles in the solutions and promoted very low toxicity to the plants. The results suggested that open-loop hydroponics should be feasible in real open systems and reveal the predicaments and growth points identified during the process.

3.2. Effects on Plant Microbiota

The rhizosphere has been a subject of interest as far as the study of plants and nanoparticles exists; in that matter, the performance of plant growth. The study of the complex relationship with its microbial fraction is also relevant for several reasons. The plant and the microbiome can communicate through specific mechanisms, where the plant signals partly trigger root exudation, which is essential for shaping the rhizosphere microbiome (Compant et al., 2010). In the other way round, the colonizing microorganisms can provide nutrients and environmental protection against potential stress factors.

Nanoparticles can have an effect on the plant rhizosphere. The structure of the rhizosphere microbial community was greatly modified by nanoparticles, affecting the specific trace element cycling that certain microorganisms perform, like the methanotrophic ones (Kumar et al., 2017). This influence of both nanoparticles was due to changes in the root exudate pattern.

Similar studies carried out with nanoparticles showed divergent results regarding their bactericidal capacity. In *Arabidopsis*, after exposure to certain concentrations, both the soil biota and the plant roots were affected. The soil microbiome was profoundly altered, reducing the abundance of specific species that could be involved in both nitrogen and carbon cycles (Ge et al., 2011). These results did not correlate with the plant pathogenicity observed with the model system used.

It has also been reported that an excess of nanoparticles can hinder the rhizobia-plant interaction. The long-term effects of certain elements at low levels have to be approached as well. This can be relevant with NP-modified plant exudation, which elicits soil microorganisms preferably beneficial for plant growth (Mahmoudi et al., 2013). Earlier germination of maize seeds exposed to certain nanoparticles was observed. On the other hand, some prokaryotic microorganisms require heavy metals, which can also function as cofactors in metalloenzymes.

3.3. Toxicity and Safety Concerns

Nanoparticles have been reported to have beneficial effects on some types of plants at low concentrations. However, toxic effects have also been reported. In the present study, no toxic effects of nanoparticles were found in any of the parameters studied for the plant, nor for the plant water intake, nor in the chemical composition of the water consumed by the plants (Tripathi et al., 2017).

Since the intake of nanoparticles cannot be controlled when they are found inside fruits or vegetables, it is necessary to increase studies on the effect of the consumption of nanoparticles present inside the plants and the possible damage that this consumption could cause on human health to guarantee the safety of any nanoparticle treatment of plants used before they are commercialized (Klaine et al., 2008). Any other application of nanoparticles in crop irrigation must follow the same procedure, not inducing crop or human toxicity.

Many industrial applications of nanoparticles involve their incorporation into different consumer products. Consequently, the risk that nanoparticle residues may reach humans is not insignificant, and potential toxicity must be ascertained. A few studies have addressed the problem of the effect of nanoparticles on crops in soil. However, the number of studies dealing with hydroponic systems is limited.

The use of manufactured nanoparticles in agricultural practices has some associated benefits. It can alter the obtained yields, the crop's resistance to biotic and abiotic stress, the bioavailability of the nutrient elements, and the necessary dose for the fertilizer required (Rico et al., 2011; Nair et al., 2010).

4. Future Perspectives and Research Areas

There are many current attempts to apply nanoparticles, especially for enhancing the growth and/or yield of protected crops. Based on the approaches of the reported applications of nanoparticles in hydroponic systems, the possible future perspectives or research areas can be summarized as follows:

Embrace the inherent environmental benefits of hydroponic systems. To provide a real solution to the future guarantee of the sufficient supply of food, the development of environmentally friendly strategies or approaches is essential (Raliya et al., 2015). Hydroponic systems can be a wise choice among the potential agricultural techniques. However, to further win larger market shares, the economic advantages are still not guaranteed. Researchers should focus their attention on the research for effective management systems or products to optimize the potential yield of the hydroponic growing systems, which should partly result from the selection of the appropriate and effective materials or chemicals in agricultural production (Khot et al., 2012).

We not only should embrace the inherent environmental benefits of hydroponic systems but also should take advantage of the integrated controlling ability and the smart nature of the systems to further improve economic profitability. To actually figure out the real changing mechanisms of the nanoparticle application, it is necessary to address concrete economic traits in hydroponic crops subjected to different nanoparticle treatments, since very few reports are available and the results found are sometimes scarce and contradictory (Tripathi et al., 2017).

To accumulate results that can be used to define correct window applications and to establish the recommended dosages and final nanoparticle concentrations applied, the nanoparticles need to be delivered and tested in practical static NFT (Nutrient Film Technique) and DFT (Deep Flow Technique) hydroponic devices with sustainable and low-cost recycling capabilities.

The low-cost employment of magnetic nanoparticles could possibly become a convenient driving approach in order to reduce the nanoparticles recollection and repeated matrix applications (Mahmoudi et al., 2013). The development of recycling magnetic conduits underlines the importance of the further application of other nanoparticles. These goals have to be considered in order to improve the economic feasibility of such techniques as required by the smart agriculture framework.

4.1 Standardization of Nanoparticle Concentrations and Types

It will be necessary to test a wide range of concentrations of each type of nanoparticle before being able to obtain the right amounts for the successful use of ENM on plant systems. A good starting concentration range would be the same used in other systems, and normally those ranges would be 0, 1, 10, 50, 100, 200, and 300 mg of nanoparticles per kg of plant dry mass, or even up to 500 and 1000 mg for some specific ENM (Tripathi et al., 2017). An overall estimation of doses in nanomolar and micromolar amounts of nanoparticles might also be tested in order to have an idea of the response of the nanoparticles as they are inserted into the plant.

Different working concentrations of nanoparticles may be tested to find specific effects, which may include growth stimulatory or inhibitory effects, higher sturdiness, lateral root abnormal development, top or base shoot effects, incidence of diseases, parasite attraction, and induction of systemic resistance or stress response (Nair et al., 2010). Other more specific effects indicating the presence of nanoparticles on treated plants will also be recorded in both single and combined treatments, and would include, among other parameters, changes in osmotic pressure on roots and tips, uptake and transport defects, early root malformations, and higher vulnerability evidenced in either smaller or larger leaf area.

4.2 Commercial Potential of Nanoparticle Applications in Hydroponics

This chapter provides an overview of the key recent advances in nanoparticle applications in hydroponics and their possible effects on the nutritional content of crops and environmental safety. Metal, metal-oxide nanoparticles, and carbon-based nanoparticles are discussed, followed by their applications in hydroponics (Khot et al., 2012). The nanoparticles have drawn special attention from researchers in hydroponics because of their unique physicochemical properties that contribute to increasing efficiency in crop production. However, their potential applications for commercial purposes, as well as safety and regulatory aspects, are not fully understood yet.

The potential applications of nanoparticles in hydroponics are huge: enhancing crop productivity; seed priming with nanoparticles; leaf feeding—foliar spray or drenching with nanoparticles; soil, growth media, or substrate amendment using nanoparticles; water preparation using nanoparticles—fertilizer mixing, irrigation, or solution storage; and plant-root surface modification with external nanoparticles (Raliya et al., 2015). Nanoparticles are used to promote germination, post-germination growth, flowering, fruit, and seed development, along with the yield.

The current requirements for fertilizing solutions to enter the engineered root in the plant are met and improved by the use of membranes of agglomerated nanoclays governed by principles of applied nanotechnology using nanoparticles (Sharma et al., 2019). With the advancement in nanotechnology, the root under the influence of the magnetic field is developed with the help of spiculated nanoparticles. The improved membranes are anticipated for implantable protection in water-culture containers and for the derivation, assessment, and selective characterization of targeted cells in the process of the transfer of standardized production methods.

4.3. Development of Eco-Friendly Nanomaterials

To seek an answer to environmental requirements for more sustainable materials, technologies that allow the use of more naturally abundant raw materials or facilitators that are less harmful to the environment need more attention. Among the different solutions that have been considered, environmentally friendly methodologies and the development of sustainable nanomaterials are of particular importance (Kumar et al., 2017; Raliya et al., 2015).

There is a growing interest in the development of sustainable and eco-friendly nanomaterials that can be potentially used as agricultural inputs to promote growth, manage plant defense, and protect the environment. The present trends are to develop green scalable processes that should be cost-effective and suitable for large-scale applications.

Key challenges that need to be addressed in sustainable nanomaterial design and technologies are related to the establishment of safer and faster industrial standards for their processing, to promote their up-scale production, to adhere to stringent regulations to list them as permissible, and to promote education and outreach for public acceptance (Sharma et al., 2019).

In essence, the parts that need to be more aware are related to raw material acquisition or depletion, manufacturing process sustainability, end-of-life disposal, and applications. Consequently, it is necessary to develop biobased constituents or constituents obtained from renewable feedstock sources and to develop green scalable manufacturing techniques.

5. Conclusion

Over the past decades, nanoparticles have been described as having useful plant beneficial properties and may enhance food production using protected strategies. The application of nanoparticles in agriculture is called nanofertilization (Tripathi et al., 2017). In this context, several studies have shown that the joint application of nanoparticles and phytohormones or nanoparticles and plant growth regulators demonstrated a cooperative effect, leading to a higher plant response.

In conclusion, available literature data encourages the use of nanoparticles such as nanostimulated compounds to promote plant growth in a new agricultural perspective. After the selection of the best combination of nanoparticles to induce the desired plant response, the importance of employing eco-sustainable materials and methods should be considered.

A greater knowledge of potential impacts and hazards associated with the application of nanoparticles to plants is due to toxicity studies (Khot et al., 2012). Taking into account the expected shortages of water and fertilization, the use of nanoparticles in the next-generation fertilizers should support more efficient and more sustainable strategies.

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Chapter 17

Effects of Different Light Spectra on Plant Stress Factors in Hydroponic Systems

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1. Introduction

Indoor farming systems such as hydroponics and aeroponics have been increasingly utilized to produce leafy vegetables in controlled environments. In hydroponic systems, however, several problems should be resolved to maximize their productivity and sustainability. For example, the shortage of labor for plant cultivation and plant denials have caused lowered production (Butturini & Marcelis, 2020). To cope with these issues, plant growers need to evaluate stress signals of the crops, such as wilting and falling leaves, and various nutrient deficiencies. Multi-parametric sensor systems enable us to frequently measure the fresh/dry weight, nutrient content, supply of nutrients, and active physiological responses in plants (Van Iersel & Gianino, 2017). Hundreds of sensors installed in the hydroponic system, however, may cause an increase in the cost per unit area. By evaluating the adaptability of plants to environmental changes and nutrient availability and stimulating internal antioxidant systems in plants, we believe that the plant stress signals can be identified with a limited number of sensors (Trouwborst et al., 2016).

The introduction of engineered LEDs in horticulture may contribute to providing the right light spectrum for plant growth. One of the most important aspects of developing red LEDs is to show strong growth, high efficiency, and a long life with a high utilization rate. This can then produce high biomass while requiring a small amount of energy (Hogewoning et al., 2012). In terms of required research for plant cultivation, the appropriate red light spectrum to regulate plant stress responses has not been efficiently developed. In addition, various environmental factors, such as temperature, humidity, CO2 concentration, and plant species, also need to be taken into account. There is general agreement among plant science researchers that light quality, intensity, and duration are important and that relatively minor modifications of these factors can result in large and rapid modifications (Massa et al., 2008).

1.1. Importance of light for plant growth

Sunlight is necessary for plants, animals, and humans to live. Plants, through the process of photosynthesis, absorb the light emitted by solar radiation and convert the light into necessary nutrients for life (Chen et al., 2016). Artificial light sources with rich light spectral properties can be used as a substitute for sunlight in controlled environment systems used for plant growth. At the same time, it can provide more suitable light for plant growth. Light sources often used in plant factories include fluorescent, high-pressure sodium lamps, and white LEDs. However, these light sources generally have high power consumption, significant heat generation, service life limitations, and narrow spectral properties. With the development of LED technologies, LEDs have become an artificial light source used in plant factories due to their lightweight properties, electrical savings, customizable spectra, long lifetime, and small form factor (Mitchell et al., 2015).

1.2. Light spectra and plant physiology

Plants produce the energy necessary for life from light by the process of photosynthesis. This process also controls carbon sequestration and changes in environmental factors within the natural world (Murchie & Lawson, 2013). From an economic standpoint, it is easy to realize that increased levels of planting and the early production of food are the major obstacles to high-yield crops. The spectrum of light is one of the most important factors in the field of technical and economic plant cultivation. Although there is a serious need for plants to be exposed to a spectrum similar to that of natural light, so far it appears that exposure to mixed spectra of light has not greatly increased plant productivity and, at the same time, increased electricity consumption (Darko et al., 2014).

1.2.1. Effects of Different Light Colors (Blue, Red, Green, etc.) on Plant Physiological Processes

Different light spectra (blue, red, green, etc.) can influence the physiological processes of plants as well as the abundance and quantitation of necessary materials within the plant. Blue light affects the intracellular CO2 concentration in chloroplasts of mesophyll cells, with a strong increase in concentration, suggesting that the increased CO2 availability contributes to previously detailed increases in light respiration and net assimilation rates (Hogewoning et al., 2010). Furthermore, sunshine-grown leaves contain many more blue light-absorbing phytochromes that bind cytochrome b6f complexes, not only to plastocyanin of electron transport but also to balance excitation energy between PSII and PSI in the light. It also shifts the potential absorption of the cytochrome b6f complexes and influences photosynthetic activity (Muneer et al., 2014).

When the blue light-absorbing stroma-located adenylyl cyclase is excited, the abscisic acid (ABA) level rises and the phosphate transporter NRT1.2 is dephosphorylated (Gould et al., 2018). The cells of the leaf meristem already store red or R-rich responses to evaporative demand de novo synthesized ABA and respond to the light more effectively. In addition, UV-B radiation induces the first ABA peak. These expected links could only be observed by considering the frequency of systematic relationships. Ultimately, they seem to change temporarily from induced production, gradually set in as a function of the evaporative demand of the atmosphere, and establish one of the interacting negative-feedback loops (Ballaré et al., 2011).

1.3. Plant Stress Factors

Plants are affected by many stress factors throughout their life. Under the hydroponic system, if there are any shortages or excesses of nutrient elements, the plants encounter stress from nutrient deficiency or toxicity (Wu et al., 2017). In addition, light intensity, lighting time, lighting quality, air temperature, air humidity, root zone temperature, and carbon dioxide content also substantially affect the growth and stress of the plants being cultivated by the hydroponic system (Kalaji et al., 2017).

1.3.1. Light Intensity

The lights affect carbohydrates, pigments, chlorophyll content, CO2 content, and general plant growth. However, there are also many reports about plant injury from continuous light (Vänninen et al., 2010). It is generally accepted that light stress increases with decreasing intensity of the photoperiod. Some researchers have assumed that the basis for these effects is the combination of continuous light with temperatures that are not concomitantly high enough to enable normal photosynthetic rates, resulting in the over-reduction of the photosynthetic electron transport chain, in turn leading to enhanced generation of reactive oxygen species (Yang et al., 2017).

2. Light and Plant Stress in Hydroponic Systems

Light is the most significant environmental factor influencing plant growth and development. Plants respond to light intensity and light quality, including the light spectra. Light quality refers to the range within an electromagnetic spectrum that is visible to biological eyes. Light-regulated plant physiology includes a wide range of downstream responses, including regulation of gravitropism, phototropism, inhibition of hypocotyl and coleoptile elongation, and optimization of photosynthetic light-quality acclimation through adjustment of chlorophyll biosynthesis, allocation, conformation, and light capture (Chen et al., 2022; Fankhauser & Christie, 2015). Most growth and developmental responses are mediated by blue-light photoreceptors or phytochromes, while a few are mediated by cryptochromes, phototropins, and UVB receptors.

Conditions of hydroponics include management of the following factors: temperature, pH, water, nutrients, photosynthetic photon flux, CO_2, and relative humidity. These culture conditions can expose plants to environmental stress. Generally, relative humidities must be naturally maintained at specific vapor pressure deficit values depending on the time of day, as they significantly influence leaf temperature. Temperature and VPD can be managed using microclimates, which enable control of temperature and relative humidity through temperature-control port systems with a fan and pad, and light transmission, respectively. These systems emit different light spectra, and light spectra and light intensity can be adjusted by the culture duration (Van Iersel et al., 2016; Demmig-Adams et al., 2020).

2.1. Effects of Different Light Spectra on Plant Development

Light is the driving force for plant growth, with far-reaching effects. Plants exchange many signals with the light environment. Growth and development are plastic and can be adjusted in response to environmental factors, such as mechanical, humidity, and light conditions (Pires et al., 2021). Artificial light has been widely used for plant growth and crop production in a controlled environment, such as a greenhouse or hydroponic system. The plants are exposed to artificial light for an extended period, and inappropriate light may directly or indirectly injure the plant. Plant stress tolerance is partly determined by environmental factors that affect plant development and physiological conditions (Zhen & Bugbee, 2020).

Light, which is comprised of many different wavelengths, can cause photomorphogenic responses in plants. To achieve an appropriate light condition for the growth of specific plant species and to meet the requirements of the desired plant presentation in a greenhouse, artificial light with designed wavelengths has been extensively studied to optimize specific plant growth or improve the nutritional value of some specific plants or plant ingredients (Hogewoning et al., 2010). Different light qualities, such as blue, red, far red, and ultraviolet, can affect different responses in plants. For instance, ultraviolet A, blue, red, and far red are known as the photoreceptors of the plants in perceiving the light signals, while the roles of the spectral range, known as the green gap, on plant photosynthesis, photosynthetic rate, and morphology, have attracted extensive attention (Li et al., 2022; Kim et al., 2022).

2.1.1. Blue Light

While blue light can be found in all white light sources, it is emitted exclusively as monochromatic light. In the photosynthesis process, blue light provides the energy that converts carbon dioxide and water into glucose and oxygen. The absorption spectrum of blue light is generally broad, with peak absorption centers of 430 nm in chlorophyll a and 460 nm in chlorophyll b (Wang et al., 2020). Absorption of blue light in the visible spectral region gives the photosynthetic pigments chlorophyll a and chlorophyll b a distinct blue-green color.

Blue light influences the morphogenic responses of plants in many ways. It mediates phototropism, leaf expansion, stem attraction, anthocyanin production, and internode elongation suppression in plants. Blue light enhances the opening of the stomata and activates various signaling pathways in plants, including the cryptochromes and phototropin systems (Hogewoning et al., 2010). Furthermore, many abiotic stress factors, such as extremely high or low temperatures, high irradiance or UV irradiation, and wounding are related to excessive accumulation of specific types of reactive oxygen species such as singlet oxygen and hydrogen peroxide, which oxidize lipids, proteins, and DNA. Blue light has been described as an effective stress factor; it ameliorates the excessive accumulation of reactive oxygen species, as well as the effects of abiotic stress factors in plants (Li et al., 2022).

2.1.2. Red Light

The relationship between red light and the resistance of plants to stress factors is currently the most widely studied in artificial lighting. Experiments on wheat grown under LEDs with different light spectra observed that the impact of different environmental stresses primarily affects the photosynthesis, pod synthesis, and carbohydrate metabolism of wheat plants (Hernandez et al., 2016). The red LED light increased the activity of SOD, POD, CAT, and APX enzymes, ultimately improving the plant's resistance to stress and increasing yield. However, adding a small amount of far-red light during the dark period reduced thermal effects, which included eliminating growth inhibition and increasing carbon assimilation, therefore enhancing climate change adaptation for hydroponic cultivation (Liu et al., 2020).

In a study of ethanol edible chrysanthemum cultivation under different red and blue light ratios in a turntable cultivator, a significant increase in stress tolerance and a slight increase in growth partially depend on enhancing the regulation of ROS levels in the edible chrysanthemum (Zhen & Bugbee, 2020).

Another study found that three different ratios of red LED light had a feedback effect on the antioxidative enzymes of Panax ginseng saponin. A low R/B ratio reduced the growth of the ginseng seedlings used in the turntable cultivation. However, during this period, MDA and antioxidant enzymes increased slightly, thereby reducing the harmful effects caused by high levels of light operation on Panax ginseng saponin.

In summary, using a high blue light can stably enhance plant growth under a high red light environment, while the R/B ratio can protect the plant from ROS in an environment with high blue light. The resistance of grafted cucumber seedlings to water-root stress was assessed using different far-red light treatments of red light-cultivated cucumber seedlings. The stem yield of the grafted cucumber treated with red light was higher than that of the other grafted cucumber seedlings using far-red light, and palisade tissue, chlorophyll content, Fv/fm, and antioxidant enzymes SOD and POD decreased the stress reaction to the stress level (Chen et al., 2022).

2.1.3. Green Light

Green light gives plants signals to grow against the gravity of the Earth, as it has a high ratio of far-red light. Under several unfavorable conditions, plants showed enhanced hypocotyl growth, which is reversed in gravistimulation. Green light was highly effective in the inhibition of root growth in the presence of air pollutants. It was concluded that green light was indispensable for the gravi-responding growth of the roots. It promotes both hypocotyl and root growth in several plant species (Kim et al., 2022).

Green light plays a role in a wide range of plant growth stages throughout the entire plant life cycle, compared with other light spectra. These effects of green light may have some relation to ethylene and gibberellin biosynthesis. Green light could be more destructive to pectin and the cell membrane than white or red light. Hydrogen peroxide may function in signaling hypocotyl growth inhibition. Additionally, green light is responsible for the regulation of plant stress factors such as salinity under supra-optimal growth conditions, aluminum, and water stress.

The stress of various cultivars of wheat plants grown at three different light spectra (including green, red, blue, and yellow) was studied. It was found that when green light was present, the plants grew taller hypocotyls than in the absence of green light. Particularly, the F2 and F3 generations of two cultivars with tall green plants differed greatly in their growth response to the presence or absence of green light. It was reported that spinach plants required green light for better growth at a specific light intensity. It was demonstrated that green light may be responsible for legume root growth under other conditions. Furthermore, green light promotes cucumber seed germination.

There are remarkable differences in chlorophyll levels between cucumber seedlings grown under different light conditions. It was shown that green light exposure alleviated chilling injury in stored cucumber fruit. Additionally, green light can regulate the level and size of the vitamin C pool, altering the quality of red leaf lettuce developed using nutrient film technique hydroponic growth to produce a high nutritional value. Moreover, green spectral quality may increase the levels of phenylpropanoids, flavonoids, and anthocyanins, acting as a blue light blocker relative to lettuce. Other research has suggested that green light may alter the metabolic pathways of single leaf lettuce. However, little information is available on the role of green light in the hydroponic growth of Brassicaceae species (Zhang et al., 2021).

2.2. Light-Induced Stress Mechanisms in Plants

Light is the driving force for plants. The solar spectrum is tuned by pigments that absorb light of appropriate wavelengths so that the energy is used for photosynthesis or photomorphogenesis in plastic responses. Absorbed solar radiation is also an innate factor due to the fluctuating transfer of electrons and activation of oxygen species, causing an inevitable stress to a fraction of the molecules (Chen et al., 2022). Following a brief outline of various plant micro-stresses, the review intends to provide insights on plant cell reactions to light. Light excitation of pigments serves as the electric source; photons are utilized in building organic foundations, and oxygen maintains homeostasis (Demmig-Adams et al., 2020).

How do plants avoid inevitable photo-excitation of incomplete charge separations, and how might it be penetrated to study the process? To assist understanding of the basic function of the chloroplast, the structure of the photosynthetic apparatus, the photon input, and products are discussed before touching on the functional plant cell reactions to photo-excitation, using oxygen reactive species and free radicals. Subsequently, other less studied misconceptions regarding the onset and maintenance of oxygenic photosynthesis under natural conditions are explored (Foyer et al., 2022). Finally, a future insight where plant stress research could adapt knowledge gained from photo-excitation stress in the study of the solar spectrum is proposed.

2.3. Impact of Light Spectra on Gene Expression

This article presents important genes associated with different light spectra. For potential stress genes, gene expression was compared after the application of different light qualities. The search for potential regulatory genes is also presented. Many regulatory factors can be screened through gene expression analysis. Construction of transcriptional networks can be used to monitor the gene expression of all regulatory factors. Through network analysis, the regulating relationships and responsive signaling interactions of different stress factors can be demonstrated (Guo et al., 2021).

In hydroponic systems, diverse environmental stresses usually affect plants. Non-destructive imaging can monitor the expression of regulatory genes at various time points and be widely used in the hydroponic field to advance work in crop production and pharmaceutical gene research. Applying light stress is the easiest way to control plant stress. In the hydroponic system, the application of specific light spectra can avoid interference from soil bacteria, and it also saves more energy (Zhen & Bugbee, 2020). Plant light-sensing photoreceptors can absorb specific light qualities and trigger light signaling pathways. These photoreceptors have specific receptor responses and imported regulatory genes of AUX/IAA, CRY, PHY, FHL, and UVR8, and regulatory factors such as COP1, SPA, HY5, HOT, and PIF. In the far-red region, phytochrome signals promote photomorphogenesis in plants (Phukan et al., 2019). In light fluence rate 1, the phytochrome B photoreceptor is used to control photoperiodic flowering in plants. The phytochrome-interacting factor transcription factor is the main factor that regulates the light response pathway in Arabidopsis after the phytochromes have been inactivated.

3. Stress-Alleviating Roles of Different Light Colors

Light of different colors alters the efficiency of CO2 fixation, light utilization, and testes, thereby leading to varying energy levels in plant cells and differences in the synthesis of important recently identified factors that positively relate to ROS scavenging (Chen et al., 2022). As left nuclide, the effect is beneficial in increasing the redox potential, thus resulting in increasing ETR through lowering the formation of ROS at PSII and increasing the transformation of xanthophylls from V + A to ZEA and from D to ZEA within a certain extent, as a virtuous circle for efficient scavenging of ROS. On the contrary, right nuclide has the opposite impacts, resulting in a rather limited ETR, intense formation of ROS at PSII, and slower transformation or even retro-transformation of xanthophylls from ZEA to V and A, as a vicious circle for excessive accumulation of ROS. The anti-ROS system is very important for plants to overcome various environmental stressors, thus enhancing the redox homeostasis required for normal metabolic processes (Foyer et al., 2022).

Light of appropriate spectrum could alter formation and regeneration of NADP, so as to alter levels of NADPH, NADH, and NAD. Altered ratio of NADPH and NADP could lead to adjustments in antioxidant activity and concentrations of total antioxidants of the ascorbate and glutathione redox pool, with higher ascorbate in the reduced form, which plays a vital part in the effective removal of ROS (Demmig-Adams et al., 2020). Furthermore, the CAT and POD of plants under 70% red-blue mesh showed up-regulated trends, as the key enzymes for hydrogen peroxide breakdown, removing hydrogen peroxide to prevent degraded lipid and further damaged carotenoids, chlorophyll, and P700. As expected, the expression rate of the ascorbate–glutathione cycle, such as APX, which is responsible for the recycling of ascorbate, and activities of SOD, DHAR, and GR, showed a corresponding increase. By contrast, SOD expression, which is responsible for scavenging O2−•, showed up-regulated trends under low-E group conditions, which could increase the photorespiration of the photosynthetic electron transport chain, so as to avoid the yield of O2−• at the expense of ATP (Guo et al., 2021).

Additionally, CAT and POD enzyme activity could be induced to prevent the generation of hydroxide radicals, so as to prevent the oxidative damage of photosystem II. Collectively, the elevated ROS scavenging capacity observed in small cabbage starts under moderate green-blue light was due to the continuous transcriptional activation of the ROS-scavenging genes and the stability of ROS-scavenging enzymes (Kim et al., 2022).

Overall, the supplementation of LED lights with low intensity and high light energy at middle green-blue spectrum ratio over hydroponic systems could be beneficial in the active ROS removal process. Induction of the antioxidant enzymes SOD, POD, APX, GR, and CAT, and the up-regulation of their transcription levels might concomitantly contribute to enhancing ROS-scavenging capacity in the developing or mid-phase of plant growth and stress resistance (Hernandez et al., 2016). Therefore, promoting high photosynthetic antioxidant enzyme activities in the early stage of pepper transplants via proper intensity and ratio of green-blue light could be beneficial for efficient light utilization and ROS scavenging. Together, combining monochromatic blue/red light with moderate green light could be beneficial for stimulating inductive processes in lettuce seedlings. Such an effective balance might drag out the time span of the slow plant growing phase and avoid the trend of non-recovering after a certain period of time (Zhen & Bugbee, 2020).

3.1. Blue Light [Adaptation Mechanisms Under Temperature and Water Stress]

The effects of different light spectra on the lower effects of marginal differences in temperature and water stress can converge and amplify the response of the photosynthetic machinery and stress-related genes. The expression of selected marker genes related to light and drought stress is significant. Blue LED can significantly alleviate excessive accumulation of NR and PAL, and reduce the overproduction of superoxide and H_2O_2 in basil, broccoli, and red lettuce (Chen et al., 2022). Thus, the light intensity and spectral composition can be optimized, which simultaneously reduces the metabolic responses of phenolic compounds and non-enzymatic antioxidant enzymes.

In contrast, the existence and detection of light color-specific effects in PHRs with environmental stress have not yet been fully elaborated. It may be due to the measured physiological and biological responses under different light quality conditions, which depend on plant species, variety, or cultivated environment. In summary, acknowledging the effect of the light quality achieved through the adjustment of light spectra on the acclimation and enlargement of multiple stressors is significant. The study has a challenging and intriguing long-term perspective. The ability of plants to favor certain light spectrums and adjust the variation of multiple stressors is the main key for the application and optimization of the LED (Zhen & Bugbee, 2020).

3.2. Red Light [Carbon Assimilation and Tolerance to Salinity Stress]

Carbon assimilation is the metabolic process vital for a plant's life that transforms atmospheric CO_2 into organic molecules. This is a complex process involving two main phases: the conversion of CO_2 into an organic product and the production of ATP and NADPH by light. It is an extremely slow response involving complex mechanisms like energy dissipation and the dissipation of excess energy during photosynthesis. Green leaves absorb light, and the energy is used in chemical processes in photosynthesis, fluorescence, and heat. Light is absorbed and converted by chlorophyll, and absorbed non-radiative dissipation occurs when chlorophyll is in excess. Salinity reduces the energy utilized in these processes (Liu et al., 2020).

The dark-adapted leaves' fluorescence F0 may be an important indicator of the low acquisition of CO2 by the carboxylation reactions, and the increase in F0 can be a visual indication of the photoinhibition and photoprotection from PSII damage, which is also indicative of the plant's photochemical conversion effectiveness (Hernandez et al., 2016). Both the total photochemical efficiency of PSII and effective efficiency reduced with the salt treatment; however, this decrement was more prominent in plants exclusively treated with white emitters. However, when combined with deep red, Sal + W + DR showed the best protection of photochemical reactions and electron transport between PSII and the end of the electron transport chain. Low electron flow from PSII involves non-radiative energy dissipation as an important method of plant self-protection processes used to dissipate excess light energy, therefore reducing high-energy states. The NPQ of LED-treated, well-watered plants was increased, particularly of the W-emitted group, in comparison with the control plants collected at midday, which can be considered a stress condition and a time when the blue and green lights helped maintain the natural prepredescent NPQ situation (Kim et al., 2022). Salinity stress not needing water tended to increase NPQ using blue for maintenance rather than green, a phenomenon that was quite contrary to previous findings.

3.3. UV Light [Production of Defense Compounds and Pathogen Resistance]

UV radiation is the strongest environmental factor to trigger defense compounds in the leaves of higher plants. The supply of ultraviolet-B radiation significantly affected the rapidly advancing phenotype (small leaves, strongly indurated petioles, and strong reduction in chlorophyll content), but not the cold-avoiding adaptive phenotype (high anthocyanin content) of the plants. These results suggest that, on the one hand, UV radiation can compromise plant performance in harsh alpine environments via a direct negative effect on the photosynthetic responses to low temperature, and on the other, it triggers rapid changes in the tissue of plants, such as increased avoidance of invertebrate herbivory from changes in the size and color of leaves and petioles (Foyer et al., 2022).

Ultraviolet-B pre-exposure effectively increased the plant's tolerance to abiotic stress, such as heat, drought, and salt. The ultraviolet-B-induced protective mechanism involved the slight enhancement of photosynthetic metabolism activity and an increase in the antioxidant capacity in plants. The flavonoids in plant leaves play an important role in promoting cell development, pigmentation, sexual reproduction, and providing defense mechanisms against biotic and abiotic stress such as UV, pathogen infection, and xenobiotic compounds (Hideg et al., 2021).

The accumulation of flavonoids has been found in many reports. The variations in the types and contents of flavonoids in Arabidopsis leaves when supplied with two levels of UV-B were found. The most significant effects of UV-B exposure were observed on flavonol glycosides. In addition, the amounts of t-hydroxycinnamoyl kaempferol and tigloyl kaempferol were upregulated by UV-B exposure. The total flavonoid content and the antioxidant capacity of the leaves were upregulated after ultraviolet pre-treatment. These results probably occurred due to the upregulation of the phenylpropanoid and flavonoid pathway genes (Guo et al., 2021).

3.4. Significance of LED Technology [Optimization of Different Wavelengths for Plant Stress Management]

The light quality provided by LED is a unique feature that makes it different from traditional light sources. Plants are sensitive to light quality, which is provided by LED with extremely accurate target light spectra that can promote plant quality and production through spectrum adjustment to realize precise and economical light effects (Liu et al., 2020). As early as the 1980s, an American scientist convinced NASA to adopt LED technology in biological illumination. Then, plant scientists applied it to plant growth and development and obtained significant results. From space to Earth, LED plant factories were established around the world. Now, using the LED system, one can easily provide different spectra and intensities of light conditions to plants in both basic research and commercial production areas. In other words, the target spectra, ratio, and intensity of different wavelengths and composite spectra are provided by LED, while other light sources are not able to meet the needs of the plant but have better market cost performance (Kim et al., 2022).

From the simulated sunlight source, research on the early prediction, diagnosis, and improvement of plant health was difficult. However, with the development of different light sources with an accurate ratio of red and blue light, they were widely used in the management of horticultural crops, orchid seedlings, and medicinal plants. With the continuous expansion of the above-mentioned LED plant cultivation research, expectations for market applications are constantly improving (Zhen & Bugbee, 2020).

In terms of commercial running time and plant variety output limitations, companies use the latest LED technology to grow vegetables and herbs with excellent taste and market competitiveness at low cost, low carbon footprint, low risk of environmental pollution, and zero dependence on agricultural conditions, natural disasters, geographical location, soil type, and climate. Therefore, LED lighting could adapt and become the most important light source for solving the global food crisis, constantly radiating profitability and new vitality for the horticultural and plant research industry. As LED technology meets the requirements of different wavelengths and light intensity of specific plant varieties, it will gradually replace traditional light sources with the wide applications of plant factories using plant light recipes.

4. Practical Applications and Case Studies

In this chapter, we outlined the results of studies investigating the effects of different light spectra on the development of plant pests and diseases, and performed practical experiments about growing strawberries in the hydroponic garden filled with full spectrum light LEDs. In the process of the experiments, in addition to discussing the effect of light on the growth of strawberries, there was an in-depth discussion on the stress factor of lettuce. Prior to conducting the study, the factors influencing the nutrition of the strawberry hydroponic garden include temperature, light, humidity, carbon dioxide, ventilation, and fertilization. Due to the limitations of the lighting facilities in Taiwan, greenhouses require the help of artificial lighting to meet the light needs of plants. Different light spectrum compostable light sources contain different wavebands, and the standards pursued in the research are the light recipes that meet the needs of plants (Chen et al., 2022).

With the study of light quality on plants, it can also be used to provide artificial light culture light source technology for plants and is expected to be promoted to the per-family level. In another experiment, lettuce has a plant height of 1 to 2 inches after irradiating six hours of blue light, and CK does not grow. After 30 days, the lettuce under different irradiation conditions is still in the seedling stage of CK. Under different light spectra, the plants are differentiated. After 30 days of lettuce germination, there is already an obvious difference in growth. The plant morphology of the plant which is less than 7 cm in height is more compact than the group. After cultivating 20 days of lettuce under different lighting conditions, seedlings with a certain production value entered the stage, and we found that the initial development of LCV is better than CK (Kim et al., 2022).

On the 20th day, RWC, DLOA, and CV are rapidly improved, and it is found that all treatments are present when water stress is stressed. Under the higher V/FR range of near far-red light, the highest initial differentiation of

LCV is observed, which is better than other treatments. The results of the experiments can provide a reference and ideas for the design in the future and can be used as the same plant growth facilities. To improve the system, practice the application and design of the plant factory (Liu et al., 2020).

5.1. Light Management in Hydroponic Systems

Due to the increased emphasis on nutrient uptake across different environmental conditions, more accurate plant models have been developed to forecast plant nutrient uptake under changing growth periods, including both low and high photoperiods. Alternatively, light deficiency or high natural irradiance can eventually lead to stress and reduce plant growth, their phenology, quality, and shelf life, and enable plants to be less resistant to several plant diseases. Light transfer in plant tissues is generally affected by fluctuations in microclimatic conditions or greenhouse fading, instead of abrupt changes in other abiotic disturbances, such as temperature or humidity.

While it is generally known that primary metabolites change slightly with altered irradiance, secondary plant matters, such as photosynthetic pigments or polyphenols, can fluctuate. These changes can increase plant defense mechanisms, improve plant fitness, or enhance the sensory and nutritional properties of edible plant tissue. Therefore, these collective effects are more concrete when plants grow to produce healthy foods and face minor possible challenges in case of high production efficiency and product storage. Over the previous years, light quality has been evaluated in fields and has contributed importantly to growing established organic plants (Chen et al., 2022).

In this sense, by exploiting modern light photonics and combining electro-dynamic real-time adjustment in a three-frequency LED microclimate system, we propose an autonomous automation system capable of reverting to conventional LED lighting in hybrid electrical circuit breakers. This contributes to the reduction of lighting power, decreases manufacturing costs, and opens door panels to verify alternative target interaction with crop species in similar greenhouse-light growth studies (Zhen & Bugbee, 2020). The goal of this text is to further explore the effect of different light spectra on the expression of plant stress factors specific to their potential use as assistive tools in hydroponic production.

5.1.1. Selection of Optimal Light Spectrum Combinations

To construct plant-affecting strategies, the interactions among relevant factors are necessary to produce the desired effect. Monitoring and programming the behavior of plant stress factors in a controlled environment that features automatic supervision, control, and feedback through computer programs are essential in intelligent agricultural applications. This study investigated the effects of different light spectra on regulating and accumulating factors related to plant growth. The light in a hydroponic system was provided by four LED arrays, namely, warm white, cool white, and two blue wave components of 450 nm and 475 nm.

Natural solar light was provided on the growing platform with eight parallel mirrors that could automatically track and reflect sunlight. The experimenters measured the related indices and compiled a plant database to scientifically regulate predefined plant behaviors with changes in selected light spectra (Kim et al., 2022). After analyzing the emission and absorption spectra of plant groups A and B, four key evaluation indices were compared to select the optimal light-spectrum combination. The best result was produced by a combination of warm white light input at 120,000 lux with a blue wave component with a peak at 450 nm at high power-driven white light at 60,000 lux, which produced a deep pink light for group B plants. The research results could offer valuable information for factories to adjust the light spectrum to better control plants in a greenhouse.

5.1.2. Balancing Energy Efficiency and Plant Productivity

Various light combinations were tested for lettuce growth and power efficiency. Sprouts had an increased thickness mainly due to an enhanced thickness of cell walls. Photosynthetic pigment content, chlorophyll fluorescence, quantum yield, and photosynthetic activities were also upregulated with monochromatic light. For R–B, the area of lettuce and production of heads were larger than the B–R group, and the fresh weight of the plant was increased by 48% and 2%, respectively. Based on the results, R–B treatment resulting in a significant increase in lettuce growth and photosynthetic activity has strong practical implications in vegetable production (Kim et al., 2022).

Hydroponic systems protect the natural environment, its metabolic and exogenous basics, no pests, diversified patterns of supply, light intensity, and integral and weatherproof functions. The major problems of current hydroponics are high production costs, higher consumption of water and nutrients, and limitations in mass industrialization. Higher productivity and RAs of various LEDs may promote wide applications of artificial light sources in hydroponic systems (Zhen & Bugbee, 2020).

LED modules showed higher power efficiencies compared to traditional sodium lamps, which emit strong light in the deep red and yellow regions and received regeneration treatment. With the rapid development of LED technology, various narrow light spectrums and combinations can be tailored to meet the needs of various photomorphogens for improving vegetable crop quality. LEDs with different light densities varied in energy efficiency. Phytochrome and photochromes are major photoreceptor proteins. PPFD is important for plant growth; energy demand for light sources is limited. To improve the productivity of LEDs in hydroponics and reduce production costs, tuning light spectra and light densities to optimize various photoreceptor proteins should be prioritized. In previous experiments, differences in developmental rates, biomass allocation, and contents of photosynthetic pigments to various light spectra were demonstrated (Liu et al., 2020).

5.2. Future Research Directions

While stress mitigation through spectra manipulation has been well studied in natural environments, such a study is still limited in controlled environments. For instance, light spectra were frequently modified in the natural environment by supplemental light in commercial greenhouses and plant factories to improve plant morphology and alter the production process. In hydroponic production, heat stress is an important factor that triggers plant stress. To maximize the beneficial effect of the spectrum, stress-tolerant characteristics of individual crops need to be taken into consideration.

The relationship between light spectra and the heat stress of various crops still lacks research. In addition, various conditions, including light intensity and environmental conditions, show an ability to interact with the spectrum. A comprehensive investigation of the effects of enhancing heat stress tolerance in various crops on optimizing the beneficial light spectrum is also suggested (Chen et al., 2022). Furthermore, composite spectra that provide both light and disinfection effects are well-demanded substrates typically used in hydroponic systems. A study of spectra manipulation over *E. coli*, as well as the correlation between heat treatment and the disinfecting broad spectrum, will provide important information for future plant factories.

5.2.1. Investigating Genetic Adaptation and Light-Sensitive Biochemical Pathways

Evolution, or genetic adaptation, is a long process under specific environmental conditions and is particularly important. It allows plants to accommodate their ambient light conditions. Yet, the speed of acclimation and the extent of acclimation are both important, particularly for horticultural practices. Acclimation to far-red light occurs over several hours to days as it requires de novo protein synthesis and is usually referred to as greening. Moreover, acclimation to far-red light can last for at least as long as the period of far-red treatment (Liu et al., 2020).

The first differences in gene expression profiles between short- and long-term light acclimation were probed in *Arabidopsis*. Recognizing that the transcriptome is largely fixed, this provides opportunities to study the transient transcriptome changes at different time points. Seedling response to changes in the light spectrum is multi-phased, dynamic, and cascaded. This response triggers many different transcriptional changes, both up- and down-regulated genes upon far-red light treatment. Plant response to the spectral composition in light quality is assumed based on transcriptional changes, post-transcriptional modifications, and the release of mature salts through protein turnover, which in turn regulates various processes including development and stress response (Chen et al., 2022).

Signatures found associated with biological activity can provide targets for biotechnological applications. Further understanding of these processes would enable fine-tuning of horticultural lighting systems to improve both yield and quality under controlled environment agriculture (Kim et al., 2022).

6. Conclusion

The goal of this study was to obtain valuable information about different current light technologies of hydroponic systems in view of stimulating and retarding plant stress. Taking into account the stimulation of abscisic acid, brassinolide, and salicylic acid activities as stress factors and the results obtained in *Brassica napus* plants, we can conclude that in lighting systems with red, blue, and far-red light-emitting diodes, red and far-red gas discharge lamps, or mixed lighting systems, the presence of far-red or red radiation is necessary for the inhibition of abscisic acid, brassinolide, or salicylic acid activity and for decreasing the salicylic acid content in *Brassica napus* plants (Zhen & Bugbee, 2020).

For other light sources, red radiation should dominate in the light spectrum, supplemented with blue, far-red, or yellow radiation in order to inhibit abscisic acid, brassinolide, or salicylic acid activity and to decrease the salicylic acid content in *Brassica napus* plants (Foyer et al., 2022). This study highlights the necessity of combining specific light spectra to regulate stress-related pathways in plants while achieving optimal growth and quality in hydroponic systems.

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Chapter 18

Development of Fuzzy Logic Model (ANFIS) for Prediction of Marine Fisheries Production

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INTRODUCTION

Marine capture fisheries remain a crucial component of global food security and economic stability. However, the inherent complexity and dynamic nature of marine ecosystems make accurate prediction of fish production particularly challenging. In recent years, advanced computational methods, particularly adaptive neuro-fuzzy inference systems (ANFIS) and fuzzy logic approaches, have emerged as promising tools for modeling and predicting marine fish capture production (Gladju et al., 2022).

The integration of artificial intelligence with fuzzy logic has shown remarkable potential in addressing the uncertainties inherent in fisheries data. Traditional statistical methods often struggle to capture the non-linear relationships and complex dynamics that characterize marine fisheries systems (Glaser et al., 2014), making advanced hybrid approaches increasingly relevant. ANFIS, which combines the learning capabilities of neural networks with the reasoning framework of fuzzy logic, has demonstrated particular promise in this domain.

Recent studies have highlighted the versatility of ANFIS in fisheries applications. Do et al. (2022) demonstrated the method's effectiveness in predicting fish distribution patterns and adapting to changing environmental conditions, a critical consideration in the context of climate change. The success of these approaches lies in their ability to handle both qualitative and quantitative data while accounting for the uncertainty inherent in biological systems.

Fuzzy logic systems have shown significant advantages in fisheries management, particularly in addressing the complexities of stock-recruitment relationships and catch predictions (Chen et al., 2000). These systems excel in situations where traditional mathematical models may fall short, especially when dealing with imprecise or incomplete data sets common in marine fisheries research. Koutroumanidis et al. (2006) demonstrated that the integration of fuzzy logic with other computational methods has enabled more robust forecasting capabilities, particularly for short-term predictions of fish catches.

The development of reliable prediction models for marine fish capture production is increasingly critical for sustainable fisheries management. Current challenges in fisheries forecasting include the need to account for environmental variables, fishing effort, and ecosystem interactions (Gladju et al., 2022), making the adaptability and learning capabilities of ANFIS particularly valuable. These models not only aid in production forecasting but also contribute to more informed decision-making in fisheries management.

Marine fisheries are an important economic and ecological activity in various parts of the world. Sustainable management of fish stocks and prediction of future production are critical to the long-term success of this sector. The complexity and accuracy limits of traditional forecasting models necessitate the use of modern artificial intelligence approaches. This study aims to develop an ANFIS model by using fuzzy logic approaches in predicting marine fish capture production.

MATERIAL AND METHODS

Data

This study is based on the following data collected from five different seas between 2006-2023: (i) year, (ii) total number of ships, (iii) total number of employees, (iv) seas (Mediterranean Sea, western Black Sea, eastern Black Sea, Aegean Sea, Marmara Sea; labelled with 1 to 5, respectively) and (v) marine fish capture production (in tons). These data were gathered via the Central Data Dissemination System of the Turkish Statistical Institute.

Data Preprocessing

Data with any missing values were removed from the dataset. Then data was separated into input-output groups. Year, sea code, total number of ships and total number of employees were used as input variables; marine fish capture production was used as output variable.

Fuzzy Logic Approach

ANFIS Model Structure

Takagi-Sugeno (T-S) fuzzy inference system (FIS) is one of the most extensively used accurate fuzzy models which proposed by Takagi and Sugeno (1985). The ANFIS architecture was explained in detail by Kale (2020a) and Sonmez et al. (2018).

In the training phase, ANFIS generates appropriate membership functions for each input variable (Figure 1). These membership functions are then adjusted using the hybrid algorithm in line with the error correction training method. Additionally, the constant parameter of the output functions is adapted during the learning phase based on the least mean square algorithm. The ANFIS model processes 100 training data points throughout the training period. The dataset was divided into 75% for training and 25% for testing, following the recommendations of Sönmez et al. (2018) and Kale (2020a). The hybrid algorithm was selected as the training method for ANFIS, and the grid partition method was employed to construct the FIS.

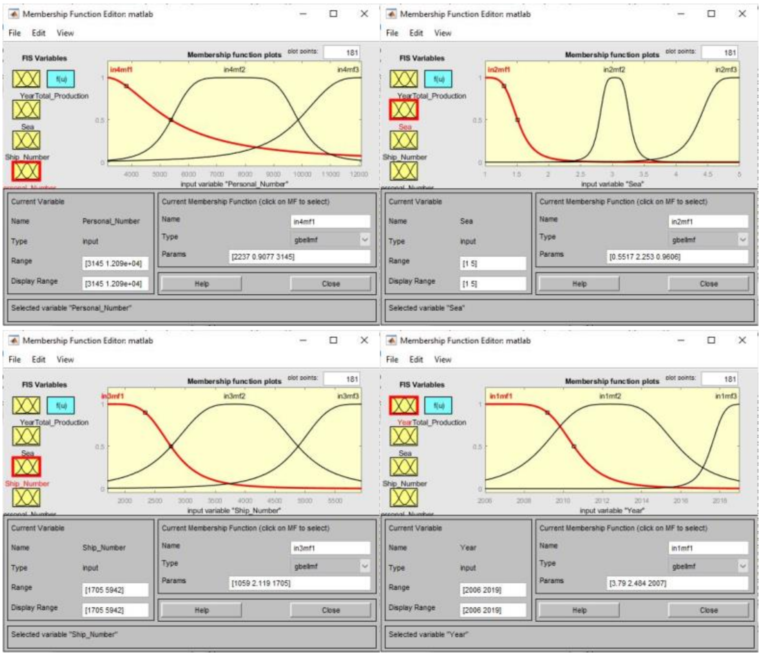

Figure 1. Membership functions of input variables for ANFIS model

ANFIS defines the relationships between inputs and outputs via fuzzy rules. Three "bell-shaped" type membership functions are defined for each input. The model was trained for 100 epochs by using Fuzzy Logic Toolbox in MATLAB environment (Matlab R2021b).

Performance Evaluation

The success of the model was measured by performance metrics such as root mean squared error (RMSE), mean square error (MSE), mean absolute percentage error (MAPE), mean absolute error (MAE), Nash-Sutcliffe efficiency (NSE) and correlation coefficient (R^2). More information about the formulas and equations of these metrics can be found in Kale (2020a).

RESULTS

The descriptive statistics of the dataset were given in Table 1. There is no statistical correlation between total production and both total number of fishing ships and total number of employees in fisheries.

Table 1. Basic statistics of the dataset

Variable	Mean	SE	SD	Max	Min	Cor
Fishing ships	3013.34	113.77	1079.29	5942.00	1595.00	0.28
Employees	7400.32	231.11	2192.47	12092.00	3145.00	0.47
Production (tons)	67221.91	7896.12	74909.19	341188.00	8599.90	1.00

Note: *SE*: standard error; *SD*: standard deviation; *Max*: maximum; *Min*: minimum; *Cor*: correlation with total production

The accuracy of the prediction against actual data was checked for both training and testing stages. Table 2 provided the performance parameters of ANFIS model for each stage of training, testing and whole dataset.

Table 2. The performance parameters of ANFIS model for testing, training, and whole stage

Stage	MAD	MSE	RMSE	MAPE	MAE	NSE	R-squared
Training	13858.478	2031675409.930	45074.110	17.250	0.173	-0.814	0.67617
Testing	2135.554	51388176.328	7168.555	8.314	0.083	0.819	0.13794
Total	15994.032	2083063586.258	45640.591	25.564	0.256	-0.814	0.68645

Figure 2 shows the diagram of the actual values for the total production of marine fish capture and the predicted values using ANFIS models. It shows a comparison between the actual and predicted values. In addition, Figure 3 demonstrates the scatter plots of actual and predicted values. The correlation coefficient of the model is found to be lower.

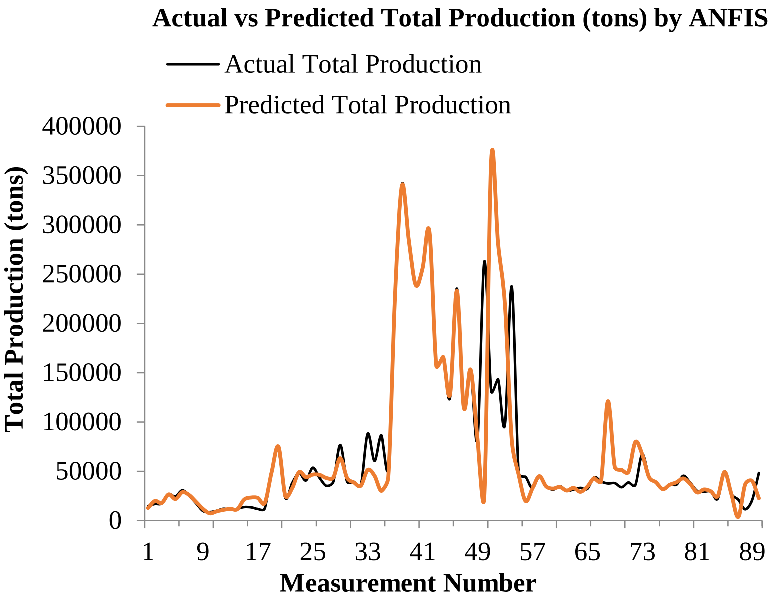

Figure 2. Comparison of actual and predicted values by ANFIS model

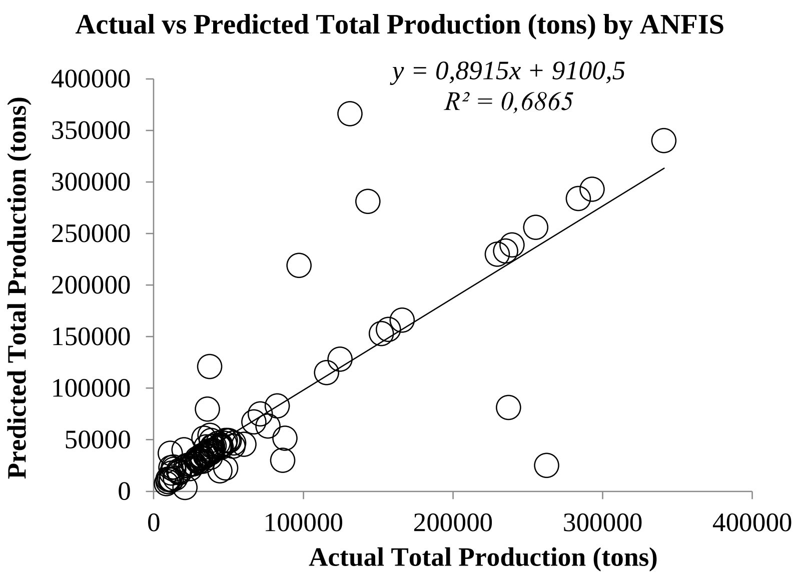

Figure 3. Scatter plot of actual and predicted values by ANFIS model

The output surface maps for the developed ANFIS model were illustrated in Figures 4. The 3D surface visualization of the relationships between inputs and output for ANFIS model was plotted in these figures. These figures display the dependence of predicted values on any two inputs.

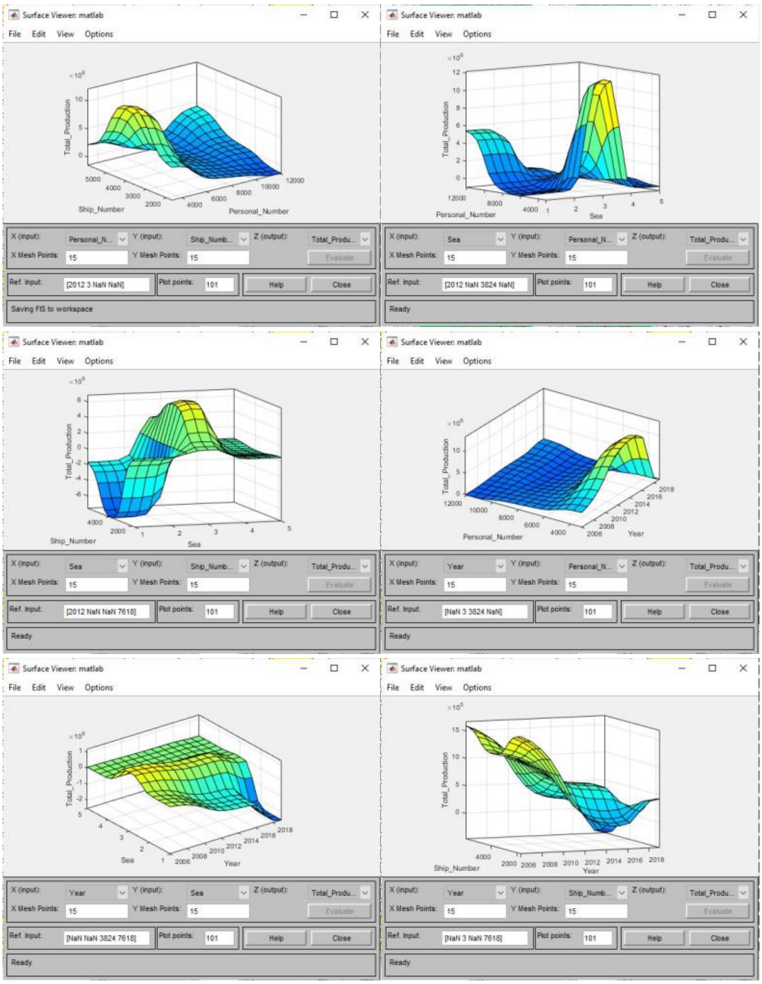

Figure 4. A 3D surface visualization of the relationships between inputs and output for ANFIS model

DISCUSSION

The results of this study showed that the ANFIS model is effective in terms of prediction performance in marine fisheries data. The developed ANFIS model successfully modeled complex data structures and nonlinear relationships, providing superiority in prediction accuracy. The low RMSE value and relatively acceptable correlation coefficient of the model prove that it has a structure suitable for the data set used.

The effect of different seas (e.g., eastern Black Sea) on model performance was found significant. Differences were found in fish production according to seas, especially production was estimated higher in the eastern Black Sea and Marmara Sea. Differences among seas show the effect of regional factors (e.g., fish stocks, fishing intensity and environmental conditions) on production amount. This situation reveals the importance of evaluating the regions separately.

Several statistical approaches have been used to estimate some values in fisheries. Kale and Berber (2023) developed an artificial neural network (ANN) model for estimating growth model of freshwater crayfish (*Pontastacus leptodactylus*) in a reservoir in Çanakkale, Türkiye. Kale and Sönmez (2022) used innovative trend analysis methodology for the aquaculture production of rainbow trout *Oncorhynchus mykiss*. Kale and Berber (2020) forecasted future trends of the freshwater crayfish production in Türkiye. Kale (2020b) estimated future trends in marine capture fisheries in Türkiye by using different statistical methods. Kale et al. (2021a) analyzed trends in the global fisheries and aquaculture production of the grooved carpet shell *Ruditapes decussatus*. Kale et al. (2021b) analyzed trends in the aquaculture production of rainbow trout *O. mykiss*. Although the current study developed an ANFIS model by fuzzy logic approach, it can also be used for estimating future possibilities of production. One of the potential limitations of this study could be the restricted input dataset. However, as noted by Nayak et al. (2004), one key advantage of ANFIS is that, unlike many time series modeling methods, it does not require a predefined model structure. Therefore, the developed ANFIS model stands out among other techniques for predicting marine fisheries production. By addressing the limitations of traditional methods and incorporating the advantages of hybrid intelligent systems, the present study seeks to develop a more robust framework for fisheries production prediction. Compared to traditional statistical models, ANFIS's ability to better manage uncertainties and nonlinear relationships shows the advantage of the model. On the other hand, the model showed lower performance in certain seas. This situation reveals the necessity of expanding the scope of input variables or optimizing model parameters. For example, the inclusion of additional variables such as environmental factors or socioeconomic data can increase model accuracy.

CONCLUSION

In this study, a fuzzy logic approach was applied and an ANFIS model was developed to estimate the production amounts of marine fisheries. The results show that the model can successfully handle nonlinear relationships and complex data structures. The developed ANFIS model can be used as a reliable estimation tool. On the other hand, it is emphasized that regional differences should be taken into account, especially in the marine fisheries sector. This study demonstrates the potential of ANFIS as a decision support tool in fisheries management. It provides an effective method for making future production estimates, especially for sustainable management of fish stocks. In the future, it is recommended to expand this study with more comprehensive data sets and other artificial intelligence methods. Further studies can be conducted on comparing different fuzzy logic approaches and model optimization using a larger data set. In addition, hybrid models can be developed with other artificial intelligence techniques to increase prediction accuracy.

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Chapter 19

Reuse of Treated Wastewater

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Introduction

Water is one of the most basic natural resources needed by all living things. The total amount of water in the world is 1.4 billion km^3. Of this, 97.5% is salt water in oceans and seas and 2.5% is fresh water in rivers and lakes. At most, the ratio of usable water is between 0.5% and 1%. Since 90% of the freshwater resources are trapped in the poles and underground, it is clear how little fresh water is available for human beings to easily benefit from (DSİ, 2008; Erdağ, 2015). That's why using and protecting the limited water resources essential to all living things and good water management have become increasingly important in recent years.

According to the Falkenmark Water Scarcity Index, an important international criterion, the amount between 1000-1700 m^3 per year is accepted as the water stress range (Falkenmark and Widstrand, 1992). Considering the population of Turkey in 2021, the annual amount of water per capita is 1,323 m^3 (DSİ, 2021). This means that Turkey is one of the stressed countries. The Turkish Statistical Institute (TUIK) predicts that our population will reach 100 million in 2030. In this case, we will be a water-poor country, with an estimated 1,120 m^3/year of usable water per capita in 2030 (DSİ, 2009; Öztürk et al., 2015; Çankaya, 2017).

Our country is not rich in water resources and the available resources are not evenly distributed throughout the country. According to the reports of the General Directorate of State Hydraulic Works (DSİ), our country has a total of 234 billion m^3 of usable water but 112 billion m^3 of this amount is not available for economic and technical reasons. Therefore, it is important to focus on R&D studies for both the supply of water resources and the reuse of used water (Kitiş et al., 2019). According to the information obtained from the TUIK and DSI reports, these figures show that the recovery and safe use of wastewater is of crucial importance for Turkey.

Population growth and the need to meet the food demand of a growing population have increased the need for agricultural and industrial activities, while at the same time increasing the demand for water resources. Despite the continuous increase in water consumption, the fact that available water resources are limited and gradually decreasing has made it necessary to manage resources more effectively and efficiently and to take measures to reduce water consumption (Bingül and Altıkat, 2017; Agrafioti and Diamadopoulos, 2012).

Population growth, climate change, water stress, pollution and land-use changes affecting water quantity and quality will continue to put increasing pressure on water resources around the world. Water scarcity, declining water quality and quantity, difficulties in supplying water resources have made the use of alternative water resources a priority. One of these alternative sources is the reuse of treated wastewater after treatment by various methods. The recovery and reuse of wastewater after treatment has become an essential component in terms of water sustainability at both national and international levels, and has found a wide range of applications, particularly in arid and semi-arid regions where water is scarce (Bingül and Altıkat, 2017; Pedrero et al., 2010; Demirer, 2011; Koyuncu and İmer, 2016; Zaibel et al., 2016). Water scarcity and water pollution are among the most important issues in the world today. This study has reviewed scientific studies on the reuse of treated wastewater, as well as publications and reports from relevant institutions and organisations, to provide up-to-date information.

Definition, importance and areas of application of wastewater

According to the Regulation on Water Pollution Control (2004), wastewater is defined as water that has been polluted or whose properties have been partially or completely changed because of urban, industrial, domestic, agricultural and other uses, as well as water from installations such as mines, car parks, roads and similar areas because of precipitation becoming surface or subsurface flow.

The reuse of wastewater is becoming more common in cities due to water scarcity, increasing costs and supply difficulties. The benefits of wastewater reuse are briefly described below.

- It can be used as a sustainable alternative water source, it is a reliable water source when the necessary controls are in place.

- It results in less energy consumption.

- It results in less use of new water resources.

- Reusing treated wastewater reduces surface water degradation (Miller, 2006).

1.1. Urban reuse

Drinking quality water supplied to an urban area is also used for the following purposes in addition to its use as drinking water (Anonymous, 2004):

- Irrigating landscaped areas around parks, recreation areas, sports fields, school gardens and playgrounds, major roads, buildings and other public facilities,

- Landscaping areas surrounding workplaces, shops and industrial facilities,

- Commercial uses (car washes, window washing, preparation of pesticide and herbicide solutions, preparation of liquid fertilisers, etc.),

- Providing water for artificial uses such as swimming pools, fountains, waterfalls in the city,

- Use of water for concrete construction and dust control in construction projects,

- Supplying fire water for fire protection,

- Use as toilet water in buildings,

- Golf course irrigation.

Reusing wastewater in these areas provides significant water savings.

2.2. Industrial reuse

Recycled industrial water is widely used in developed countries. Reclaimed water is ideal for many industries that do not require potable water. Reclaimed water can be achieved by recycling industrial wastewater within the plant and/or by using water treated in domestic wastewater treatment plants.

Water recycling within the industry itself is often implemented as part of the process. Many industries, such as steel, textiles and electronics, treat and recycle their wastewater either to protect the water or to meet required effluent standards. Recycled water is used in industry to cool, feed boilers and process water. Among the industrial uses, cooling water is the most common (Güneş, 2002).

2.3. Reuse for environmental and recreational purposes

It is used to irrigate parks and golf courses, particularly in arid regions, and to fill lakes for recreational purposes. It also includes processes for the enhancement of wetlands. For recreational purposes, treated wastewater can be used for golf courses, fishing and snowmaking.

2.4. Recharge and reuse of groundwater.

Although it is not a common practice in Turkey, the use of the treatment capacity of the soil by infiltration of treated wastewater into the ground is practised in developed western countries (USA, Netherlands, Germany, etc.). In the USA, studies on the injection of treated wastewater into groundwater, which have been carried out since 1962, have been improved since 1978 and continue as injection of wastewater into groundwater at drinking water standards after treatment.

Treated wastewater can be discharged into groundwater by surface spraying, river discharge, sand filtration, soil-water treatment systems and direct injection.

The purposes of discharging treated wastewater to groundwater are listed below (Güneş, 2002);

- To prevent saltwater intrusion into the aquifer in coastal areas,

- To ensure better treatment and reuse of wastewater,

- To increase the water capacity of drinking water or other aquifers,

- Ensure storage of treated water and prevent lowering of groundwater levels.

2.5. Reuse for irrigation purposes

Reuse for agricultural activities is another method of water resource management. Reuse of treated wastewater in agriculture has many advantages. Firstly, applying treated wastewater in farms increases production. This is because treated wastewater contains many nutrients that plants need.

This reduces the need for additional nutrients after irrigation. This increases the yield of the crop. However, there are many health issues that need to be considered. As well as nutrients, wastewater contains many micro-organisms that are harmful to health. The amount of water used for agricultural activities accounts for a large percentage of total freshwater consumption. Approximately 70 per cent of the world's water is used for irrigation, including the extraction of groundwater by pumping for agricultural purposes (Kretschmer ve ark., 2002). The uses and applications of treated wastewater are summarised in Table 1.

Table 1. Uses and practices of treated wastewater (Fesliyen, 2017)

Reuse Areas	Applications
Environmental	Stream flow regulation Swamps and wetlands Recreational areas (parks and lakes) Fishing and aquaculture
Agriculture and horticulture	Fodder and seed crops Edible crops Basic feed water Turf and forests Tree Nursery Protect against freezing
Urban	Fire protection Toilet flushing Street/Car washing Dust control Air conditioning
Industrial	Cooling Boiler feed Construction Process water Flue gas cleaning
For drinking	Direct drinking Indirect drinking

1.6. Some examples of reusing treated wastewater in Turkey and some other countries

Major reuses of treated wastewater include irrigation (both agricultural and landscape), aquifer recharge, seawater barriers, industrial applications, dual distribution systems for toilet flushing and other urban uses. National governments have recognised the importance of water and environmental benefits of wastewater reuse. The value of wastewater is increasingly recognised in arid and semiarid countries, and many are seeking ways to improve and expand wastewater reuse. Recognising both the benefits and the threats, researchers are considering this as one of the options for future water needs. Today, the planning of wastewater treatment and reuse projects is increasing significantly in many countries. International organisations such as the World Bank, the Food and Agriculture Organization of the United Nations (FAO) and the World Health Organization (WHO) estimate that the average annual increase in water reuse is between 25% in the USA, China, Japan, Spain, Israel and Australia. The countries where wastewater reuse is most widespread are the USA, Israel, Australia, Japan, the United Arab Emirates and Western European countries (Polat, 2013; Saraoğlu, 2019).

Wastewater reuse can supplement existing water resources, particularly in arid/semi-arid climates. Most large-scale reuse projects are located in arid regions of Israel, South Africa and the USA, where alternative water sources are limited. Even in areas where there is sufficient rainfall, there are water shortages due to the variability of rainfall both in location and time. For example, the US state of Florida is not an arid region but has a limited water storage capacity and suffers from water shortages during dry periods. Wastewater reuse programmes therefore make an important contribution to the region's water resources. (Vigneswaran and Sundaravadivel, 2004)

The use of wastewater in Europe varies by region. In Southern Europe, 44% of wastewater projects are mainly used for agricultural purposes and 37% for urban/environmental purposes. In Northern Europe, 51% of wastewater projects are mainly used for environmental purposes and 33% for industrial purposes. In Portugal, depending on the duration of wastewater storage, the size of land irrigated with treated wastewater varies between 35,000 and 100,000 hectares (ha). Irrigation with treated wastewater covers 38,200 ha in Cyprus and 28,285 ha in Italy (Sato et al., 2013).

In Florida, United States, in 2001, 19 % of the treated effluent from 461 municipal wastewater treatment plants was used for agricultural irrigation, 44 % for public landscaping, 16 % for surface water recharge, 15 % for industrial uses, and 6 % for wetlands and other areas. (Bozdoğan, 2009; Saraoğlu, 2014).

In Iran, studies have been conducted on the use of treated wastewater for irrigation of forage crops such as maize, millet and alfalfa, and have found that the amount of fertiliser and water used for irrigation has been substantially reduced due to the nutrients contained in the wastewater. The 'Wastewater Discharge Standards' that came into force in 1994, regulate the practice of reusing treated wastewater in the country. These standards set acceptable discharge standards for the receiving environment and standards for agricultural use, but as the microbiological criteria set are inadequate, reliable international standards such as WHO and EPA are generally used in wastewater reuse practices (US EPA, 2004; Saraoğlu, 2014).

Karataş et al. (2005) investigated the usability of domestic and industrial wastewater generated in İzmir province as irrigation water in the Menemen Plain after treatment. It was found that the total salt, electrical conductivity (EC), dissolved solids (DS), sodium adsorption ratio (SAR) and chloride (Cl) in the treated wastewater of İzmir exceeded the tolerance limits of many crops and could not be used for irrigation in its current state, according to the Water

Pollution Control Regulation (WPCR) Communiqué on Technical Procedures and related literature.

According to Kukul et al. (2007), the use of wastewater in agriculture is considered to be a good and useful method of wastewater management with an appropriate strategy. In addition to protecting clean water resources, this situation reduces the need for agricultural fertilisers due to the plant nutrients contained in wastewater and increases the metabolic activities of soil microorganisms useful for plant growth. Research shows that recycled wastewater, which does not contain toxic heavy metals, improves soil fertility (Fesliyen, 2017).

An economic study in Şanlıurfa has shown that the elements arsenic (As), copper (Cu) and cadmium (Cd) in the effluent of the onion farm irrigated with the water of the Karakoyun stream, which passes through the city centre and where domestic and industrial effluents are discharged, are above the limits allowed for irrigation water (Doğan, 2003; Fesliyen, 2017).

The project titled "Investigation of the Usability of Treated Wastewater in Irrigation in the Ergene Basin" examined the treated wastewater resulting from the treatment of 13 domestic wastewaters in the Ergene Basin. According to the results of the study, it was found that biochemical oxygen demand (BOD), turbidity and faecal coliform parameters were limiting for the use of irrigation water and that rapid sand filters and ultraviolet (UV) disinfection units should be added to the plants in order to use treated wastewater for irrigation. Another study investigating the use of treated effluent from the Kayseri Advanced Biological Treatment Plant for agricultural irrigation reported that sand filters and UV disinfection units should be added to the plant in order to use the plant effluent in the Süksün area, where irrigation water demand is high between May and September (Duman, 2017).

Gülocak and Kıymaz (2022) investigated the suitability of wastewater from the city centre of Kırklareli, which is treated in existing domestic and industrial wastewater treatment plants and discharged into the Kırklareli stream, for agricultural purposes by determining the quality and pollution status of the irrigation water. The results obtained showed that the seasonal quality class of the Kırklareli stream water samples is Class IV in terms of physical and inorganic-chemical parameters according to the criteria specified in the Water Quality Control Regulation, and Class C3S1 in terms of EC and SAR values according to the US Salinity Laboratory Classification and should be used with caution due to the high salinity. Another study, carried out in Konya, looked at using municipal wastewater for agricultural irrigation and how it affected maize production. It was found that the flowering and vegetative periods in the development of maize plants were significantly changed, the harvest index decreased, dry matter production increased and yield elements such as cob length and cob width were not affected. The study concluded that urban and municipal wastewater can be used in maize cultivation by purifying and diluting it. However, it was concluded that the use of waste and wastewater-based mixtures without salinity control, microbiological treatment and heavy metal treatment will significantly affect the drying of soils and the rate of microbial contamination and continuity of contamination (Çay, 2013).

Conclusions and recommendations

Rapid population growth, increasing demand for water and the gradual depletion of clean water resources and limited access to them have created a need for the best possible management of our water resources. Increasing water scarcity, difficulties in water supply and decreasing freshwater resources have put the search for alternative water resources on the agenda. Among these, the reuse of wastewater through treatment is becoming increasingly important. Reusing treated wastewater for urban and industrial purposes, recharging aquifers and irrigating green areas is becoming increasingly common around the world. Extensive studies and case studies on this subject have become important, especially in the last twenty years.

The purpose of wastewater reuse depends on many factors. These include the characteristics of the application site, the topography, the status of the water resources and the socio-economic characteristics of the users. At the same time, local government plans, wastewater reuse policies and legislation are also important.

However, the reuse of treated wastewater causes a number of problems if the necessary precautions are not taken. Health problems are the most important of these. To eliminate the environmental and health risks associated with wastewater reuse, it is necessary to develop water quality standards and to treat wastewater to a level that meets these standards. Many countries around the world are making progress in establishing criteria or standards. In recent years, the focus in establishing these standards has been on treatment and standardisation according to the purpose of use.

The Technical Procedures Circular for Wastewater Treatment Plants, published in the Official Gazette on 20 March 2010, number 27517, sets out the technical principles for the recovery and reuse of treated wastewater in our country, the quality standards to be met by treated wastewater depending on its use, and the appropriate treatment methods. This Circular has been prepared to regulate the basic technical procedures and applications to be used in the selection of technology, design criteria, disinfection, reuse of treated wastewater and deep-sea discharge of treated wastewater and disposal of sludge generated during treatment activities.

It is important that the reuse of treated effluent is in accordance with the water quality criteria required for the intended use. Proper collection of wastewaters and its use for irrigation with safe methods after treatment should be encouraged. In this way, water is saved and water resources are not polluted, crop productivity is increased, the need for artificial fertilisers is reduced, and wastewater is disposed of in the most beneficial way without harming nature.

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Chapter 20

Slow-Release Technology in Fertilizer Use

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INTRODUCTION

Controlled-release fertilizers (CRFs) offer numerous advantages, such as enabling one-time fertilization, reducing nutrient losses, preventing the toxic effects of chemical fertilizers on seeds, and lowering harmful gas emissions (Shaviv, 2000; Hutchinson et al., 2002; Sempeho et al., 2014). However, these technologies have disadvantages, including high costs, the non-biodegradability of coating materials, and potential negative effects on soil pH (Azeem et al., 2014). Soil properties such as structure, pH, lime, and organic matter directly or indirectly influence plants' ability to absorb nutrients (Tisdale & Nelson, 1975). When fertilizers are added to the soil, various chemical reactions occur. For example, nitrogen-containing fertilizers in calcareous soils are prone to losses through volatilization and leaching, while phosphorus fertilizers form insoluble compounds like Al-phosphate or Fe-phosphate in acidic soils and Ca-phosphate in alkaline conditions (Azeem et al., 2014; Syers et al., 2008). Furthermore, potassium can become fixed in 2:1 clays like illite, and phosphorus in 1:1 clays like kaolinite, making them unavailable to plants (Tisdale & Nelson, 1975). To mitigate these issues, various technologies have been developed, including controlled-release fertilizers (CRFs) and slow-release fertilizers (SRFs) (Hanafi et al., 2002).

Although CRFs and SRFs may appear similar, they differ in certain aspects. In SRFs, the release of nutrients occurs at an unpredictable rate and is dependent on environmental factors. In contrast, CRFs allow for a more predictable release rate and amount over time (Azeem et al., 2014). CRFs release nutrients gradually, helping to maintain nutrient balance in the soil for an extended period. The availability of adequate nutrients in the soil solution is critical for healthy plant growth (Cole et al., 2016).

SRFs represent an innovative technology designed to enhance agricultural productivity and ensure environmental sustainability. Manufactured through advanced methods such as encapsulation and microencapsulation, these fertilizers prevent the loss of essential nutrients like nitrogen and phosphorus. The uncontrolled and excessive use of traditional fertilizers has led to environmental pollution, nutrient losses, and long-term soil degradation. SRFs offer an effective alternative by addressing these problems, providing a more efficient option for agricultural activities. These innovative fertilizers release nutrients in accordance with plant needs, regulating soil nutrient balance. Such features optimize plant growth, reduce environmental pollution, and promote sustainable agricultural practices. Additionally, they provide various environmental benefits, such as conserving energy, protecting water resources, and reducing greenhouse gas emissions.

The materials used in the production of these fertilizers include sulfur, polymers, water-retaining agents, and biocomposites, with variations in release duration and rate (Azeem et al., 2014). For instance, polymer-coated fertilizers provide prolonged nutrient release; however, the release rate and quantity may vary depending on environmental conditions (Cabrera, 1997). To develop fertilization methods suited to plant needs, the effects of environmental factors, especially temperature and humidity, on fertilizer release must be thoroughly analyzed (Merhaut et al., 2006; Du et al., 2006).

While SRFs and CRFs offer specific advantages for supporting plant growth, they may not be effective for plants with short growth cycles (Andiru et al., 2015). Nutrient release in these fertilizers typically occurs in three stages: lag period, linear release period, and decay period. This process can take longer for nutrients such as phosphorus compared to others (Shaviv et al., 2003; Du et al., 2006). Their use is particularly important in container-grown plants, where the limited volume necessitates minimizing nutrient losses (Chen & Wei, 2018; Uçgun et al., 2021). The aim of this review is to provide information on the advantages and general effects of slow-release fertilizers on plants.

SLOW-RELEASE FERTILIZERS

Slow-release fertilizers (SRFs) have been a frequently researched topic in recent years across various plant species. The primary advantage of these fertilizers lies in their high efficiency due to slow dissolution, minimizing losses caused by leaching. They do not undergo chemical changes in the soil, bind with clay, lime, or organic matter, or form compounds with other elements. Consequently, nutrients remain readily available for plant uptake without transitioning into non-usable forms (Raun & Johnson, 1999).

Nitrogen is one of the most crucial nutrients for plant growth and development. However, the nitrogen use efficiency in cereal crops has been reported to be only 33% (Mukherjee et al., 2015; Akgün et al., 2021). SRFs emerge as an effective tool for improving nitrogen use efficiency. These fertilizers provide a consistent nutrient source for plants, enhancing productivity and reducing environmental losses.

SRFs are a specialized fertilization method designed to increase nitrogen use efficiency in agriculture while minimizing environmental losses. By extending the duration of nitrogen availability in the soil, SRFs enable plants to achieve balanced nitrogen nutrition, resulting in increased yield and quality. Additionally, they prevent nitrogen loss through leaching, reducing environmental pollution. Nitrogen losses typically occur via processes such as denitrification, volatilization, soil erosion, and immobilization. To address these issues, specialized fertilizers have been developed to minimize nitrogen losses and slow the conversion of ammonium nitrogen to nitrate (Trenkel, 2010).

These fertilizers are categorized based on their composition and release mechanisms, including pelletized SRFs, chemically modified formulas, and coated SRFs, which are the most common types (Anonymous, 2020). SRFs provide balanced nutrient supply to plants while minimizing adverse effects on soil and the environment. Nitrogen fertilizers are one of the most expensive inputs in agriculture, with an estimated annual global cost of approximately $50 billion (Ladha & Chakraborty, 2016). However, even under ideal conditions, only about 50% of the nitrogen fertilizers applied to the soil are utilized by plants, while the remainder is lost through volatilization, leaching, or binding with soil organic compounds (Korkmaz, 2007; Kocabaş & Akgün, 2021).

ADVANTAGES OF SLOW-RELEASE FERTILIZERS

SRFs significantly enhance plant yield and quality by facilitating effective and balanced nutrient use in agriculture. Various studies have highlighted the advantages of these fertilizers. Sramek and Dubsky (2007) demonstrated the positive effects of SRFs on plant growth in a two-year study on container-grown woody plants. Lopez et al. (2008), in their study on maize fields with nitrification inhibitors and increased nitrogen doses, found significant yield improvements and confirmed the effectiveness of nitrification inhibitors in this process. These findings illustrate the potential of SRFs to reduce nitrogen losses and increase yields. Çelebi et al. (2009), in their research on maize in Van province, reported that nitrogen doses significantly influenced silage yield and feed value. Durmaz (2012) investigated the effects of SRFs and foliar fertilizers on sunflower plants, reporting the highest yield and oil quality in combinations of SRFs and foliar fertilizers. Moreover, in plots using only SRFs, the reduction in stearic acid content highlighted their positive impact on oil quality (Cengizer, 2024).

CONCLUSION

Slow-release fertilizers represent a vital innovative technology for enhancing yield and quality in agricultural production while minimizing environmental impacts. By providing nutrients effectively over an extended period, SRFs reduce nitrogen losses and environmental pollution. They also help maintain soil nutrient balance, optimize plant growth, and support a more sustainable agricultural model. Various studies have clearly demonstrated the positive effects of SRFs on plant yield, nutrient use efficiency, and product quality.

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Chapter 21

The Usage Areas of Natural Fertilizers

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INTRODUCTION

The increase in global food demand has directed agricultural production toward more efficient and environmentally friendly methods. The environmental degradation and economic burden caused by chemical fertilizers have accelerated the development of alternative solutions in agriculture. Implementing sustainable agricultural practices is of great importance for reducing environmental harm and maintaining agricultural productivity in the long term. The rapid growth of the world population has necessitated an increase in agricultural production, which, in turn, has encouraged the widespread use of chemical fertilizers. However, the excessive and uncontrolled use of chemical fertilizers has led to serious problems, harming the environment and human health. Issues such as water and soil pollution, long-term productivity loss of agricultural lands, and increased greenhouse gas emissions are among the most pressing concerns. Furthermore, the overuse of chemical fertilizers disrupts the microbial balance of the soil, weakening plants' defense mechanisms. These adverse effects have made the need for sustainable and environmentally friendly solutions in modern agriculture inevitable. In this context, natural fertilizers emerge as an environmentally friendly alternative.

Natural fertilizers are products derived from natural resources that enhance agricultural production while minimizing environmental damage. These biological fertilizers have positive effects on soil and plant health, preserving the natural microbial balance of the soil. They also promote the efficient utilization of nitrogen cycles and other nutrients by plants. The aim of this review is to explain the production stages of natural fertilizers in detail and to highlight their benefits for plant and soil health.

NATURAL FERTILIZERS

The diversity and expanded usage areas of fertilizers necessitate their classification into specific groups. Fertilizers are generally divided into two main categories. Researchers have used various terms such as Natural and Artificial Fertilizers, Organic and Mineral Fertilizers, or Farmyard and Commercial Fertilizers, depending on temporal and regional differences. Today, the classification of fertilizers as Chemical and Organic is commonly used. However, advancements in technology and increasing product diversity have introduced innovations in fertilizer classifications. For instance, fertilizers can also be categorized based on their physical properties, such as granular or water-soluble fertilizers. In terms of usage frequency and diversity, organic and chemical fertilizers stand out.

The production processes of natural fertilizers rely on various techniques and methods to maximize the benefits they provide to plants. Fertilization methods range from traditional techniques like manual spreading to mechanized applications that have become widespread in modern agriculture. Mechanized fertilization, in particular, enhances efficiency and ensures even distribution of fertilizers over larger areas. The fertigation method is an example of these innovations. Fertigation involves mixing fertilizers with irrigation water, which has been shown to save approximately 17% on fertilizer consumption and achieve a 20-30% increase in yield (Soylu et al., 2010). The production processes of natural fertilizers are crucial for plants to derive maximum benefit. However, even under optimal conditions, it is noted that only 50-60% of the applied fertilizer is utilized as plant nutrients (Koca, 2008; Zengin and Gezgin, 2011). This underscores the need to improve the efficiency of fertilizer use. For example, of the 5.8 million tons of fertilizer consumed in Turkey in 2013, approximately 3.4 million tons were directly used as plant nutrients (Şahin, 2016).

The rapid increase in global food demand has led to the widespread use of chemical fertilizers in agricultural production. However, this has resulted in significant environmental and economic problems. Although chemical fertilizers provide essential nutrients for plant growth, their excessive use has adverse effects, such as increased greenhouse gas emissions, groundwater pollution, and long-term productivity losses in agricultural lands (Peng et al., 2022). Moreover, intensive fertilization disrupts the natural structure of the soil, making plants more vulnerable to pests and diseases by weakening their defense mechanisms. Additionally, the leaching of nitrogen into groundwater poses severe pollution risks to human and animal health (Prather et al., 2012). For these reasons, environmentally friendly alternative approaches in agriculture are becoming increasingly important.

Fertilizers are classified into different categories based on their purposes and contents. These categories include organic, chemical, microbial (biofertilizers), and organomineral fertilizers. Organic fertilizers consist of subcategories such as animal/manure fertilizers, green manures, peat soil, composts, and humic acids. Chemical fertilizers are divided into subcategories such as single-nutrient fertilizers, compound fertilizers, micronutrient fertilizers, and specialty fertilizers. Microbial fertilizers contain microorganisms beneficial to plants and soil. Organomineral fertilizers combine the characteristics of organic and chemical fertilizers (Şahin, 2016).

Biofertilizers play a significant role in reducing nitrogen losses and minimizing environmental impacts in agriculture. For example, symbiotic microorganisms such as Rhizobium convert atmospheric nitrogen into forms usable by plants, naturally meeting nitrogen requirements (Feng et al., 2014; Muthusamy et al., 2023). Additionally, Bacillus species have been found to promote nitrogen fixation, root development, and shoot growth (Dinesh et al., 2013; Antil et al., 2022). According to TAGEM (2021), biofertilizers consist of commercial formulations produced with non-genetically modified microorganisms and are effective in processes such as nitrogen fixation and phosphorus mobilization. These characteristics make biofertilizers a solution that supports agricultural sustainability and minimizes environmental damage. Particularly in organic farming practices, the use of biofertilizers contributes significantly to reducing environmental harm while enhancing agricultural productivity (Ergün, 2024).

THE BENEFITS OF NATURAL FERTILIZERS

Natural fertilizers make significant contributions to both agricultural production and environmental sustainability. In a study by Stephens et al. (1989), the effects of organic mushroom compost applied alone or in combination with chemical NPK fertilizers on different plant species were investigated. The study found that the highest yield in tomato cultivation was achieved by combining mushroom compost with NPK fertilizer, whereas compost alone was sufficient for kale and pumpkin. Similarly, Erdin (1992) noted that composting organic wastes under suitable conditions serves as a continuous source of essential nutrients such as carbon, nitrogen, phosphorus, and potassium, acting as a complement to synthetic fertilizers. This method is considered a major step not only for agricultural benefits but also for environmental cleanliness.

In Kozak's (1996) study on organic and mineral fertilization, it was observed that organic fertilization provided greater resistance to pests and diseases, while mineral fertilization was more effective in improving quality characteristics. Robertson and Morgan (1996) evaluated the effects of green legume compost on properties such as microbial activity, nitrogen, and water content in soils used for pasture and vegetable cultivation. This study highlighted that organic fertilizers contribute to soil organic matter and increase water content.

The contributions of natural fertilizers to agricultural production are noteworthy in terms of soil fertility and environmental sustainability. In a study by Robertson and Morgan (1996), the effects of transforming organically grown vegetable fields into pastures and conventional farmland were examined. The application of green legume compost (0, 1, and 2) was assessed for its impact on soil bacteria, fungal hyphal lengths, microbial carbon mass, nitrogen, and water content over 18 months. The results showed that previously pasture-used fields exhibited more positive outcomes compared to vegetable fields. Bacteria populations declined during the first six months but stabilized afterward. Water content and microbial activity remained higher in pasture areas, while legume rotation in vegetable fields improved these values. Overall, the applications significantly enhanced soil organic matter and water content.

Abbasi et al. (2002) investigated the effects of compost derived from processed waste on tomato cultivation. The study demonstrated a 33% increase in yield with compost application compared to the control group. Additionally, compost application resulted in more mature and higher-quality fruits, showcasing the potential of fertilizers derived from organic waste for plant growth and product quality (Özer, 2012).

Organic materials like leonardite and vermicompost improve soil structure and support plant growth. Yıldız et al. (2019) found that both applications effectively enhanced phosphorus content and soil quality, with vermicompost achieving greater success. This underscores the importance of biofertilizers in regulating soil structure and facilitating nutrient transport to plant roots.

In greenhouse-grown tomato cultivation, mycorrhiza and vermicompost applications increased tomato yields by 2.5% and 8.3%, respectively. Additionally, mycorrhiza applications were noted to increase total soluble solids (Brix) content (Ergün, 2024). These results demonstrate that the effects of biofertilizers can vary depending on the plant species and application method.

CONCLUSION

Natural fertilizers improve plant growth and product quality by maintaining the microbial balance of the soil in agricultural production. These fertilizers play an effective role in reducing environmental pollution. Considering the adverse effects of chemical fertilizers, natural fertilizers offer a sustainable solution. While improving soil quality, they also support environmental health in the long term. The widespread adoption of natural fertilizers will make a significant contribution to environmental sustainability. Therefore, natural fertilizers should become an indispensable component of modern agriculture.

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Chapter 22

Assembly Line Balancing Problems: A Case Study in the Furniture Industry

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INTRODUCTION

The furniture industry plays a vital role in the Turkish economy, serving as a key driver of employment, production, and international trade. According to the Turkish Statistical Institute (TÜİK, 2021), in 2020, there were almost 40 thousand enterprises in the sector, employing ove than 200 thoushands employees. The sector achieved an impressive export value of 4.5 billion USD in 2023, covering products of furniture, bedding, mattress supports, and cushions (#82 in SITC, Rev.4) (TÜİK, 2024). In contrast, imports remained significantly lower at 729 million USD, underscoring the industry's strong export-oriented structure and trade surplus. As of 2022, Turkey ranked as the eleventh-largest furniture exporter globally, contributing 1.74% to the total global furniture trade (Ministry of Trade, 2022). The sector's competitive advantage stems from its rich domestic resources, skilled workforce, and growing production capacity. These factors have allowed Turkish manufacturers to establish a strong foothold in international markets, particularly in Europe, the Middle East, and North Africa. Türkiye's strategic geographical location, coupled with increasing investments in innovation, sustainable production practices, and contemporary design, enhances the Turkish furniture industry’s global competitiveness. As a result, Türkiye continues to solidify its position as a significant player in the global furniture trade, contributing both to economic growth and the country's export performance.

The furniture industry in Türkiye predominantly consists of independent, small-scale workshops that rely on traditional methods and skilled craftsmanship to produce household items (Gungor & Oguz, 2024). On the other hand, there has been a noticeable rise in the number of medium and large-scale businesses in recent years (Ministry of Trade, 2021). Transitioning to larger, mass-production enterprises would contribute even more to the country's economy. This shift would enhance efficiency and productivity by streamlining operations and reducing lead times. In traditional workshop-based production, processes are often fragmented and less standardized, leading to higher costs and slower production. Adopting a mass-production approach, on the other hand, allows manufacturers to optimize the use of resources, such as labor, materials, and machinery, thus achieving economies of scale. The shift to larger production systems also supports innovation by enabling the integration of advanced technologies, such as automation and robotics, which enhance precision, reduce human error, and increase overall productivity. This not only offers operational benefits but also positions the industry for long-term growth and sustainability in the competitive global furniture market.

It should be noted that mass-production also presents challenges, one of the most critical being line balancing. Inadequate balancing can lead to bottlenecks, uneven workloads, and inefficiencies, which undermine the benefits of mass-production. Assembly line balancing is the process of assigning tasks to workstations in such a way that production is streamlined and the overall efficiency is maximized. The key problem lies in distributing tasks across workstations while minimizing idle time and ensuring that each station's workload is balanced. Various methods exist to solve this problem, such as the largest candidate rule, the position-weight method, and the Kilbridge and Wester method, each offering unique approaches for different production scenarios. In the literature, there exist several studies working on line efficiency and assmbly line balancing in the furniture industry (Akin, 2015; Bambura et al., 2020; Bon Ali & Zulkifli, 2017; Bulut & Altunay, 2016; Guner Goren, 2017; Karsiyaka & Sutcu, 2019; Nouri & Abdulnour, 2019; Sithebe, 2013; Sutcu et al., 2019).

Performance criteria are essential for evaluating the effectiveness of assembly line balancing. Key indicators of good performance include low cycle time, high throughput, minimal idle time, and balanced workloads across workstations. On the other hand, poor performance can manifest in long cycle times, frequent bottlenecks, and significant variation in the time required at each station. These criteria help identify areas for improvement and guide decisions for optimizing production efficiency.

Traditional assembly line balancing problems are generally classified into two types (Tuncel and Topaloglu, 2013). In Type 1 problems, the objective is to minimize the number of workstations for a given cycle time. This approach focuses on reducing labor and equipment costs and is typically used when designing a new production line. In contrast, Type 2 problems aim to minimize the cycle time for a fixed number of workstations. This type is commonly applied when there are changes in product demand or modifications to production processes.

This study aims to minimize the number of active workstations while adhering to several constraints. These include ensuring proper task allocation, respecting workstation capacity limits, maintaining task precedence relationships, and ensuring that the total time assigned to each workstation does not exceed the cycle time. To achieve this objective, a mixed-integer linear programming (MILP) model was employed to address the Type 1 variant of the Assembly Line Balancing Problem (ALBP) in the furniture industry. The study will discuss line balancing performances for two different cysle times: 15 and 18 minutes.

MATERIALS & METHODS

Definition of the problem

A furniture manufacturing company intends to design an assembly line for mass-production. The production will focus on a type of armchair (Figure 1). There are no market-related challenges regarding the sale of the manufactured product. On the other hand, to ensure efficient operation of the workstations, the production assembly line needs to be balanced.

Figure 1. The armchair showing its production components (Web_Link 1).

The armchair to be produced consists of a metal and wooden frame. The frame will be upholstered with foam and fabric. The production process involves 23 different tasks in various departments, including logistics, metal workshop, metal welding line, metal paint shop, spring line, wood workshop, wood assembly line, wood paint shop, foam shop, sewing department, upholstery line, quality control, and packaging line. The tasks required for armchair production, along with their durations and precedence relationships, are presented in Table 1. The precedence relationships are also illustrated in Figure 2.

Table 1. The tasks required to produce the armchair

Task #	Activity	time	I.P.	Process Description
1	Transport raw materials from stock area	13	-	Transport metal profiles, foam, fabric, and wood.
2	Profile cutting (multi-cut machine)	5	1	Cut metal profiles to specified dimensions.
3	Profile bending	4	2	Bend metal profiles for the frame structure.
4	Drilling holes (drill press)	3	3	Drill holes for screws and spring coil connecti-ons.
5	Robotic welding process	8	4	Weld the metal frame using robotic systems.
6	Post-weld deburring	3	5	Clean metal surfaces after welding.
7	Metal surface painting and paint curing	5	6	Apply electrostatic paint on metal surfaces and cure the paint in the drying oven.
8	Spring assembly	4	1	Prepare springs for seating surfaces.
9	Mount springs to metal frame	2	7, 8	Attach springs to the metal frame.
10	Wood cutting (CNC mac-hine)	5	1	Cut wooden components using CNC machines.
11	Wooden frame assembly	4	10	Assemble wooden components into frames.
12	Sanding	4	11	Sand wooden surfaces before painting.
13	Wood surface painting	4	12	Paint wooden frames in the paint line.
14	Foam cutting	4	1	Cut foam for seating and backrest sections.
15	Fabric cutting	5	1	Prepare fabric using CNC cutting machines.
16	Fabric stitching	6	15	Sew fabrics for cushions and upholstery.
17	Assembling metal and wood frames	3	9, 13	Assembling metal frame and wood frame toget-her
18	Foam mounting	6	14, 17	Attach foam to the frame structure.
19	Fabric upholstery (fabric fitting)	7	16, 18	Stretch and staple fabric over foam surfaces.
20	Cushion filling and place-ment	4	16	Fill and place interior cushions.
21	Quality control	3	19, 20	Inspect the product visually, structurally, and functionally.
22	Packaging	5	21	Wrap products with stretch film and carton.
23	Storage and shipment	4	22	Transport packaged products to the shipping area.

time: *duration in minute,* ***I.P.:*** *Immediate Predecessor*

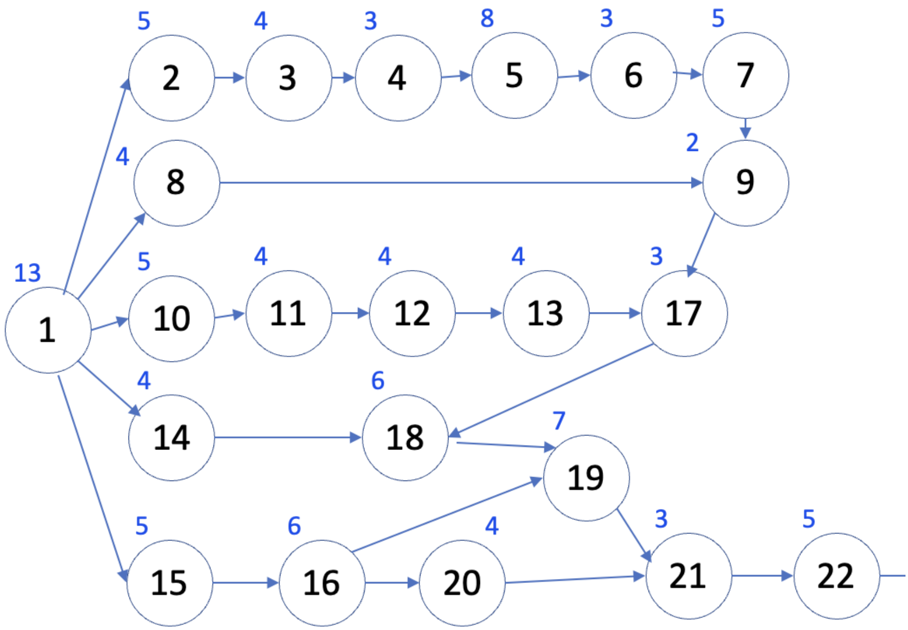

Figure 2. The precedence relationships

Mathematical model

Parameters:

- n: Number of tasks ($n = 23$).
- d_i: Duration of task i, $i \in \{1, 2, ..., n\}$.
- P_{ij}: Precedence matrix where $P_{ij} = 1$ if task i precedes task j, otherwise $P_{ij} = 0$.
- C: Cycle time (maximum time per workstation).

Cycle time for this present study is selected as 18 minutes.

Decision Variables:

- x_{ik}: Binary variable, $x_{ik} = 1$ if task i is assigned to workstation k, 0 otherwise.
- y_k: Binary variable, $y_k = 1$ if workstation k is active, 0 otherwise.
- w: Total number of active workstations.

Objective:

Minimize the number of active workstations:

$$\text{Minimize } w$$

Constraints:

1. **Task Assignment:** Each task is assigned to exactly one workstation:

$$\sum_{k=1}^{n} x_{ik} = 1 \quad \forall i \in \{1, 2, ..., n\}$$

2. **Workstation Capacity:** The total duration of tasks assigned to a workstation cannot exce the cycle time:

$$\sum_{i=1}^{n} x_{ik} \cdot d_i \leq C \cdot y_k \quad \forall k \in \{1, 2, ..., n\}$$

3. **Precedence Constraints:** Precedence relationships between tasks must be respected:

$$\sum_{k=1}^{n} k \cdot x_{ik} \leq \sum_{k=1}^{n} k \cdot x_{jk} \quad \forall i, j \text{ where } P_{ij} = 1$$

4. **Workstation Activation:** A workstation is considered active if any task is assigned to it:

$$\sum_{i=1}^{n} x_{ik} \leq n \cdot y_k \quad \forall k \in \{1, 2, ..., n\}$$

5. **Total Active Workstations:** The total number of active workstations: $w = \sum_{k=1}^{n} y_k$

6. **Sequential Activation:** Prevent non-consecutive active workstations:

$$y_{k-1} \geq y_k \quad \forall k \in \{2, 3, ..., n\}$$

Variable Definitions:

$$x_{ik} \in \{0, 1\},\ y_k \in \{0, 1\},\ w \in \mathbb{Z}^+$$

There is a need for some explanations to understand the mathematical model:

- The objective function minimizes the number of active workstations. The task assignment constraint ensures all tasks are assigned to exactly one workstation.
- The cycle time constraint prevents any workstation from exceeding its time capacity.
- The precedence constraints maintain the required task order.
- The sequential activation constraint ensures workstations are used consecutively.
- The model uses binary variables x_{ik} and y_k to enforce task assignments and workstation activation.

Performance Metrics:

1. **Line Efficiency:**

$$\text{Efficiency} = \frac{\sum_{i=1}^{n} d_i}{w \cdot C}$$

2. **Balance Delay:**

$$\text{Balance Delay} = 1 - \text{Efficiency}$$

Linear programming model

IBM ILOG CPLEX Optimization Studio (v.22.1.1.0) software installed in Apple M2 processor with an 8 GB memory and macOS Sequoia 15.1.1 operation system is employed for optimization analyses. The code for the model file is given below:

```
//*****************************************************

int n = 23;

float duration[1..23] = [13,5,4,3,8,3,5,4,2,5,4,4,4,4,5,6,3,6,7,4,3,5,4];


int precedence[1..23][1..23] = [
  [0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0],
  [1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0],
  [0, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0],
  [0, 0, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0],
  [0, 0, 0, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0],
  [0, 0, 0, 0, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0],
  [0, 0, 0, 0, 0, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0],
  [1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0],
  [0, 0, 0, 0, 0, 0, 1, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0],
```

```
  [1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0],
  [0, 0, 0, 0, 0, 0, 0, 0, 0, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0],
  [0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0],
  [0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0],
  [1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0],
  [1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0],
  [0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1, 0, 0, 0, 0, 0, 0, 0, 0],
  [0, 0, 0, 0, 0, 0, 0, 0, 1, 0, 0, 0, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0],
  [0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1, 0, 0, 1, 0, 0, 0, 0, 0, 0],
  [0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1, 0, 1, 0, 0, 0, 0, 0],
  [0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1, 0, 0, 0, 0, 0, 0, 0],
  [0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1, 1, 0, 0, 0],
  [0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1, 0, 0],
  [0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1, 0]
];
float cycle_time = 18;
// Note that cycle_time is changed to 15 for the second run.
float total_task_time = sum(i in 1..n) duration[i];
float total_idle_time = 0;

dvar boolean x[1..23][1..23];
dvar boolean y[1..n];
dvar int+ w;

minimize w;
subject to {

  forall (i in 1..n)
```

```
    sum(k in 1..n) x[i][k] == 1;
      forall (k in 1..n)
    sum(i in 1..n) x[i][k] * duration[i] <= cycle_time * y[k];

  forall (i in 1..n, j in 1..n)
    if (precedence[i][j] == 1)
      sum(k in 1..n) k * x[i][k] <= sum(k in 1..n) k * x[j][k];

  forall (k in 1..n)
    sum(i in 1..n) x[i][k] <= n * y[k];


      w == sum(k in 1..n) y[k];


   forall (k in 1..n)
    sum(i in 1..n) x[i][k] >= y[k];


   forall (k in 2..n)
    y[k-1] >= y[k];
}
execute {
  var total_idle_time = 0;
  for (var k = 1; k <= n; k++) {
    if (y[k] == 1) {
      var used_time = 0;
      for (var i = 1; i <= n; i++) {
        if (x[i][k] == 1) {
          used_time += duration[i];
        }
```

```
      }
      total_idle_time += cycle_time - used_time;
    }
  }
  writeln("Total Idle Time: ", total_idle_time);
}
execute {
    var efficiency = total_task_time / (w * cycle_time);
    writeln("Line Efficiency: ", efficiency);
}
execute {
  writeln("Minimum number of workstations: ", w);
  for (k in 1..n) {
    if (y[k] == 1) {
      writeln("Workstation ", k, ":");
      for (i in 1..n) {
        if (x[i][k] == 1) {
          writeln("  Task ", i);
        }
      }
    }
  }
}

float total_task_timeS = sum(i in 1..n) duration[i];
float efficiency;
float balance_delay;
```

```
  writeln("Line Efficiency: ", efficiency);
  writeln("Balance Delay: ", balance_delay);
}

//*****************************************************
```

RESULTS

MILP Problem Results for 18 minutes Cycle Time

A mixed-integer linear programming (MILP) model has been developed for an armchair production line consisting of 23 tasks, with a cycle time set to produce one armchair every 18 minutes. The goal was to open the minimum number of workstations while ensuring effective utilization of these stations and balancing the workload among them. This model, comprising 142 constraints, reached an optimal solution with 7 workstations after 247 iterations. The outputs of the optimal solution are presented below. The total idle time was 15 minutes yielding a 88.1% of line efficiency and 11.9% of balance delay.

```
// solution (optimal) with objective 7
// Quality Incumbent solution:
// MILP objective                              7.0000000000e+00
// MILP solution norm |x| (Total, Max)          3.70000e+01  7.00000e+00
// MILP solution error (Ax=b) (Total, Max)       0.00000e+00
0.00000e+00
// MILP x bound error (Total, Max)              0.00000e+00  0.00000e+00
// MILP x integrality error (Total, Max)        0.00000e+00  0.00000e+00
// MILP slack bound error (Total, Max)           0.00000e+00  0.00000e+00
//
```

```
w = 7;
    x = [[0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
   [0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
   [0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
   [0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
   [0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
   [0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
   [0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
   [0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
   [0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
   [0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
   [0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
   [0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
   [0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
   [0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
   [0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
   [0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
   [0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
   [0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
   [0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
   [1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
   [1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
   [1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
   [1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]];

    y =         [1 1 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0];
```

// solution (optimal) with objective 7

Total Idle Time: 15

Line Efficiency: 0.880952381

Minimum number of workstations: 7

Balance Delay: 0.119047619

Tasks are color-coded based on their assigned workstation in the precedence relationship graph (Figure 3). For instance, tasks 3, 8, 10, and 14, belonging to workstation 3, are represented in green, while tasks for other workstations are shown in different colors. The 7 workstations are presented in a flow diagram (Figure 4), where each workstation is distinguished by the same color-coding as in the precedence relationship graph. The tasks assigned to each workstation are listed below the respective workstation boxes, while the total processing times for the tasks are indicated above the boxes.

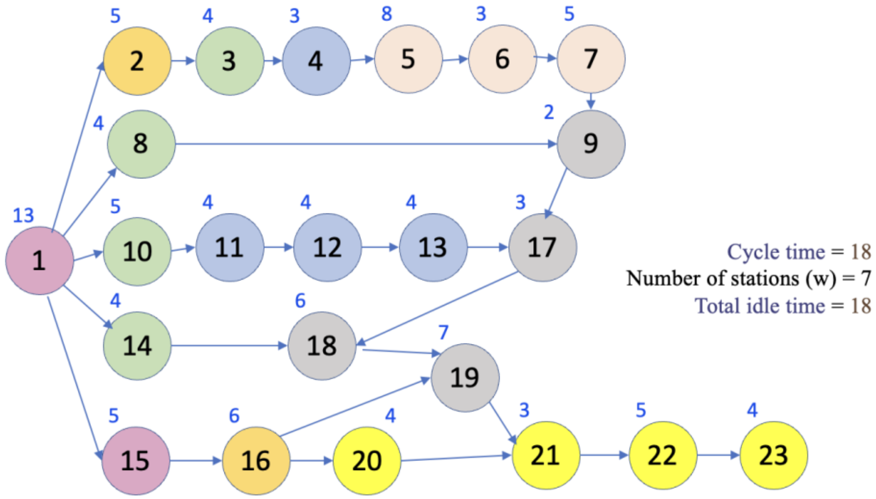

Figure 3. Precedence relationship graph with tasks color-coded by workstation allocation (CT=18).

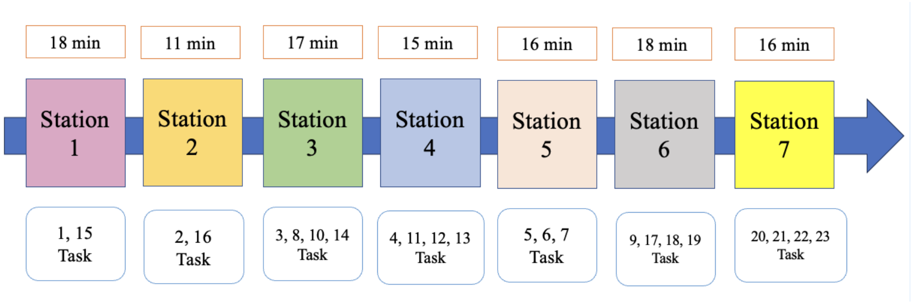

Figure 4. Flow diagram of 7 workstations with color-coded task allocation and processing times (CT=18).

MILP Problem Results for 15 minutes Cycle Time

Instead of 18 minutes, the cycle time was reduced to 15 minutes to produce one armchair within this timeframe. This model also consist of 142 constraints and achieved optimality with 8 workstations after 299 iterations. The solution ensures effective utilization of the workstations while maintaining workload balance across them. The outputs of this optimal solution are provided below. The total idle time was 9 minutes yielding a 92.5% of line efficiency and 7.5% of balance delay.

```
// solution (optimal) with objective 8
// Quality Incumbent solution:
// MILP objective                              8.0000000000e+00
// MILP solution norm |x| (Total, Max)          3.90000e+01  8.00000e+00
// MILP solution error (Ax=b) (Total, Max)       0.00000e+00
0.00000e+00
// MILP x bound error (Total, Max)              0.00000e+00  0.00000e+00
// MILP x integrality error (Total, Max)        0.00000e+00  0.00000e+00
// MILP slack bound error (Total, Max)           0.00000e+00  0.00000e+00
//
          w = 8;
          x = [[0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
         [0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
         [0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
```

```
[0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
[0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
[0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
[0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
[0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
[0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
[0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
[0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
[0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
[0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
[0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
[0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
[0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
[0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
[0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
[0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
[0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
[1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
[1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
[1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]];

y = [1 1 1 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0];
// solution (optimal) with objective 8
Total Idle Time: 9
Line Efficiency: 0.925
Minimum number of workstations: 8
Balance Delay: 0.075
```

Figure 5 presents the precedence relationship graph where tasks are color-coded based on their assigned workstation. Figure 6 presents the 8 workstations in a flow diagram, where each workstation has a color-coding.

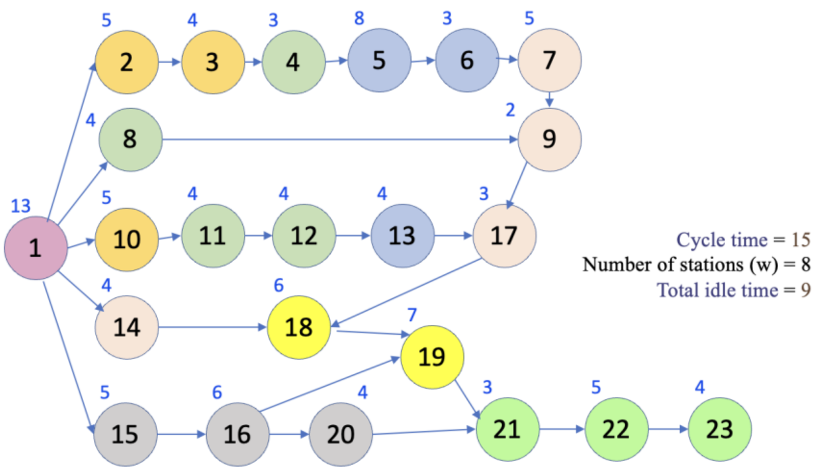

Figure 3. Precedence relationship graph with tasks color-coded by workstation allocation (CT=15).

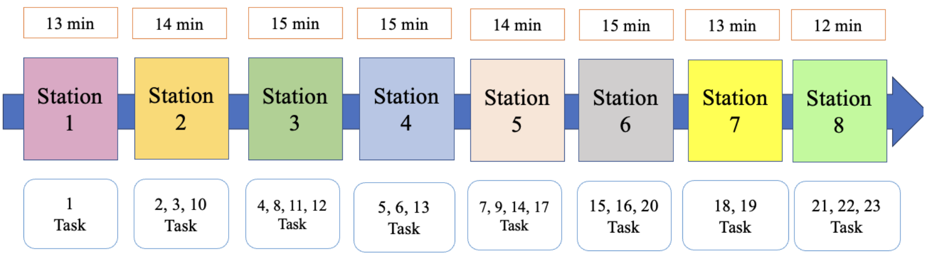

Figure 4. Flow diagram of 7 workstations with color-coded task allocation and processing times (CT=15).

Please note that the model performs better with a 15-minute cycle time compared to an 18-minute cycle time. Total idle time decreased from 15 minutes to 9 minutes, and line efficiency increased from 88.1% to 92.5%. Smoothness index, another performance metric used to compare different scenarios, was also calculated for both models. The smaller the smoothness index, the better the solution. If all workstations are evenly loaded, the smoothness index becomes zero. In the solutions obtained with two different cycle times, the smoothness index was calculated as 6.5% for the 18-minute cycle time and 7 workstations, and 3.6% for the 15-minute cycle time and 8 workstations. Similar to line efficiency, the smoothness index also demonstrates that the solution with a 15-minute cycle time and 8 workstations is superior.

Fixed processing times were used in this study; however, it is known that, in reality, processing times vary. If time studies are conducted to determine the mean and standard deviation of each task, the problem can be modeled with variable processing times, leading to more realistic solutions.

Declaration of generative AI and AI-assisted technologies in the writing process: During the preparation of this work the author used ChatGPT in order for proofreading to improve readability. After using this tool/service, the author reviewed and edited the content as needed and takes full responsibility for the content of the publication.

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Chapter 23

The Role of Fuzzy Logic Modeling in Fisheries Production Estimation

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INTRODUCTION

Fisheries production is a crucial component of global food security, supporting millions of livelihoods worldwide. Fisheries production estimation presents significant challenges due to the inherent variability in environmental, biological, and human-driven factors. The dynamic nature of marine ecosystems and the interplay of various environmental and socio-economic factors make predicting fisheries production a complex task. Variability in oceanographic conditions, species interactions, and socio-economic activities introduces uncertainties that traditional statistical models struggle to address. Traditional models, while useful, often struggle to account for the inherent uncertainties and variabilities present in fisheries systems (Chen et al., 2000). Fuzzy logic, with its capability to process data in terms of degrees of truth, offers a robust framework for addressing these challenges (Gadallah et al., 2024). Consequently, fisheries scientists have turned to fuzzy logic, a computational approach designed to handle vagueness and imprecision effectively.

The concept of fuzzy logic was first introduced by Lotfi Zadeh in the 1960s as a means to model the imprecision inherent in human reasoning. Fuzzy logic is rooted in the concept of partial truth, where values lie between absolute true and false. The relevance of fuzzy logic extends beyond environmental modeling. It has applications in supply chain optimization, resource allocation, and economic forecasting within fisheries. By integrating fuzzy systems into decision-making processes, stakeholders can better navigate the uncertainties inherent in fisheries management. Moreover, its ability to process incomplete or imprecise data adds to its versatility (Marzjarani, 2018). Its flexibility in managing imprecision has made it an invaluable tool for fields characterized by variability, such as fisheries production. The field of aquaculture faces dynamic challenges, including environmental fluctuations, market demands, and biological uncertainties. Traditional deterministic models often fail to address these complexities, leading to inaccurate predictions and inefficiencies in production planning (Zadeh, 1965).

Fuzzy logic models often outperform traditional statistical approaches, particularly in scenarios involving incomplete or imprecise data. For instance, a comparative analysis of fuzzy logic and Ricker stock-recruitment models in predicting Pacific herring stock recruitment revealed superior accuracy with fuzzy models (Chen & Ware, 1999). The inherent flexibility of fuzzy systems enables them to incorporate qualitative variables and expert opinions, which are challenging for conventional models. Additionally, hybrid models combining fuzzy logic with neural networks or regression methods have demonstrated improved performance in fisheries stock forecasting (Chen et al., 2000). Such comparisons highlight the need for broader adoption of fuzzy logic methodologies in fisheries science.

In fisheries science, fuzzy logic allows for the modeling of complex interactions between environmental variables and fish populations, providing a more flexible and adaptable approach to prediction and management (Pujaru et al., 2024). This adaptability is particularly valuable in fisheries production, where data may be incomplete or uncertain (Sylaios et al., 2010). Numerous variables, such as water temperature, dissolved oxygen, pH, and salinity, significantly impact production. These parameters often exhibit nonlinear relationships, which are difficult to model using conventional methods. Fuzzy logic bridges this gap by enabling the modeling of such systems using linguistic rules and membership functions. For instance, Bautista et al. (2022) demonstrated how fuzzy systems could optimize aquaculture environments based on real-time water quality data.

Researchers have increasingly recognized the potential of fuzzy logic to enhance the accuracy and reliability of fisheries production models. By integrating fuzzy logic with traditional methodologies, scientists can improve predictive capabilities, particularly in data-limited situations. This integration also facilitates the incorporation of expert knowledge and stakeholder input, promoting a holistic understanding of fisheries systems (Teh & Teh, 2011).

The objective of this chapter is to explore the state-of-the-art in fuzzy logic applications in fisheries production estimation. By examining methodological advancements, real-world applications, and future prospects, this chapter aims to provide a comprehensive understanding of the field. The findings serve as a valuable resource for researchers, practitioners, and policymakers seeking to leverage fuzzy logic for sustainable fisheries and aquaculture development.

Methodological Advancements in Fuzzy Logic for Fisheries

The evolution of fuzzy logic methods has introduced sophisticated tools tailored to the challenges of fisheries data analysis. Traditional fuzzy systems were limited to single-variable inputs, but advancements have enabled the development of multi-input multi-output (MIMO) systems. For instance, Mamdani-type inference systems, employing trapezoidal or Gaussian membership functions, have been widely used to model environmental influences on fish production (Sylaios et al., 2010). The integration of genetic algorithms with fuzzy logic has further enhanced model optimization, addressing uncertainties in stock-recruitment relationships (Chen et al., 2000). Another critical advancement involves the coupling of fuzzy models with neural networks to create hybrid systems that leverage the strengths of both approaches. Adaptive neuro-fuzzy inference systems (ANFIS) exemplify such hybrid models, excelling in pattern recognition and predictive accuracy (Yaseen et al., 2018). These methodological enhancements provide robust frameworks for handling the multifactorial nature of fisheries systems, facilitating more accurate predictions and informed decision-making.

Fuzzy logic modeling in fisheries production employs diverse methodological frameworks tailored to address specific challenges in aquaculture systems. At the core of these methodologies is the fuzzy inference system (FIS), which translates linguistic variables into actionable outputs. Among the most popular types of FIS are Mamdani and Sugeno systems, each offering distinct advantages. Mamdani systems prioritize interpretability and are often used for environmental modeling, while Sugeno systems provide computational efficiency, making them suitable for real-time applications. A prominent example was done by Pujaru et al. (2024), which modeled Indian fisheries production using a Mamdani FIS with 243 rules.

The design of a fuzzy system typically involves defining input variables, constructing membership functions, and formulating rules. Input variables, such as water temperature, seed quality, or market demand, are characterized by fuzzy sets with associated membership functions. Membership functions can take various shapes, such as triangular, trapezoidal, or Gaussian, depending on the system's requirements. For example, Bautista et al. (2022) utilized trapezoidal membership functions for water quality management.

Rule formulation is another critical step, where the "IF-THEN" logic governs system behavior. These rules incorporate expert knowledge and empirical data, allowing the system to account for complex interactions between variables. For instance, a rule might state, "IF water temperature is high AND dissolved oxygen is low, THEN fish stress level is high." The robustness of a fuzzy system often depends on the comprehensiveness and accuracy of its rule base.

Software tools like MATLAB and Simulink are widely used to design and simulate fuzzy systems. These platforms enable researchers to visualize membership functions, test rule sets, and validate system performance. For instance, Chua et al. (2023) demonstrated the efficacy of a MATLAB-based FIS for managing water quality in *Penaeus monodon* cultivation.

While traditional fuzzy systems rely on static rule bases, recent advancements have introduced adaptive fuzzy systems that learn from data. These systems integrate machine learning techniques, such as neural networks, to refine rules and membership functions dynamically. This approach enhances model accuracy and scalability, particularly in complex aquaculture environments with high variability.

Another innovative methodology is the integration of fuzzy logic with other modeling techniques. Hybrid systems combining fuzzy logic with probabilistic models, optimization algorithms, or agent-based simulations have shown promise in addressing multifaceted challenges. For example, Marzjarani (2018) combined fuzzy logic with probability theory to estimate missing data points in fisheries datasets.

The diversity in methodological approaches underscores the flexibility of fuzzy logic as a tool for fisheries production estimation. Whether used independently or as part of a hybrid system, fuzzy logic provides a robust framework for navigating the uncertainties of aquaculture systems. As research in this area progresses, the development of standardized methodologies and tools will be crucial for advancing the field.

Applications in Fisheries Production Estimation

Fuzzy logic has been applied in numerous case studies to improve fisheries production estimation. A study by Wirata et al. (2024) used fuzzy logic approach to develop a model for predicting fish productivity in Indonesia, highlighting the importance of integrating both biological and environmental factors in production estimation. One of the most critical areas is water quality management, as water parameters directly influence fish health and growth. Bautista et al. (2022) developed a Mamdani fuzzy system that evaluated limnological parameters such as pH, dissolved oxygen, and temperature. By categorizing water quality into states like “excellent,” “good,” and “poor,” the system provided actionable insights for maintaining optimal aquaculture conditions.

Fuzzy logic extends beyond capture fisheries, playing a pivotal role in aquaculture and water quality management. Real-time water quality assessment systems based on fuzzy logic have been developed to monitor critical parameters and provide actionable recommendations for aquaculture operations (Bokingkito & Caparida, 2018). These systems integrate environmental, chemical, and biological data, enabling proactive responses to potential threats. Additionally, fuzzy models have been used to predict aquaculture yields under varying environmental conditions, contributing to sustainable aquaculture practices (Khatua et al., 2020).

In addition to environmental monitoring, fuzzy logic has been applied to predict fisheries output based on resource inputs. For example, Pujaru et al. (2024) modeled Indian fisheries production using inputs like fish seed, post-harvesting facilities, released fund and temperature. The system revealed that optimal resource allocation could significantly enhance production, especially in regions with limited resources.

Aquaculture systems often face challenges in predicting fish growth and feed requirements. Fuzzy logic has been employed to model growth stages and automate feeding processes. Magsumbol et al. (2019) developed a system that assessed carp fish growth stages, informing feeder systems in real-time by fuzzy logic approach. Another notable application is in inventory management and supply chain optimization. Fuzzy logic helps model uncertainties in supply and demand, enabling better decision-making. Kuppulakshmi et al. (2021) used fuzzy systems to optimize production schedules for perishable fish items, reducing waste and improving profitability.

Economic applications extend to market analysis and pricing strategies. Fuzzy models can predict market trends based on historical data, enabling fisheries to align production with demand. This approach minimizes losses due to overproduction or underproduction.

Fuzzy logic also plays a role in addressing ecological concerns. By optimizing resource use and minimizing environmental impact, fuzzy systems contribute to sustainable aquaculture practices. For example, Widyaningrum et al. (2022) evaluated supply chain performance while considering environmental impacts by fuzzy logic approach.

In integrated aquaculture systems, fuzzy logic facilitates the coordination of multiple subsystems, such as water treatment, feeding, and harvesting. These systems benefit from the holistic decision-making enabled by fuzzy logic, ensuring efficient operations across the production cycle. The adaptability of fuzzy logic extends to different types of aquacultures, including freshwater, marine, and ornamental fisheries. Each application is tailored to the specific requirements and challenges of the ecosystem, demonstrating the versatility of this approach. For instance, Gadallah et al. (2024) developed a fuzzy-based approach for modeling water quality requirements for a set of fish types and evaluating the suitability of a water site for fish farming. The authors reported that the developed fuzzy-based approach greatly helped to manage and plan fish farming, to improve the productivity and avoid possible catastrophic damage. Sonmez et al. (2018) developed an ANFIS model for predicting heavy metal concentration in a natural aquatic ecosystem and reported that the ANFIS model presented practical estimations for the cadmium concentrations. Kale (2020) applied a fuzzy logic approach to predict sea surface temperature and compared eight different algorithms. Both research clearly stated that ANFIS can be used in water quality monitoring studies.

Fuzzy logic has been instrumental in addressing real-world challenges in fisheries production estimation. A notable application involves the Gulf of Mexico's shrimp data files, where fuzzy logic was used to estimate missing data points, outperforming probability-based approaches in robustness (Marzjarani, 2018). In another study, fuzzy rule-based models assessed the effects of global warming and pollution on Hilsa fish production, demonstrating the system's ability to integrate environmental and anthropogenic factors (Khatua et al., 2020). Additionally, the Greek fisheries sector employed fuzzy c-means clustering to rank and classify fishing areas based on species yield and economic value, providing actionable insights for sustainable management (Sylaios et al., 2010). These case studies underscore fuzzy logic's versatility in handling diverse datasets and its potential to inform fisheries management policies.

Emerging technologies, such as internet of things (IoT) and sensor networks, have enhanced the capabilities of fuzzy logic systems. Real-time data collection and processing enable dynamic adjustments, making fuzzy systems more responsive to changing conditions. For instance, IoT-enabled fuzzy controllers are increasingly used for water quality management in aquaculture farms.

The broad range of applications underscores the transformative potential of fuzzy logic in fisheries production. By addressing critical challenges and enabling innovative solutions, fuzzy systems contribute to the advancement of aquaculture practices worldwide.

The relationship between fish stock and recruitment is a fundamental aspect of fisheries management, providing insights into population dynamics and informing management decisions. Traditional models, often deterministic, may not fully capture the variability and uncertainty inherent in these relationships. Fuzzy logic offers a solution by incorporating imprecision and allowing for more nuanced interpretations of data (Chen et al., 2000).

One of the primary advantages of using fuzzy logic in stock-recruitment modeling is its ability to handle uncertain and incomplete data. In scenarios where data on fish populations are sparse or unreliable, fuzzy logic models can provide more robust estimates of stock dynamics. By using fuzzy sets, researchers can model the uncertainty inherent in stock-recruitment relationships, improving the accuracy of predictions and enhancing the reliability of management decisions (Mackinson, 2000).

Several studies have demonstrated the effectiveness of fuzzy logic in stock-recruitment modeling. For instance, Chen et al. (2000) developed a fuzzy logic model combined with a genetic algorithm to analyze fish stock-recruitment relationships. This approach enabled the researchers to capture complex interactions between environmental variables and fish populations, leading to more accurate predictions of stock dynamics (Cheung et al., 2005). Similar applications have been explored in other fisheries, highlighting the versatility of fuzzy logic in addressing diverse stock assessment challenges (Hamid-Mosaku et al., 2017).

The integration of fuzzy logic into stock-recruitment models also facilitates the consideration of multiple management objectives. By incorporating fuzzy logic, managers can evaluate trade-offs between different strategies, such as maximizing yield versus conserving biodiversity. This multi-criterion decision-making approach supports more holistic management strategies that align with ecosystem-based management principles (Jarre et al., 2008).

Predicting fisheries yield is a critical component of sustainable fisheries management, providing essential information for resource allocation and policy-making. Traditional yield prediction models often rely on deterministic approaches that may not fully accommodate the complexity and uncertainty of marine ecosystems. Fuzzy logic offers a promising alternative by allowing for the modeling of imprecise and variable data (Sylaios et al., 2010).

Fuzzy logic models can improve yield predictions by integrating diverse data sources and accounting for uncertainties in environmental conditions, fishing effort, and biological parameters. This capability is particularly valuable in data-limited situations where traditional models may struggle to provide reliable predictions. By using fuzzy sets, researchers can model the uncertainty inherent in yield predictions, enhancing the accuracy and reliability of forecasts (Baziukė et al., 2014).

Recent studies have explored the application of fuzzy logic in fisheries yield prediction, demonstrating its potential to improve management outcomes. For instance, Sylaios et al. (2010) applied fuzzy logic models to rank and classify fishing areas based on yield potential. This approach allowed for the identification of high-yield areas and informed resource allocation decisions, promoting sustainable fisheries management (Zare & Ghazali, 2017).

The use of fuzzy logic in yield prediction also supports the consideration of multiple management objectives. By incorporating fuzzy logic, managers can evaluate trade-offs between different strategies, such as optimizing yield versus minimizing environmental impact. This multi-criterion decision-making approach aligns with ecosystem-based management principles and supports more holistic management practices (Jarre et al., 2008).

Ecosystem management is a holistic approach to fisheries management that considers the ecological interactions and human impacts on marine resources. Fuzzy logic provides a valuable tool for ecosystem management by accommodating the complexity and uncertainty inherent in marine ecosystems (Jarre et al., 2008).

Fuzzy logic frameworks can model the interactions between environmental variables, fish populations, and human activities, supporting the evaluation of management strategies that balance ecological, economic, and social objectives. By integrating diverse data sources and stakeholder input, fuzzy logic models facilitate a comprehensive understanding of ecosystem dynamics and support adaptive management practices (Teh & Teh, 2011).

One application of fuzzy logic in ecosystem management is the evaluation of habitat suitability for marine species. By integrating environmental factors such as temperature, salinity, and habitat quality, fuzzy logic models can assess habitat suitability and predict species distribution. This information is critical for identifying priority areas for conservation and guiding management decisions related to fishing and resource extraction (Hattab et al., 2013).

Fuzzy logic has also been used to assess the impact of human activities on marine ecosystems. By modeling the interactions between human activities, such as fishing and tourism, and ecological processes, fuzzy logic frameworks can evaluate the potential impacts of different management scenarios. This approach supports the development of adaptive management strategies that balance conservation and development objectives (Prato, 2007).

The use of fuzzy logic in ecosystem management promotes a more integrated and adaptive approach to planning and decision-making. By accommodating the uncertainties and complexities of marine ecosystems, fuzzy logic frameworks support the development of flexible management strategies that can respond to changing environmental conditions and human pressures (Paterson et al., 2007).

Fuzzy logic aligns seamlessly with the principles of ecosystem-based fisheries management (EBFM), offering tools to balance ecological, economic, and social objectives. Multi-criteria decision-making frameworks, underpinned by fuzzy inference systems, allow managers to evaluate trade-offs between competing priorities (Paterson et al., 2007). For example, fuzzy logic models have been employed to assess the sustainability of South African sardine fisheries, integrating ecological performance indicators with stakeholder input (Paterson et al., 2007). Such applications underscore fuzzy logic's potential to enhance the resilience of fisheries systems through comprehensive and adaptive management strategies.

These case studies demonstrate the potential of fuzzy logic to improve fisheries management practices, offering more accurate and reliable predictions in dynamic and uncertain environments. As more case studies are conducted, it is likely that fuzzy logic will become an increasingly important tool for fisheries scientists and managers worldwide.

The application of fuzzy logic in fisheries management holds significant implications for policymaking. By synthesizing complex datasets into actionable insights, fuzzy models support evidence-based decision-making and adaptive management strategies. Policymakers can leverage these tools to address pressing issues such as overfishing, habitat degradation, and climate change impacts on fisheries (Ramos et al., 2015). Furthermore, integrating fuzzy logic into national and international fisheries management frameworks can enhance transparency and stakeholder participation.

LIMITATIONS AND CHALLENGES

Despite its strengths, fuzzy logic modeling is not without limitations. Challenges in fuzzy logic methodology include determining the optimal number of membership functions and avoiding rule explosion, where too many rules lead to computational inefficiency. Techniques such as rule pruning and clustering are employed to address these issues. Moreover, validation of fuzzy models requires rigorous testing against real-world data to ensure reliability and applicability. One significant challenge is the reliance on expert knowledge for rule creation, which can introduce subjectivity and variability in outcomes. Additionally, the computational intensity of complex fuzzy systems can be a barrier to widespread adoption in resource-constrained settings (Suryanarayana et al., 2008). Addressing these issues requires advancements in automated rule generation and the integration of machine learning techniques to enhance model robustness and scalability. Furthermore, efforts to standardize methodologies and develop user-friendly software tools will be crucial in overcoming these barriers.

Designing and implementing fuzzy logic models requires a multidisciplinary approach, drawing on expertise from ecology, computer science, and fisheries management. Moreover, the interpretation of fuzzy logic outputs can be subjective, necessitating careful consideration of model design and parameter selection (Chen & Irvine, 2007). Addressing these challenges is essential for realizing the full potential of fuzzy logic in fisheries production. The adoption of fuzzy logic in fisheries, though relatively recent, represents a significant step toward addressing global challenges in food security and sustainability. As the world grapples with climate change and resource scarcity, the importance of such adaptive modeling techniques becomes increasingly evident.

The application of fuzzy logic in stock-recruitment modeling presents challenges. The design and implementation of fuzzy logic models require careful consideration of model parameters and membership functions. Additionally, the interpretation of fuzzy logic outputs can be subjective, necessitating transparent and reproducible methodologies. Addressing these challenges is crucial for ensuring the credibility and acceptance of fuzzy logic models in fisheries management (Hattab et al., 2013).

The application of fuzzy logic in yield prediction presents challenges. The design and implementation of fuzzy logic models require expertise in both fisheries science and fuzzy logic techniques. Additionally, the interpretation of fuzzy logic outputs requires careful consideration, as the subjective nature of fuzzy logic can lead to differing interpretations of results. Addressing these challenges is essential for maximizing the potential of fuzzy logic in fisheries yield prediction (Ramos et al., 2015).

The application of fuzzy logic in ecosystem management presents challenges. The design and implementation of fuzzy logic models require expertise in both ecological modeling and fuzzy logic techniques. Additionally, the subjective nature of fuzzy logic requires careful consideration of model parameters and membership functions. Addressing these challenges is essential for realizing the full potential of fuzzy logic in ecosystem management (Jones & Cheung, 2018).

CONCLUSION

Fuzzy logic offers significant advantages for fisheries production estimation, providing a powerful tool for handling the uncertainty and complexity inherent in aquatic ecosystems. Its applications extend across stock assessment, aquaculture, and ecosystem management, underscoring its versatility and potential to drive sustainable fisheries practices. By integrating expert knowledge, environmental variables, and nonlinear relationships, fuzzy logic models can offer more accurate and reliable predictions of fish populations and production. Despite challenges in model construction, validation, and data quality, the continued development and application of fuzzy logic in fisheries science holds great promise for improving resource management and ensuring the sustainability of fisheries worldwide. Future research should focus on refining fuzzy logic models, exploring hybrid approaches, and developing robust validation frameworks to enhance the effectiveness of fuzzy logic in fisheries production estimation. Continued advancements in fuzzy methodologies and interdisciplinary collaboration will be critical in unlocking the full potential of this innovative approach.

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