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# Chapter 1

## BATHYMETRIC DISTRIBUTION OF DEEP WATER ROSE SHRIMP (*PARAPENAEUS LONGIROSTRIS* LUCAS, 1846) IN THE MEDITERRANEAN SEA AND TURKISH COASTS AND FACTORS AFFECTING THE DISTRIBUTION

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## 1. Introduction

Deep water rose shrimp (*Parapenaeus longirostris* Lucas, 1846) (Figure 1), which is an epibenthic decapod crustacean species is distributed in wide geographical area from the East and West Atlantic coasts to the Mediterranean Sea and Sea of Marmara (FAO, 2022; Palomares and Pauly, 2022). *P. longirostris* has high commercial value for Spain, France, Italy, Tunisia, Greece, and Türkiye on the Mediterranean coast (Deval et al., 2006; Dereli, 2010).

**Figure 1.** *Deep water rose shrimp (from Dereli, 2010)*

This target species dominates the catch composition in trawl fisheries in many fishing areas (Zengin et al., 2004; Tosunoğlu et al, 2009; Dereli, 2010; Dereli et al., 2021). The catch amount of the species in 2021 constituted 63% of the total shrimp catch (5494 tons) in Türkiye. Deep water rose shrimp catches from the Turkish coasts have increased by 26% from 2761 tons (2007) to 3478 tons (2021) in the last 15 years.

As well as it is catched intensively in the Sığacık and Kuşadası Bays in the Aegean Sea (Tosunoğlu et al, 2009; Dereli, 2010; Dereli et al., 2016; Dereli et al., 2021), and a significant part of the total catch (61%) is obtained from the Marmara Sea (Figure 2) (TUİK, 2022) It has been reported that a significant portion (70%) of the stock on the Turkish coasts is located in the Sea of Marmara, which coincides with the catch (DEÜ/DBF-JICA, 1993).

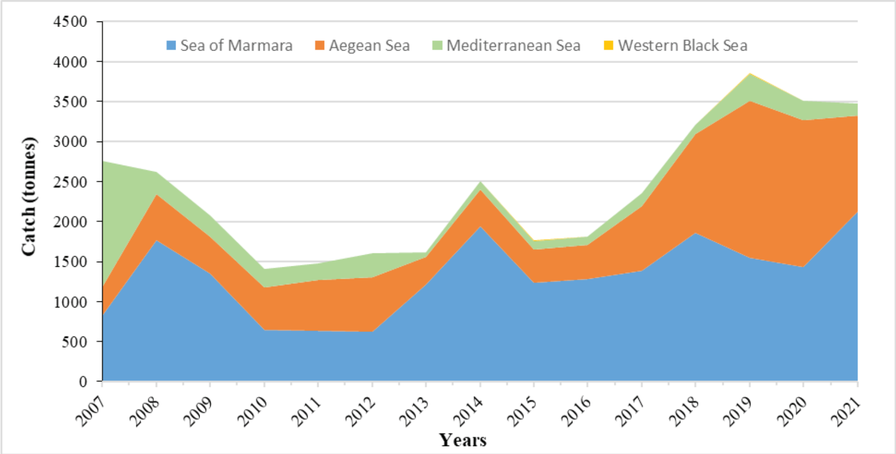


**Figure 2.** *Deep water rose shrimp catches from the Turkish coasts (2007–2021) (TUİK, 2022).*

*Parapenaeus longirostris* is targeted by trawlers on the Aegean and Mediterranean coasts of Türkiye and by beam trawls and boat seine (manyat in Turkish) in the Sea of Marmara, where trawl is prohibited, in waters deeper than 50 meters. According to the commercial fishing notification, fishing of the species starts on 1 September (16 September for the Mediterranean Sea) and continues until 14 September (fishing is prohibited in January in the Sea of Marmara) (Anonymous, 2020).

The bathymetric distribution of the *P. longirostris* is decisive in the catch amount of the species and knowledge of the spatio-temporal pattern of *P. longirostris* is crucial for sustainable exploitation of the stock. Therefore, in this study, the bathymetric distribution of the species in the Mediterranean Sea and Turkish coasts (the Aegean Sea and Sea of Marmara) and factors affecting the distribution were discussed in detail in light of the literature.

## 2. Bathymetric Distribution

Due to the migration of juveniles of the species from the continental shelf to the slope (Sobrino et al., 2005), the deep water rose shrimp shows a wide bathymetric distribution. It has been reported that the bathymetric distribution of the species is between 20 and 840 m for the Mediterranean Sea (Politou et al., 2005; Sobrino et al., 2005) and 35-700 m for the Turkish coasts (Kocataş et al. 1991; Artüz, 2005). Despite this wide bathymetric distribution range, the species is intensely found in the Mediterranean Sea at depths of 100-400 m (Abad et al., 2007; Fanelli et al., 2007; Guijarro et al., 2009; Sbrana et al., 2019). Ungaro et al. (2005) detected that the species is mostly found on the shelf border and the upper slope in the Southern Adriatic Sea.

In the Eastern Mediterranean coasts of Türkiye, the species is generally distributed between 100 and 400 m (Geldiay and Kocataş, 1973) and prefers parts deeper than 100 m (Manaşirlı, 2008).

On the Aegean Sea coasts, the depths where the species are mostly found are between 200 and 350 m (Kara and Gurbet, 1999; Bilgin et al., 2009; Dereli, 2010). The species is extensively distributed at depths of 40-120 m in the Sea of Marmara (40-110 m, Artüz, 2005; 44-110 m, Zengin and Akyol, 2009 and 50-100 m, İnceoğlu et al., 2021). Zengin et al. (2004), unlike these studies, found that the species is distributed at depths of 150-200 m.

## 3. Factors Affecting Bathymetric Distribution

Oceanographic conditions, seasons and temperatures, water temperature and circulation, geographic variability of bottom structure, average salinity of the bottom water, and potential prey (bait) density are factors that affect the distribution of the species (Ungaro et al., 1999; Ungaro et al., 2005; Guijarro et al., 2009).

Guijarro et al. (2009) reported that the most important environmental factors are the bottom sediment structure, the average salinity of the bottom water, and the density of potential prey (bait) as a result of their study carried out in the Balearic Islands in the Mediterranean. The presence of juveniles was positively correlated with the percentage of silt, sand, and clay soils and feed density, and negatively correlated with the mean salinity of the bottom water, while adults were negatively correlated with the mean temperature of the bottom water. The entire population (juveniles and adults) was negatively correlated with mean salinity and temperature, and positively correlated with feed (Guijarro et al., 2009).

### 3.1. Bottom Structure

Deep water rose shrimp are distributed in all substrate types except rocky bottom structure (Nouar and Maurin, 2001), and generally prefer muddy and sandy-muddy bottom structures (Ardizzone and Corsi, 1997; Mori et al., 2000; Artüz, 2005).

The species is distributed especially in silty and clayey sedimentary substrates along the Mediterranean coasts of Europe (Abello et al., 2002). Similarly, it has been reported that the silty and clayey sediment structure after 100 m depth on the Eastern Mediterranean coasts of Türkiye is suitable for the habitat of the species (Manaşırlı, 2008). On the other hand, it has been reported in different studies that the species primarily prefers substrates with *Funiculina quadrangularis* and *Octocorallia* (Nouar and Maurin, 2001), and are distributed on sandy bottoms (Abellan and Cardenas, 1990).

### 3.2. Water Temperature

Water temperature affects the depth-dependent spatial distribution of the species (Quattrocchi et al., 2020). The species prefers waters between 12.5-25 °C and is found densely in waters between 13.5-15.5 °C (Dall et al.,1990; Nouar, 2001; Ungaro and Gramolini, 2004; Ungaro and Gramolini, 2006). It was suggested by Bombace (1972) that the distribution was related to the 14 °C water of Atlantic origin. In support of this theory, species showed a dense distribution around 14 °C temperatures in many areas in the Mediterranean Sea and the Sea of Marmara (Yüksek et al., 2000; Nouar, 2001; Ungaro and Gramolini, 2006).

In the Mediterranean, water temperature is especially effective in habitat selection of young individuals (Ghidalia and Bourgois, 1961). Since the Mediterranean-origin water located under the thermocline layer is 14.2 °C constantly throughout the year in the Sea of Marmara, the species especially prefers this water layer (between 40 m and 110 m) (Artüz, 2005). In the Aegean Sea (Sığacık Bay), *P. longirostris* is abundantly found at depths of 200-400 m, where the sea water temperature is at 14-15 °C (Dereli, 2010; Dereli et al., 2021).

### 3.3. Spawning Season

The spawning season in the Mediterranean Sea and the Sea of Marmara is based on maturity rate and GSI development. The species is assumed to reproduce throughout the year, as mature females and spawning are seen all year round (Relini et al., 1999; Mori et al., 2000; Meriem et al., 2001; Sobrino et al., 2005; Abdel Razek et al., 2006; Garcia-Rodriguez et al., 2009; Arculeo et al., 2014). However, reproductive activity peaks at different times depending on the oceanographic situation and the studied area (Garcia-Rodriguez et al., 2009).

Spawning peaks are usually in late spring and early autumn in the Mediterranean waters of Europe (Levi et al., 1995; Mori et al., 2000; Sobrino et al., 2005). It was reported by Meriem et al. (2001) that the spawning season on the Tunisian coast was from April to November (peak in June-July). On the Egyptian coast, mature females were found in the spring (Drobisheva, 1970) and spawning peaks were in November and in deep waters (Abdel Razek et al., 2006). In the South Tyrrhenian Sea, the spawning peaks were in January and August-September (Arculeo et al., 2014).

On the Turkish coasts, it has been determined that juveniles (7-15 mm carapace length-CL) were seen in the population every month, so spawning continues throughout the year and peaks in some periods (DEÜ/DBF-JICA, 1993; Dereli, 2010). It is seen that the spawning peaks occur at the end of autumn and spring in the Sea of Marmara (DEÜ/DBF-JICA, 1993; Bayhan et al., 2005; Artüz, 2006). The spawning peaks in the Mediterranean coast (Silifke) of Türkiye occur between December and March and at the end of spring (Manaşırlı and Avşar, 2008)**.** Reproductive activities of females in the Central Aegean Sea (Sığacık Bay) reach two peaks during the year, in autumn (September-November) and spring (March-April) (Dereli and Erdem, 2011).

### 3.4. Spawning Depth, Temperature and Salinity

There is different findings in the literature about the spawning depth. Spawning females are distributed at different depths throughout the year (Benchoucha et al., 2008). Mature females were not found in waters shallower than 100 m and the majority of the population consisted of immature individuals. In deep strata, practically the entire male population is assumed to be mature (Dos Santos, 1998; Sobrino et al., 2005). The spawning area was between 150-350 m depths in the North Tyrrhenian Sea in the Mediterranean (Mori et all, 2000).

On the other hand, the spawning of the species takes place in shallow waters as well as in deep waters. Adult individuals spawned in shallow waters (<80 m) closer to the shore (Holthuis, 1987). On the Israeli coast of the Mediterranean, spawning activity was observed in shallow waters at 47-73 meters throughout the year, and in deeper waters at 150-300 meters between June and August (Tom et al., 1988). Dereli (2010) reported that large individuals move towards shallow areas (0-200 m) during the spawning season (spring and autumn) on the Aegean coast of Türkiye. Larval formation is mostly seen at depths of 100 m and this depth is the upper limit of distribution of adults. This indicates that the adults migrate towards the shallows during the spawning period (Dos Santos, 1998).

Spawning of the species takes place at 15-16 °C and reproduction activities slow down below these temperature values (Tom et al., 1988). Contrary to this information, it has also been reported that temperature is not too restrictive for reproductive activity (Mori et al., 2000). There is a strong correlation between the spawning areas of females and high salinity. Spawning was greatest in high salinity (35.6-36.5 psu) and at the limits of the high-salinity pattern (36.2-36.4 psu) in the shallow (75-200 m) and deep (200-500 m) (Benchoucha et al., 2008).

## 4. Bathymetric Distribution-Carapace Length (CL) Relationship

The length of the species increases depending on the depth in the Mediterranean Sea and the Sea of Marmara (Abello et al., 2002; Zengin et al., 2004; Sobrino et al., 2005; Sbrana et al., 2006; Manaşırlı, 2008; Bilgin et al., 2009; Dereli, 2010).

Length structure is one of the main characteristics of the distribution of the species. Several authors reported a size-dependent bathymetric distribution, with adults deeper than juveniles (Froglia, 1982; Ardizzone et al., 1990). Besides, the occurrence of “adults” is also reported from the outer shelf, and conversely, the presence of recruits and juveniles (<7-15 mm CL) in the epi-bathyal layer (Rinelli et al., 2005; Bilgin et al., 2009; Kapiris et al., 2013).

The size-related bathymetric distribution is linked to the ontogenetic migration of juveniles from the continental shelf to the slope (Ardizzone et al., 1990; Lembo et al., 2000; Politou et al., 2008). The deep water rose shrimp moves to deeper waters to spend the next stages of its life, after the dispersal stage in shallow waters (Sobrino et al., 2005). Due to migration, the length structure of the population is generally in two different groups, on the continental shelf and on the upper part of the continental slope. Juveniles (7-15 mm CL) are found around 100 m on the continental shelf, while small individuals (16-22 mm CL) are found especially at depths of 150-400 m. Large individuals (20-47 mm CL) are at depths of 100-500 m in the upper part of the continental slope, but mostly prefer depths of 200-500 m (Abello et al., 2002).

Tom et al. (1988) examined the life stages of the species for the Israeli coast of the Mediterranean and gave similar results regarding migration. On the coast of Israel, the new age group joins the stock at depths of 45-300 m between July and November and then migrates towards the coast and the open sea. Individuals greater (>15 mm CL) spend the benthic phase deeper than 45 m. Migration to the coast is limited by unsuitable sandy ground, and there is no border depth for migration towards the open sea (Tom et al., 1988).

Migration of the species is also supported by findings reported by Ardizzone et al. (1990). In the Central Tyrrhenian Sea, females and males less than 20 mm CL are found in shallower waters than 250 m, individuals with 21-30 mm CL are between 250-350 m, individuals with larger CL are in deeper waters (Ardizzone et al., 1990).

In the Marmara Sea, individuals migrate from 50-100 m depths to deeper waters of more than 100 m in late spring and summer, and individuals in 10-100 m depth layers are smaller than those at 200-500 m depths (Zengin et al., 2004). Similarly, the mean length of individuals at the deep (>200 m) was longer than at shallower zones (<200 m) (DEÜ/DBF-JICA, 1993).

## 5. Conclusion and Recommendations

Deep water rose shrimp with a wide bathymetric distribution range (20-840 m), is found densely on the shelf border and upper slope (100-400 m depths), and in muddy, sandy-muddy bottom, and in the waters between 13.5-15.5 $^{o}$C. Oceanographic conditions, seasons and temperatures, water temperature and circulation, geographic variability of bottom structure, average salinity of the bottom water, and potential prey (bait) density are factors that affect the distribution of the species. Although spawning is observed throughout the year, there are 2 spawning peaks in autumn and spring. Large individuals move towards shallow areas (0-200 m) during the spawning season. After the dispersion stage, the juveniles move from the continental shelf to the continental slope and the length of species increases depending on the depth.

Fisheries in autumn in the Marmara Sea coincides with the spawning season of the species and overfishing has also been reported between 50-200 m depths for algarna fishing (Arslan İhsanoğlu and İşmen, 2020; Çiloğlu and Ateş, 2022). In the light of the distribution and reproduction information of the species, directing the algarna fleet deeper than 200 m may provide protection of individuals and juveniles in the shallow area during the spawning season, and catching of larger individuals and thus more profitable exploitation of the stock.

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# Chapter 2

## THE NEED FOR PARADIGM SHIFTING IN FISHERIES EDUCATION TO REACH PROJECTED GOALS ON FISHERIES PRODUCTION AT THE AGE OF INFOTECH, BIOTECH AND CLIMATE CHANGE: A PERSPECTIVE FROM TÜRKİYE

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## 1. Introduction

Harari (2019) states his ideas about the shaping power of global warming, biotech and infotech on our future as follows:

> *"**Climate change** may be far beyond the concerns of people in the midst of a life-and-death emergency, but it might eventually make the Mumbai slums uninhabitable, send enormous new waves of refugees across the Mediterranean, and lead to a worldwide crisis in healthcare."*

> "*In the past, we gained the power to manipulate the world around us and reshape the entire planet, but because we didn't understand the complexity of the global ecology, the changes we made inadvertently disrupted the entire ecological system, and now we face an ecological collapse. In the coming century **biotech and infotech** will give us the power to manipulate the world inside us and reshape ourselves…*"

Fisheries products (Fishing + Aquaculture) are exported from Türkiye to 82 countries, especially EU countries. The country's 2018 aquaculture exports approached the 2023 target of $1 billion, and the new 2023 export target was updated to approximately $2 billion. Türkiye is leader in the production of sea bass, trout, and sea bream in Europe today. It is seen that the aquaculture sector, which has a rapid growth (8-14%) in the world with its dynamic structure, has a production potential above the foreseen targets if the current problems are solved and the cultivation of shellfish, bivalve aquaculture and aquatic plants is developed. Türkiye has a great potential in terms of fisheries and aquaculture production due to its water resources. It is estimated that only the country's inland water resources have the potential to produce around 1 million tons of aquaculture per year. Under these conditions, Türkiye's aquaculture production, which was determined as 600 thousand tons in 2023, is targeted to reach 2 million tons in 2050. For this, the following objectives have been set by the relevant ministry (BSGM, 2019);

- Increasing production and efficiency in aquaculture,
- Ensuring sustainable aquaculture,
- Fisheries resources should be conserved and sustainable developed
- Development of seafood processing, evaluation and marketing sector,
- Increasing R&D and innovation activities in seafood.

To achieve the above-mentioned objective, a SWOT analysis that conducted by Türkiye government indicated that the strengths of country's fisheries management regime in terms of human capital were (BSGM, 2019):

- The country has many technical personnel trained in the sector and also has trained academicians and researchers,
- Fishermen's organizations that have completed their horizontal organization (Cooperatives) and vertical organizations (Unions, Central Union) and the existence of fishermen who will transfer their experience and knowledge from generation to generation,
- Obligation to employ trained personnel within the scope of the legislation,
- Finding universities to meet the fisheries training needs and finding a trained workforce,
- Presence of scientific institutions such as institutes and universities related to the subject.

Fisheries Engineers are the professional group that has the biggest role in the rapid rise and development of the fisheries sector in the last 30 years in Türkiye. According to the relevant law, Fisheries Engineer; "*Determination of production areas in sea and inland waters, planning of production facilities, in matters related to the production, hunting, marketing, distribution, import and export, registration and control of plants and animals found in seas and inland waters and their eggs, fry and adults, who have studied in the field of aquaculture, are authorized to engage in project design and managemen*t"

In all countries of the world, except Japan, fisheries education at undergraduate and graduate level is provided by different departments such as biology, fisheries biology, fisheries, hydrobiology, limnology, oceanography, marine sciences, marine biology, freshwater biology, fish farming developed within universities or faculties. If we compare the institutions that provide training on aquaculture in our country with the educational institutions of other countries; Türkiye comes after Japan in the world in terms of both faculty level education and the number of existing educational institutions. Until the 1980s, scientific studies and education on aquaculture were carried out in the zootechnics and aquaculture departments of the agricultural faculties of the universities, the hydrobiology units of the science faculties, the veterinary faculties, and the geography departments of some universities. Fisheries colleges, which were established in 1982 in accordance with the decree law numbered 41, were transformed into faculties with the law numbered 3837 adopted on 11.7.1992. According to the Turkish Employment Agency, the definition of fisheries engineer is; "*A person who works on the hunting, production, improve-*

*ment, breeding and storage of plants and animals living in water that can be used as food*". Aquaculture engineers develop projects on the preparation of aquaculture production facilities. It gives an opinion on when and how eggs should be placed in the basins for the production of fishery products in the basins. It works to improve aquaculture species and to feed them with natural and artificial feeds. It tries to purify the basins from microbes in order to protect the fishery products against various diseases. It enlightens fishermen on fishing of fishery products, fishing techniques and water quality and aquatic ecology. Today, fisheries education is given in 24 universities throughout Türkiye. Each of these universities has an aquaculture department affiliated to the Faculty of Fisheries, Marine Sciences and Technology, Marine Sciences or Agriculture. In addition to these, there are Marine Sciences Institutes in 3 universities. In Fisheries Faculties / Vocational Schools, aquaculture education is given in 3 departments (Basic sciences + aquaculture + fishing - processing). Graduates of these universities receive the titles of fisheries engineer and fisheries technology engineer (Yeşilayer et al., 2016). However, there is no other country in the world that has so many departments/faculties/units related to Fisheries. This diversity and numerical multiplicity in fishery products lead to negative effects on quality and major employment problems. For this reason, quality should be prioritized in employment, not just numbers.

In the strategic planning prepared by the Turkish government regarding the aquaculture sector, the following determinations and evaluations were made as the problems experienced in aquaculture education; "*With the extension of internships in Fisheries Faculties, Fisheries Technology and Fisheries Engineering Departments to a 4-year education period, students will have the opportunity to do internships in different fields of the sector. By providing compulsory internship and non-internship opportunities to students during their education period, competent engineers needed by the industry will be trained. Legal arrangements must be made for compulsory internships in the public and private sectors and for students who want to work out of internship, including Social Security requirements. It is necessary to ensure that the sector works together with the Fisheries Faculties, Fisheries Technology and Fisheries Engineering Departments on the transfer of new information and technology development*" (BSGM, 2019).

There are approaches that argue that basic sciences should be given at the undergraduate level for fisheries programs in universities, and that the curriculum should be given at the master's level (primarily through thesis or doctoral thesis) for specialization in the relevant discipline (Hard, 1995). It is seen that such an approach style generally exists in our country. The course curricula applied in the education are renewed and updated, taking into account the sector's needs and developments, through the work of the Fisheries Deans Council. The new curriculum consists of 45 compulsory and 8 elective courses and measures are taken to close the application gap. It makes innovations in the direction of implementing the 7+1 system recommended by YÖK, 7 semesters of lectures at the faculty, and 1 semester of continuous training-work at the workplace. However, under the conditions in which the world speaks industry 5.0 (Nahavandi, 2019; Adel, 2022), it does not seem possible for Türkiye that has claims in terms of production and export of fishery products to achieve its goals without considering important issues such as digitalization, biotechnology and climate change in the education system. On the other hand, although there are biotechnology courses in the education curriculum given at both undergraduate and graduate levels in universities from Türkiye, it is seen that there is little or no information given about information technologies and their integrated use in the production and management process (Table 1).

**Table 1.** *Fisheries Engineering Courses from Faculty of Marine Sciences and Technology/ Iskenderun Technical University*

| | | |
|---|---|---|
| English I | English II | Statistic |
| Physics | Mathematics II | General Microbiology |
| Mathematics I | Technical Drawing | Water Quality and Pollution |
| General Biology | Aquatic Invertebrates | Mechanics of Engineering |
| Chemistry | Genetic | Ecology |
| Technology Literacy | Turkish II | Biochemistry |
| Turkish I | Innovation and Entrepreneurship | Material Knowledge and Mechanization |
| Occupational Health and Safety | Ethic | Career Planning |
| Fishing Gears Model Construction Techniques | Technical English | Feed Technologies |
| Anatomy and Physiology | Aquaculture Processing Technology | Marine Fish Culture |
| Planktonology and Plankton Culture | Freshwater Fish Culture | Crustacean Culture |
| Oceanology | Maritime Law and Fisheries Legislation | Fish Disease |
| Fish Systematics | Aquarium Fish Culture | Summer Training |
| Aquatic Plants | Fishing methods | Marine Fish Culture |
| Fluid Mechanics | Career Planning | Crustacean Culture |
| Limnology | Feed Technologies | Fish Disease |
| Volunteering Work | Project | Summer Training |
| Projecting of Aquaculture enterprises | Economics and Marketing of Fisheries | Quality Control in Aquaculture |
| Fisheries Management and Population Dynamics | Professional Training in Enterprises | Technical Elective Courses |

The changing preferences, morals and values of today's college students create a unique and challenging dynamic to involve the next generation in the management of fish and wildlife resources. Critical to the success of future conservation efforts will be changing education and workplace systems to prepare and support future professionals to tackle these complex, interdisciplinary issues. Understanding the characteristics of the next generation of natural resource leaders and the individuals they will interact with in seeking conservation is key to enabling them to meet the challenges of a new era in resource management (Millenbah et al., 2011). In the current section, climate change, biotechnology and information technology issues are discussed in relation to fisheries (fishing and aquaculture), which should be included in the aquaculture education curriculum in universities to sustainable fisheries and achieve aquaculture related production targets.

## 2. The Effects of Climate Change, Digitalization and Biotechnology on Sustainable Fisheries Production

In fact, biotechnology and information technology are seen as the most important tools that can be used both to reduce the effects of climate change and to adapt to climate change for sustainable fisheries production. Globally, we are increasingly dependent on using digital and computer technologies for our daily activities. It is stated that digitalization is the integration of digital technologies into daily life, where contemporary technologies can transform socio-economic, environmental, sustainability and climate research practices (Kryzhanovskij et al., 2021; Rowan, 2022; Balogun, et al., 2022). We live in an era known as the Fourth Industrial Revolution or Industry 4.0. This period of economic development began at the beginning of the 21st century. Instead of systems and technologies characterized by rigid and centralized systems that control industries, they are gradually being replaced by agile and decentralized intelligence that more combines the physical, digital and biological dimensions for knowledge generation, product and service innovation on a larger scale, and the innovation of products and services on a larger scale. Different technological trends such as enabling nanotechnology, optimized sensors, blockchain, internet of things (IoT), artificial intelligence (AI), and machine learning have emerged (Bueno et al., 2021).

Due to reasons such as global warming, population growth and deterioration of the environment (Mazlum et al., 2022), fish stocks in the world are being depleted at an increasing rate day by day. Aquaculture seems to be the only way to provide enough seafood for the world. Although aquaculture dates back 4000 years in China, in the last 50 years, the introduction of new technologies and the application of science and in aquaculture have supported the rapid development of aquaculture. Aquaculture is more diverse than other sectors in agriculture in terms of feeds, production systems, diseases, marketing, products, species, and business structures. While scientific and technological advances have some potentials to contribute benefits almost from every aspect of aquaculture, it has faced serious challenges, such as only a few bred species, diseases, lack of traceability of products, environmental pollution, and labor intensity. Therefore, the aquaculture sector needs advanced technologies to increase fish production. New and breakthrough technologies such as genome editing, oral vaccination artificial intelligence, oils and alternative proteins to replace fish feeds and fish oils, blockchain for marketing and the internet of things can provide sustainable and profitable solutions for aquaculture (Yue and Shen, 2022). In Brazil, it is expected that aquaculture 4.0 will reduce the massive dependence on water, feed and human labor. Farmers will minimize the use of essential resources and focus on the efficiency and control of production (Bueno et al., 2021).

## 2.1. Climate Change

Global Climate Change, one of the most threatening issues in today's world, is primarily caused by global warming caused by greenhouse gases that threaten life on earth as a result of human activities (Pörtner et al., 2022). Therefore, as future fisheries manager and technical personnel candidate, students should learn about the possible effects of climate change and the curriculum should be created and updated accordingly.

The effects of global warming on the marine systems are very complex and large-scale and involve three main phenomena. These are:

- Warming of aquatic environment,
- Acidification of aquatic environment,
- Sea level rising.

A lot of work has been done to recognize how the marine system, which covers about 71% of the globe, is changing and its direct and indirect consequences on marine ecosystems and resources, including humans who use the oceans for various services. (Hu, et al., 2022; Romm, 2022; Habibullah et al., 2022). Although there have always been disagreements about fisheries regarding the sharing of resources in the world, global warming will negatively affect the structure of these conflicts in every sense. Potential pathways in which climate change can lead to conflicts in fisheries is given in Figure 1. Therefore, responsiveness and management flexibility and will be a key feature of successful fisheries management (Mendenhall et al., 2020; Galappaththi et al., 2022).

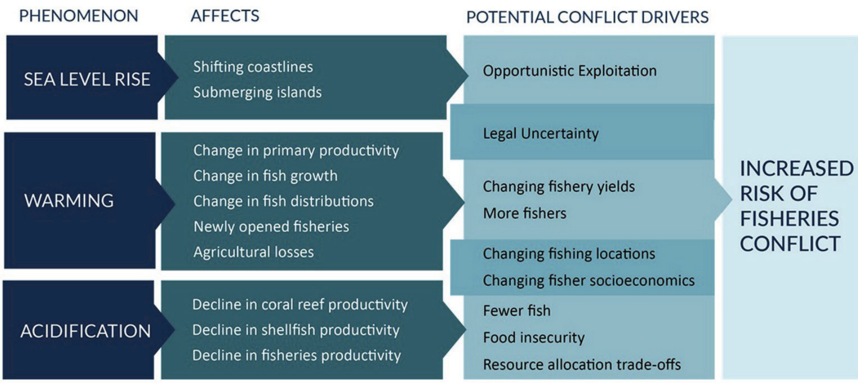


**Figure 1.** *Potential pathways in which climate change can lead to conflicts in fisheries (Mendenhall et al., 2020).*

It seems likely that changes related to climate change in aquatic environments (relocation of fish stocks, emergence of new aquaculture areas, etc.) will deepen existing conflicts between individuals, groups and countries, and more importantly, new conflicts may arise. It is considered that this rivalry may be more severe particularly in areas where there are political conflicts from the past and in countries where property rights and official governance institutions enforcement are weak, which is highly dependent on fisheries. Although climate change will produce both “winners” and “losers” in fisheries, the common theme is disruption and change in the balances that make up the system. Ocean warming causes changing species distributions and triggers multiscale spatio-temporal changes in fish stocks. Warming is also affecting the primary productivity, growth and distribution of fish populations, altering the reorganization of food webs and the yield of exploited marine species as well as the economic and social benefits they provide (Mendenhall et al., 2020; Palacios-Abrantes et al., 2022). It is argued that since the effects of climate change on land will be spatially heterogeneous, it will increase the number of fishermen and the dependence on fishing as a source of livelihood and income. As terrestrial temperatures rise, expected consequences include losses in agricultural production and an increased need for alternative livelihood options for people who depend on agriculture, and an increase in migration towards relatively open access resources such as fishing, particularly traditional fisheries of the developing world. In many agriculturally dependent coastal and delta countries the observed situation between the problems of terrestrial agriculture and the increasing local dependence on fisheries is presented as evidence for this. (Mendenhall et al., 2020).

The effects of climate change on aquaculture sector mirror the high level of difficulty embedded in aquaculture social-ecological systems.

Three categories have been defined for adaptation to climate change. These are coping mechanisms at the local level (eg water quality management techniques), multi-level adaptation strategies (eg changing cultural practices) and management approaches (eg adaptation planning, community-based adaptation). Some important impacts of the different elements of climate change on aquaculture and potential adaptive measures is given in Table 2 (De Silva and Soto, 2009). In addition, in-country aquaculture adaptation studies, household-level studies, whether different groups of aquaculture farmers (e.g. indigenous people) face and adapt differently to climate change, and the use of GIS and remote sensing to develop adaptation strategies and interventions. There are different potential areas of study for future research, including the use of cost-effective tools. (Galappaththi, etal, 2020).

**Table 2**. *Impacts of Different Elements of Climate Change on Aquaculture and Potential Adaptive Measures (De Silva and Soto, D., 2009).*

| Aq. /other activity | Impact(s) | | Adaptive measures |
|---|---|---|---|
| | +/- | Type/form | |
| For all cultivated species | - | Temperature rises above the optimum tolerance range | More suitable feeds, selective cultivation for higher temperature tolerance |
| For all freshwater fish | + | increase in growth; higher production | Increases feed intake |
| Freshwater fish in cages | - | Increased mortality from eutrophication and upwelling | Better planning; sitting, conform to cc, regulate monitoring |
| Marine and Freshwater fish and mollusks | - | Increases virulence of pathogens | None; monitoring to avoid health risks |
| Carnivorous fin fish/ shrimp* | - | Limitations on the supply and price of fishmeal and fish oil | The use of substitute products for fish meal and oil; new fish feed management; emphasis on breeding non-carnivorous species |
| Artificial propagation of species for Live fish restaurant trade | + | Coral reef destruction | None; however, aquaculture could positive impact by reducing an external contributor to destruction and helping to conserve biodiversity. |
| **Sea level rise** | | | |
| All; primarily in deltaic regions | +/- | Salt water inlet | Replace upstream stenohaline types - costly; new euryhaline species in old plants |
| | +/- | Reduction of agricultural land | Offer substitute livelihoods -aquaculture: size building and infrastructure |
| Marine carnivorous fish species | +/- | Reduced catch from artisanal coastal fisheries; fishermen's income loss | Reduced feed supply; but encourages the use of pellets -higher cost/less environmental degradation |

| | | | |
|---|---|---|---|
| Shell fish | - | Increasing harmful algal blooms | Increased risk to human health due to consumption |
| Habitat changes/loss | - | Indirect effect on estuary fishery products; some seed availability | None |
| **Acidification** | | | |
| Mollusc /seaweed culture | - | Impact on shell formation/ accumulation | None |
| **Water stress (+ drought conditions etc.)** | | | |
| Pond culture | - | Limitations for abstraction | Growing the efficiency of water use; To promote aquaculture based on non-consumption water use |
| Culture-based fisheries | - | Decreased water retention period | Using faster growing fish species |
| Riverine cage culture | - | Availability of wild progeny stocks decreased or change of period | Artificial transition to production; additional charge |
| **Extreme climatic events** | | | |
| All forms; predominantly coastal areas | - | Destruction of facilities; stock loss; job loss; mass scale escape with potential for impact on biodiversity | Promote the use of native species to diminish effects on biodiversity |

## 2.2. Information/Digital Technologies

New digital technologies will improve real-time assessment of production sites, allowing larger and more remote systems to increase control, efficiency and safety of aquaculture activity, leading to increased productivity and supporting the transition to circular economy, bioeconomy and sustainability (Bueno, et al., 2021; Setiyowati et al., 2022). In general, in order to increase the profitability of the domestic fish industry due to the application of digital technologies, it is necessary to provide the technological and financial conditions for their implementation in all main fishing centers. Efforts should be made to ensure that their use is made available to commercial establishments and is solely for the purpose of increasing the productivity of the fish industry and does not interfere with this purpose (Andronova et al., 2019). Table 3 defines common terms used for digital technologies (Rowan, 2022).

**Table 3.** *Common Terms Used for Digital Technologies (Revised from Rowan (2022)).*

| DIGITAL TECHNOLOGIES |
|---|
| **Information and communication technology (ICT):** Information and Communication Technology (ICT) is a collection of information technology, telecommunications and governance policies regarding how information should be accessed, secured, processed, transmitted and stored. |

| |
|---|
| **Internet of Things (IoT):** The Internet of Things (IoT) describes the network of physical objects embedded with sensors, software, and other technologies for the purpose of connecting and sharing data with other devices and systems over the Internet. |
| **Cloud computing:** With the development of cloud computing technology, it has become possible to store and access big data on the internet. In line with these possibilities, the definition of big data, which is one of the building blocks of Industry 4.0, has found the opportunity to be applied in the sector. |
| **Artificial Intelligence (AI):** Artificial intelligence is the ability of a computer or computer-controlled robot to perform tasks often associated with intelligent beings. |
| **Machine learning (ML):** Machine learning is a data analysis method that automates analytical model building. It is a sub-branch of artificial intelligence based on the idea that systems can learn from data, identify patterns, and make decisions with minimal human intervention. |
| **Big data:** Big data is data that contains more diversity and is increasing in volume rapidly. This also refers to the three Vs (volume, velocity, variety), namely volume, velocity, and variety. Simply put, big data is larger, more complex datasets derived specifically from new data sources. |
| **Blockchain:** Blockchain is defined as a securely shared decentralized data registry. Blockchain technology allows a common group of participants to share data. Transaction data from multiple sources can be easily collected, integrated and shared with blockchain cloud services. |
| **Augmented reality:** Augmented reality is the blending of virtual objects with real images using the object recognition feature of devices. In fact, objects are superimposed on the existing objects, thus increasing the reality. |
| **Virtual Reality:** Virtual Reality (VR) is the experience of different simulation environments created with computer technology and tried to simulate reality with the help of various agents such as computer screen, mobile devices, VR glasses. |
| **Robotics** - a branch of technology that deals with the design, construction, operation and implementation of robots. In multi-robot or swarm robot systems, the robot collaborates to complete predefined tasks. |
| **Cobot or collaborative robot** is a robot designed for direct human-robot interaction with a shared space or where humans and robots are in close proximity. |
| **Digital twin**: A digital twin is a virtual model of a product, process or service. In other words, it means creating a virtual twin, the exact equivalent of something physical. In short, we can say that it is a virtual copy of the physical object. |
| **Edge Cloud:** Edge Computing is a decentralized, distributed computing infrastructure that evolves with the growth of IoT. Cloud computing handles this through a central, cloud-based location (usually a data center) miles away from the device. On the other hand, edge computing; It brings data computing, analysis, and storage closer to the devices where data is collected, eliminating the need to move information back to the cloud. It secures data with a well-designed architecture that combines hardware and software components at the edge. |

Information/digital technologies could have the influence to revolutionize the aquaculture industry (Figure 2, Table 4). For example; Robotics to handle the tough jobs, drones for data collection, sensors to measure water parameters and monitor nutrition and health, artificial intelligence (AI) to power quick and precise decisions, augmented reality (AR) to increase production efficiency and improve aquaculture education, virtual reality (VR) for education and consulting, 3D Printing Technologies to produce tools for aquaculture, Blockchain (Figure 3) as a reliable traceability tool, Internet of Things (IoT) to connect different parts of the aquaculture industry (Yue and Shen, 2022; Rowan, 2022; Setiyowati et al., 2022).

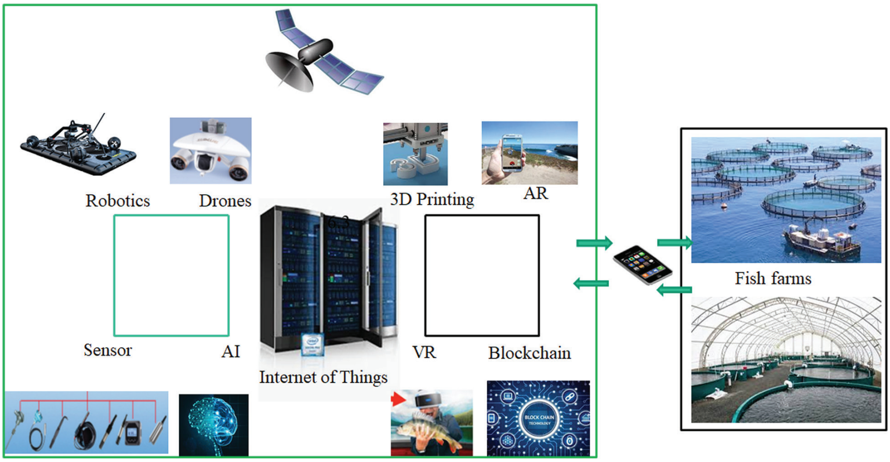


**Figure 2.** *Information/Digital Technologies Applicable to Further Increase Aquaculture Production (Yue and Shen, 2022).*

**Table 4.** *Digital Technologies Used in Fisheries and Aquaculture (Rowan, 2022).*

| Digital Technology | Application |
|---|---|
| Robotics | Perform complex tasks and laborious tasks such as cleaning ponds and repairing damaged nets |
| | Monitoring fish behavior, removal of diseased fish, feeding |
| | Fish Vaccination |
| | Control of cage nets, assessment of fish health and fish escapes |
| Drones | Monitoring of fish farms |
| | Checking for holes in damaged cages |
| | Collecting data that combines artificial intelligence and cloud computing to optimize farming operations |
| Sensors/ Remote Sensing | Real-time measurement of water parameters |
| | Monitoring the hunger levels of fish in ponds and cages using underwater sensors |
| | Measuring fish metabolism and heart rates |
| | Increasing the efficiency of feeding |
| AI | To make more accurate and faster decisions |
| | Less labor use |
| | Increasing the efficiency of feeding, monitoring and controlling the water quality of the aquaculture environment, optimizing the harvesting and processing processes |

| | |
|---|---|
| Augmented Reality (AR) | Education and training |
| | Growing production efficiency and reducing costs |
| | To facilitate the work of drones and robots used underwater |
| | Monitoring fish behavior, holes in the net and fish deaths |
| | In reducing the risks in all processes |
| | Measurement of water parameters in the aquaculture environment |
| Virtual Reality (VR) | Use of digital interface for real-time simulation of environmental conditions |
| | Use in education, training and course activities |
| | Remotely used for high-risk environments using human computer and multimedia platforms. |
| 3D printing | To print hydroponic systems |
| | 3D verification devices |
| | 3D printed water sensors to monitor water parameters |
| | Reducing equipment and production costs |
| IoT | Connecting the big data produced by the aquaculture industry |
| | Combined use of social media for marketing, awareness raising and other purposes |
| Blockchain | Cybersecurity, safe data sharing |
| | Payment processing |
| | Industry protection |
| | Full traceability across value chain |
| | Reduce food wastage, improve food safety. |

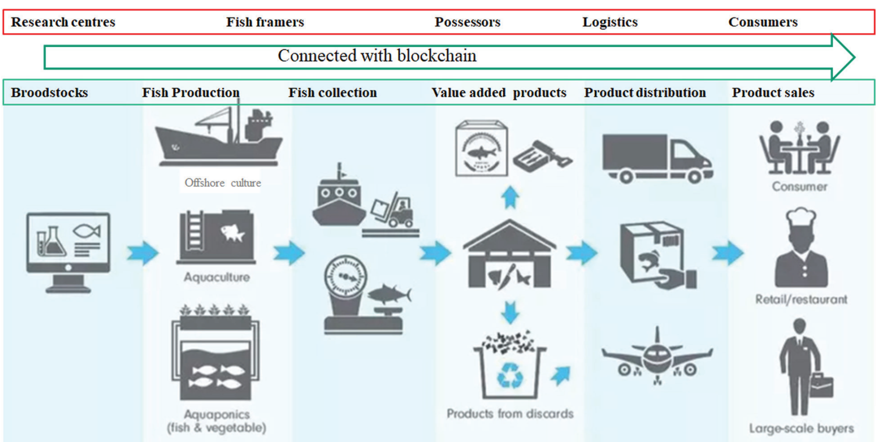


**Figure 3.** *Blockchain for aquaculture production and marketing.*

### 2.3. Molecular Technologies and Biotechnology

**New molecular technologies:** Techniques for genetic improvement are very important tools leading to dramatic increase the production in world aquaculture. Therefore, these programs will inevitably be used increasingly in the global aquaculture industry. Combining molecular technologies with existing breeding programs has significantly accelerated the genetic development of some aquaculture species. Genomic selection (GS) is one of the new approaches used in molecular breeding. GS provides more accurate estimates of breeding values (Figure 4). Genome editing (GE) using CRISPR/Cas can accelerate the genetic evolution of aquaculture species once the genes to edit are known (Figure 4). GE allows for rapid insertion of suitable alleles into the genome, increasing the frequency of favorite alleles at loci that determine important traits, generating new alleles, and/or introducing suitable alleles from other species. Aquaculture species are particularly suitable for GE due to high fecundity and external fertilization, allowing genome editing for many individuals at the same time. Advances in Genomic selection and Genome editing will significantly reshape the world aquaculture industry by helping to improve the economically important characteristics of many aquaculture species.  At the same time, joining GS and GE with cutting-edge traditional breeding strategies and mature biotechnologies could significantly accelerate genetic improvement in aquaculture. (Yue and Shen, 2022).

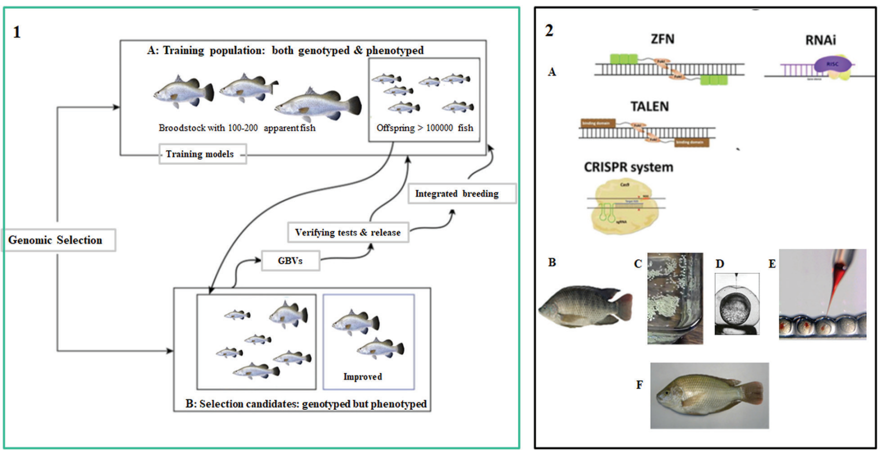


**Figure 4.** *Genomic Selection and Genome Editing that can Rapidly Improve the Economic Characteristics of Aquaculture Species (Yue and Shen, 2022).*

**Alternative proteins and fish oil:** The human food market is an emerging segment that demands raw materials from highly nutritious and sustainable sources. Innovations in biotechnology applied to fisheries and aquaculture, technical processes for developing new products, biological discovery of compounds, and production of aquatic organisms for human consumption will also push the industry towards bioeconomy. For example, farm-produced shrimp scraps can be used in several ways. One of these is the extraction of chitosan from shrimp shells for the cosmetic and pharmaceutical industries (Bueno, et al., 2021). In the aquaculture industry, especially in fish farming, including salmon, sea bream and sea bass, most feeds rely heavily on fishmeal and fish oil. Fish oil and fishmeal and are by-products of smaller bait fish, including herring, krill and other fish caught from the oceans. Fish meal contains a high amount of protein. The fast growth of the industry and the growing demand for farm-raised marine fish have led to an increase in the quantity and price of fish oils and fishmeal and in recent years. However, fishmeal and fish oil are largely based on wild-caught marine fish. Overfishing is already putting severe pressure on wild fish stocks. At the current increasing rate of aquaculture production, the fish feed supply is unable to meet the demands of the aquaculture industry. The negative impact of climate change on fishmeal production remains unclear. As a result, alternative proteins to replace fish feeds around the world are being studied extensively. In this context, seaweed and microalgae stand out with their high productivity, protein and amino acid contents, fatty acid profiles, low sugar and calorie contents. New processes of nutrients and plant components for aquatic feeds such as algal biomass and powdered insect meal have become a more permanent and sustainable alternative to extracting fishmeal from natural fisheries (Bueno, et al., 2021). Plant-based proteins, including soybean protein (Figure 5), have been investigated for many years with promising results. Fishmeal substitutes for fishmeal include micro and macro algae. Presently, high-quality algae feed is still expensive, but showing promising results. Many aquatic feed companies are working to improve their algae feed and increase accessibility. Another substitution option for fishmeal is insect-based proteins. Crickets and black soldier fly and are promising candidates for some insect-based proteins. Culture protocols using food waste have been established for these insects. Several companies started producing these insects and increased production to keep the cost down. Alternative proteins and fats to replace fishmeal are promising, but there are a few critical issues to consider. These issues include consistency of supply, cost, and production capacity. The alternative protein and oil industry for fish oils and fishmeal and can only survive with enough ingredients.

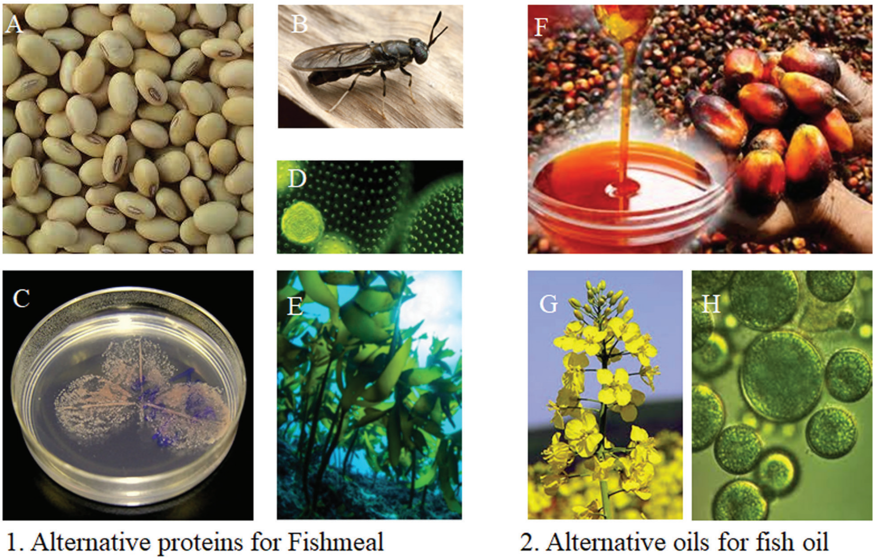


**Figure 5.** *Potential Sources for the Replacement of Fish Oils and Fishmeal in Fish Feeds. Plant-based Protein (eg A. soybean), Insect Proteins (eg B. black soldier fly), Unicellular Proteins (C), Microalgae (D), and Seaweeds (E). Potential Substitutes for Fish Oils are Palm Oil (F), Rapeseed Oil (G), and Microalgae Oil (H) (Yue and Shen, 2022).*

The 3rd type of substitute protein is unicellular proteins (SCPs). SCPs are produced by algae, fungi, and bacteria. SCPs have the potential to meet protein needs in the aquaculture industry. Feeding trials revealed that SCPs can replace fishmeal in carnivorous species. Therefore, SCPs are hopeful candidate to replace fishmeal. In recent years, significant progress has been made in replacing fish oil with vegetable oils in formulated fish feeds. Also, as promising candidates, rapeseed oil and palm oil could be replaced for fish oil.

**Oral vaccines:** Diseases are one of the biggest problems encountered in aquaculture. It is expected to increase especially with climate change. It is estimated that the economic loss due to diseases in the sector is 6 billion USD annually. Vaccination is an effective means of preventing bacterial and viral diseases. Vaccination also helps to guarantee the economic, environmental, and social sustainability of the sector. However, when compared to the livestock sector, vaccination-related processes lag behind in the aquaculture sector. Only a few vaccines have been recorded and administered in the industry. In addition, vaccination in fish is a labor-intensive process in which a dose of vaccine is manually injected into each fish. They are an alternative to labor-intensive old-style vaccination by manual injection. They reduce the mortality rate during vaccination by minimizing the handling and harm to fish. Microencapsulation incorporating antigen from pathogens could be a technology for delivering oral vaccines to fish. There are ways to develop breakthrough vaccines for oral delivery systems. However, there does not appear to be an operative oral vaccine currently available in the aquaculture industry. While oral vaccines are promising, oral administration is still very difficult for aquatic fish. Finding ways to preserve the vaccine active in water for a period of time, to overcome the challenging gastrointestinal environment, and to provide effective protection is inevitable. Given these challenges, for the advance of operative oral vaccines, delivery systems must be carefully designed and contain molecules that can amplify the effects of vaccines to elicit potent immune responses. Alternative and emerging approaches should definitely be discovered to progress effective and inexpensive oral vaccination for the aquaculture sector (Yue and Shen, 2022).

**Nanotechnology:** Nanotechnology can be applied in fish nutrition, biotechnology, genetics, reproduction, pathology and environmental quality protection etc. It has emerged as an innovative and effective tool in fields. Feed application enriched with nano elements intentionally increased fish growth. Developing nano-materials are currently being applied in water systems to reduce treatment costs by removing pollutants. Genetically modified techniques, along with nano-biotechnology, have revolutionized fish genetics research. Newer uses of nano-sensors, DNA nano-vaccine, nano-inspired genes and drug delivery systems have reformed the fish health, reproductive and immune system. Also, nanotechnology is currently used in the fish processing industry for sterile packaging, full flavor and quality. The optimum use of fisheries wastes using bio-nano-engineering technique and the application of green nanoparticles have started a new post-harvest era. The dimensions of nanotechnology applied in the water system are still in their infancy (Sarkar et al., 2022).

## 3. Conclusion and Recommendations

It seems inevitable that new technologies will be applied to the sector in order to guarantee the sustainable production of the fisheries and aquaculture sector, which is becoming more important day by day in the Turkish economy, and to achieve its goals. In this sense, it is necessary to have human resources with the vision and ability to apply these technologies in the sector. For this, a working group can be formed that includes deans of fisheries faculties, TUBITAK, relevant ministries and sector representatives. Such a working group can carry out its work under the coordination of the Turkish Higher Education Council. Such a committee may carry out the following activities;

- Introducing compulsory courses in university programs,

- Addition of these topics in the urgency areas to be supported by TUBITAK,

- Providing certified training programs on these issues to engineers working in sector,

- Quickly preparing course materials related to them. In this sense, AR and VR- Virtual Reality supported course materials could be prepared.

Acknowledge

Prof.Dr.M.Fatih CAN graduated from both Fisheries (Ankara University, Ankara) and Management and Information Systems (Anadolu University, Eskişehir) undergraduate programs.

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# Chapter 3

## A RESEARCH ON WORKERS IN THE FOREST PRODUCTS SECTOR WITH LOGISTIC REGRESSION ANALYSIS

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## INTRODUCTION

Due to factors such as intense competition, high customer and quality expectations, organizations expect their employees to take responsibility and be involved in innovation. In such an age, organizations need people who respond well to environmental challenges, are not afraid to share knowledge, and take initiatives for their own and their friends' beliefs to survive. That is, organizations need people who feel (identify with the organization) that they will continue their lives as long as their organizations continue their lives in a competitive environment. In order to achieve organizational identification, people need to trust their co-workers, managers and organization. An organization that cannot establish trust-based relationships within itself cannot be expected to have good relations with the external environment. Because trust is the main guarantee of relations within the organization. It is very difficult for the organization to survive in an environment where there is no sense of trust for a long time (Önder and Yavuz, 2019; Filiz and Bardakçı, 2020).

Employees in organizations where trust does not exist can leave their jobs voluntarily, and leave of employment may cause direct or indirect costs to the organizations. When a qualified employee leaves the job, the time and money spent on the development of the leaving personnel disappear with the leaving employee. There may be production problems and losses in the period until another personnel is employed to the same position and time and money is again spent on training new employee (Ersen et al., 2021).

In the literature, studies have been conducted on the relationship between demographic characteristics and organizational trust for university and dormitory personnel (Işık et al., 2018; Önder and Yavuz, 2019), teachers (Koç, 2019; Akpolat and Oğuz, 2022), health employees (Işık et al., 2020; Filiz and Bardakçı, 2020), bank employees (Halis et al., 2007), textile employees (Akkoyun and Kalkın, 2015).

There are also many studies with the use of logistic regression, which is one of the main subjects of the study. It is seen that logistic regression is used for researches about health (Hussen and Alemu; 2021; Mohsin et al., 2021), economic and administrative (Wang and Li, 2022) educational science (Cabero-Almenara et al., 2022; Huang, 2022), physical education and sport sciences (Abu-Omar et al., 2021; Farah et al., 2021), social science (Huang and Chen, 2022), engineering (Zheng et al., 2021), agriculture or natural science (Islam et al., 2021; Aytop et al., 2022), and energy (Berglund et al., 2021; Lee et al., 2022).

In particular, there are studies with the use of logistic regression about forest products and forest industry fields in the international literature (Dida et al., 2019; Pokharel et al., 2019; Sunaryo and Handayani, 2019; Sunaryo, 2020; Taghouti et al., 2021; Jacobsen et al., 2021; Gateva et al., 2022; Sanchez-Alegria et al., 2022; Yang et al., 2022).

In this study, the effect of the demographic characteristics of the employees in the forest products sector on the organizational trust levels of the employees was investigated with the help of binary logistic regression. For this purpose, an analysis was made on the use of logistic regression in the forest products sector. Moreover, information is given about organizational trust and logistic regression.

**Organizational Trust**

Many researches from different fields have tried to define trust. Cofta pointed out that trust has 17 different meanings. Also, the definitions of trust and the level of analysis (individual, organizational and social) differ between various fields (psychology, sociology and economics) (Rezaei et al., 2012). Lewis and Weigert (1985) defined trust as “observations that show that members of a system act according to and are secure in the expected futures consisting of each other’s presence for their symbolic representations”. Moorman et al. (1993) reported trust as “the desire of one party to trust another party”. According to Mayer et al. (1995), trust is “the willingness of a party to be vulnerable to the actions of other party, based on the belief that one party will perform a particular action that is important to the trustor, regardless of his ability to control and monitor the other party”. Trust can also be seen as a social capital that provides coordination and cooperation among people. In the context of a society, trust can be viewed as a mechanism to reduce complexity. In terms of companies, trust is a key to successful transactions and long-term relationships (Jones, 2002; Corritore et al., 2003).

Trust occurs at the organizational level as well as at the individual level. However, trust to the individual and trust to the organization are different concepts. Organizational trust is generally defined as “a psychological state that includes the intention to accept vulnerability based on positive expectations about another’s intentions or behaviour” (Rousseau et al., 1998). Another definition of organizational trust is “the positive expectations of organizational members about the intentions and behaviors of individuals based on organizational roles, relationships, experiences and interdependency in the organization” (Shockley-Zalabak et al., 2000). Organizational trust can emerge by referring to different goals (co-workers, managers, organizations) and units of analysis (individual-level trust or group-level trust).

The higher the trust in the organization level, the more willing employees will be to come to the organization. Employees do their job with pleasure, and therefore, there is an increase in the performance of the employees. As the performance of the employees increases, the productivity of the organization will also increase. When there is no or little trust to organization, employees feel that their work is not noticed by the managers, and therefore, employees may think that there is no need for more effort. There may be decreases in the performance of employees who are in this mentality, and this decrease in performance may also affect product quality. Moreover, Employees may not want to go to work because they are not happy in the organization (Halis et al., 2007). Because of the risk involved, a high level of organizational trust represents a form of intense psychological commitment to an organization (Ng, 2015). Mayer et al. (1995) suggest that organizational trust emerges when individuals believe that the organization has the virtues of talent, benevolence, and integrity. These virtues enable employees to take on the risks associated with the organization in the future (Ng, 2015).

## Logistic Regression

Logistic regression models are defined as "statistical models which describe the relationship between a qualitative dependent variable and an independent variable" as in linear regression (Nick and Campbell, 2007). Logistic regression works very similar to linear regression. The biggest advantage of logistic regression: it allows analysis of dichotomous or binary results with 2 mutually exclusive levels. In addition, logistic regression allows the use of continuous or categorical estimators. Logistic regression models are generally used to examine the effects of predictive variables on categorical outcomes (LaValley, 2008).

The logistic regression model has its basis in the odds of a 2-level outcome of interest. That is, the odds of an outcome is the ratio of the probability of the outcome to the probability of it not happening (LaValley, 2008). Probability is a value between zero and one and odds are a value between zero and infinity. The odds ratio (OR) is the ratio of two odds to each other. It is calculated as OR=exp($\beta$) in logistic regression . The logistic regression model takes the natural logarithm of the odds as a regression function of the predictors:

$$In(odds(Y=1)) = \beta_0 + \beta_1 x_1 + \beta_2 x_2 \dots \dots \beta_i x_i \quad (1)$$

where $In$ represent for the natural logarithm, Y is the outcome and Y=1 when the event happens (Y=0 when it does not), $\beta_0$ is the intercept (constant) term, β are the regression coefficients associated with the reference group and the $x_i$ explanatory variables (LaValley, 2008; Alpar, 2011; Sprerandei, 2014).

In logistic regression analysis, -2 Log Likelihood (-2LogL) statistics, Hosmer Lemeshow fit test, Omnibus test, Cox-Snell $R^2$ and Nagelkerke $R^2$ values are used to test the model fit. The -2LogL statistic is used to investigate the contributions of the independent variables added to the model to the model. That is, the -2LogL statistic is used to test the significance of the logistic regression coefficients. In this approach, two different -2LogL statistics are calculated for the model. The first is the -2LogL statistic of the model containing only the constant term; the second is the -2LogL statistic of the model, which also includes the categorical independent variable (Kalaycı, 2016). If the difference between these two calculated values is high, it indicates that the dependent variable is predicted poorly (Bindak, 2018).

The Hosmer-Lemeshow test allows for any number of explanatory variables, either continuous or categorical. The Hosmer-Lemeshow test has the advantage of dividing observations into groups of approximately equal size.  In the Hosmer-Lemeshow test, if “sig.” is gretaer than 0.05, it indicates that the model fit is good (Hosmer et al., 2013; Kılıç, 2015).

In the omnibus test, on the other hand, all the coefficients of the model are tested together with the chi-square test. The null hypothesis of this test is that there is no difference between the model in which only the constant term is included and the model in which the independent variables are also included. In the omnibus test, the degrees of freedom are equal to the number of independent variables. In the omnibus test, if the calculated test statistic is greater than the table value, it is decided that the model is appropriate (Şamkar et al., 2016).

Cox and Snell $R^2$ and Nagelkerke $R^2$ are a measure of how much variation decreases when independent variables are included in the model. The closer these values are to 1, the better the model. Nagelkerke $R^2$ has been developed to enable Cox and Snell $R^2$ statistics to take values in the range of 0-1 and therefore it is often preferred (Bewick et al., 2005; Kılıç, 2015; Kalaycı, 2016; Karagöz, 2016).

One of the criteria that measures the goodness of fit of the model is the correct classification rate. Classification tables are used to determine the correct classification rate. In the classification tables, the actual values and the predicted values of the dependent variable are cross-classified and divided into groups. First, the threshold value is determined. The threshold value is generally accepted as 0.5. If the predicted values are above 0.5, it is assigned 1, otherwise 0. The correct classification rate is found by dividing the number of correctly classified data by the total number of data (Kara, 2015).

Wald statistic was developed to test the coefficients in the model. Wald statistic; it is the ratio of the "β" parameter and the standard error and it shows the Z distribution. In Wald statistics, as the logistic regression coefficient increases in absolute value, the estimated standard errors increase abnormally. Therefore, as the coefficients increase in absolute terms, it is not recommended to use the Wald statistics in testing the hypothesis tests, and the test is performed by evaluating the changes in the 2LogL value by adding or subtracting the relevant variable from the model (Albayrak, 2006; Çelik, 2011).

## METHODOLOGY

### Sampling

The sample was obtained from employees in the field of timber, furniture and wood -based board between 2020 and 2021. The prepared questionnaire form was applied to 460 employees and 448 of the surveys were evaluated. Moreover, this questionnaire form was applied to employees in the form of face-to-face. The demographic findings of the questionnaires included in the evaluation are follows: 86.2% male, 74.1% was married, 25.9% was single, 82.6% worked in the workers or administrative staff position, 17.4% worked in the manager position, 13.2% was between the ages of 18-25, 26.8% was between the ages of 26-33, 36.4% was between the ages of 34-41, 23.7% were over the age of 41, the salary of 91.3% was less than 4501 TL, the salary of 8.7% was more than 4500 TL, 11.2% had primary school degrees, 19.9% had secondary school degrees, 45.3% had high school degrees, 11.6% had associate degrees, 12.1% had undergraduate or graduate degrees, the employee percentage of less than 11 years of working time was 72.8 %, the employee percentage of 11-15 years of working time was 11.6%, the employee percentage of more than 11 years of working time was 15.6%, 22.1% was working in the timber sector, 46% was working in the furniture sector, 31.9% was working in the wood based board sector.

### Method

It was aimed to determine whether the demographic characteristics have an effect on employees' level of organizational trust by using logistics regression. Another goal is to provide information about the use of logistics regression in the forest products sector. For these purposes, a survey form consisting of two parts was prepared. In the first section, there are questions about the demographic characteristics of the participants. In the second part, there are questions about the perceptions of organizational trust of the participants. Organizational confidence scale developed by

Omarov (2009) was used to determine the perceptions of organizational trust of employees. The scale consists of 22 items and three dimensions (trust in managers, trust in co-workers and trust in the organization). The answers were taken by applying a 5-point Likert type scale. Since questions 18 and 21 are reverse questions, their answers are reversed (e.g. 1 for 5 and 2 for 4).

## RESULTS

In the study, firstly, reliability analysis was applied to the data and the reliability value of the organizational scale was determined as 0.966. The reliability values of the sub-dimensions of the scale are as: 0.957 for trust in managers, 0.931 for trust in the organization, and 0.904 for trust in co-workers. Since a Cronbach's Alpha value of 0.70 or higher was considered sufficient in the literature (Nunnally, 1978), the scale in this study was also decided to be reliable. After testing the reliability of the scale, factor analysis was applied to test the construct validity of the scale. The varimax method was used in the principal component analysis applied to the scale. Care was taken to ensure that factor loadings were greater than 0.30 and that the factor load difference between adjacent items was equal to or greater than 0.10. As a result of factor analysis, The KMO value of the scale was 0.890 and Barlett test of sphericity (p=0.000) was significant. Therefore, it is seen that the data are suitable for factor analysis. The variables were collected in 3 factors. The first factor explains 58.8% of the variability, the second factor 7.8% and the third factor 6.7%. The first factor consists of 10 statements and is named as trust in managers, the second factor consists of 7 statements and is named as trust in the organization, and the third factor consists of 5 statements and is named as trust in co-workers. The factor loads of the first factor vary between 0.628 and 0.809, the loads of the second factor vary between 0.583 and 0.792, and the loads of the third factor vary between 0.720 and 0.825. This study is consistent with the original scale (the scale developed by Omarov in 2009).

*Table 1. Factor analysis, reliability and mean results for organizational trust scale*

| | Factor 1: Trust in Managers | Factor 2: Trust in the Organization | Factor 3: Trust in Co-Workers |
|---|---|---|---|
| I trust that my manager is sufficiently knowledgeable and skilled in matters pertaining to his or her job | 0.691 | | |
| I trust my manager will make the right decisions about his job | 0.770 | | |

| | | | |
|---|---|---|---|
| I trust that my manager will perform his job duties accurately | 0.771 | | |
| I trust my manager will keep his promises | 0.773 | | |
| What my manager says and does is not contradictory | 0.809 | | |
| My manager is supportive and helpful when we need help | 0.783 | | |
| I trust the accuracy of what my manager tells me about anything | 0.785 | | |
| I can easily tell my manager everything about my job | 0.628 | | |
| I trust my manager to be able to do his job without causing further problems | 0.757 | | |
| My manager takes the opinion of his employees in decisions and procedures regarding employees | 0.679 | | |
| If I encounter any difficulties in my workplace, I trust my co-workers to help | | | 0.767 |
| I trust most of the co-workers I work with to do their job in the right way. | | | 0.825 |
| The co-workers I work with are doing their job even if the managers not supervise | | | 0.803 |
| I trust that my co-workers will not complicate my work in tasks that require attention | | | 0.755 |
| I trust that most of the co-workers I work with are experts at their jobs | | | 0.720 |
| The company I work for always treats me fairly | | 0.583 | |
| The company I work for delivers on its promises | | 0.722 | |
| The company I work for doesn't always support me | | 0.758 | |
| I trust the company I work for is honest with its employees | | 0.714 | |
| The company I work for rewards and supports the employee who does his/her job well | | 0.744 | |
| The company I work for is not interested in my problems | | 0.792 | |
| I trust the employee policies of the company I work for | | 0.725 | |
| Eigenvalue | 12.935 | 1.715 | 1.478 |
| Percentage explanation of variance | 58.794 | 7.794 | 6.720 |
| Percentage of total variances | 58.794 | 66.588 | 73.308 |
| Cronbach alpha value | 0.957 | 0.931 | 0.904 |
| Average | 3.7128 | 3.5690 | 3.8784 |
| The overall average of the organizational trust scale | 3.7039 | | |
| Overall Cronbach alpha value of organizational trust scale | 0.966 | | |

The total mean score of the participants on the "Organizational Trust Scale" was 3.70. When the sub-dimension mean scores of the scale were examined, it was 3.71 for trust in managers, 3.57 for trust in the organization, and 3.88 for trust in co-workers (Table 1).

Logistic regression analysis is the focus of the research. The number of samples included in the logistic regression analysis is summarized in Table 2.

*Table 2. Data processing summary*

| **Unweighted Cases** | | **Frequency** | **Percent** |
|---|---|---|---|
| Selected Cases | Included in Analysis | 448 | 100 |
| | Missing Cases | 0 | 0.0 |
| | Total | 448 | 100 |
| Unselected Cases | | 0 | 0.0 |
| **Total** | | **448** | **100** |

Table 3 shows how the dependent (organizational trust) variable was coded. Coding; 0=low, 1=high. The grouping of employees' organizational trust levels as low and high was done according to the average of the scale. While the low level of organizational trust is below the average of the scale scores ($x< 3.70$), the high level of organizational trust is equal to or above the average of the scale scores ($x\geq 3.70$).The coding of the independent variables is follows: Gender variable: 1=male, 2=male; Marital status variable: 1=married, 2=single; Position variable: 1=manager, 2=worker/administrative staff; Income variable: 1=4500 TL and below, 2=4501 TL and above; Age variable:1=18-25 age, 2=26-33 age, 3=34-41 age, 4=42 age and above; Education: 1=primary school, 2=secondary school, 3=high school, 4=associate degree, 5=undergraduate or graduate; Working time: 1=10 years and below, 2=11-15 years, 3=16 years and above; Sector: 1=timber industry, 2=furniture industry, 3=wood-based board industry.

*Table 3. Dependent variable coding*

| **Original Value** | **Internal Value** |
|---|---|
| Low level of organizational trust | 0 |
| High level of organizational trust | 1 |

In Table 4, the number of cases for each category of the dependent variable is given. According to Table 4, employees were classified in the high category of organizational trust. In other words, when nothing is known about the independent variables, the prediction that the employees have high organizational trust will be the best prediction and the correct classification percentage will be 59%.

*Table 4. Classification table*

| **Observed** | | | **Predicted** | | **Percentage Correct** |
|---|---|---|---|---|---|
| | | | **Organizational Trust** | | |
| | | | Low | High | |
| Step 0 | Organizational trust | Low | 0 | 183 | 0.0 |
| | | High | 0 | 265 | 100.0 |
| | Overall Percentage | 59.2 | | | |

When Table 5 is examined, it was determined that the odds ratio value (Exp(B)) was found to be 1.448 and it was significant according to the Wald statistical value (p<0.001). This result shows that the probability of any of the analyzed employees to have a high level of organizational trust will be 1.448 times more than the probability of a low level of organizational trust.

*Table 5. Variables in the equation*

| | | **B** | **S.E.** | **Wald** | **df** | **Sig.** | **Exp(B)** |
|---|---|---|---|---|---|---|---|
| Step 0 | Constant | 0.370 | 0.096 | 14.839 | 1 | 0.000 | 1.448 |

As seen in Table 6, chi-square statistics were analyzed in three dimensions as step, block and model. Enter method was chosen to determine the model and chi-square value in all three dimensions ($x^2$=57.522; p=0.000<0.05) was significant. This result indicates that the independent variables (demographic characteristics) have a significant effect on the level of organizational trust.

*Table 6. Omnibus tests of model coefficients*

| | | **Chi-square** | **df** | **Sig. (p)** |
|---|---|---|---|---|
| **Step 1** | Step | 57.522 | 15 | 0.000 |
| | Block | 57.522 | 15 | 0.000 |
| | Model | 57.522 | 15 | 0.000 |

Compliance statistics values related to the organizational trust level model are given in Table 7. When the independent variables enter the model, the Cox and Snell $R^2$ and Nagelkerke $R^2$ values, which give the size of the variance explained in the dependent variable, are 0.12 and 0.163 respectively. That is, 16% of the total change in the level of organizational trust is explained by the independent variables used in the research. The Hosmer and Lemeshow chi-square value is 6.881, and it is seen that the logistic regression model predicted according to the Hosmer and Lemeshow test results is suitable for the data (p=0.550).

*Table 7. Compliance statistics of the organizational trust model*

| | **-2 Log likelihood** | **Cox & Snell $R^2$** | **Nagelkerke $R^2$** | **Hosmer and Lemeshow Test** | | |
|---|---|---|---|---|---|---|
| Step 1 | | | | **Chi-square** | **df** | **Sig. (p)** |
| | 548.444 | 0.120 | 0.163 | 6.881 | 8 | 0.550 |

Table 8 shows that the data is divided into 10 groups according to the dependent variable. It is desirable that the observed and expected values are quite close to each other (Gürbüz and Şahin, 2018). When Table 8 is examined, it is seen that the expected values and the observed values are close to each other. That is, it is seen that the model created is compatible.

According to Table 9, the percentage of correct classification in terms of low confidence level is 57.5% whereas the percentage of correct classification in terms of high level of confidence is 76.6%. The overall correct classification percentage of the organizational trust level is 68%. When the percentage of overall correct classification is compared with the percentage of classification done in the initial (nut) model, it is seen that the model is significant. The inclusion of independent variables in the model increases the estimation power of classification in terms of low and high confidence levels.

*Table 8. Probability table for Hosmer and Lemeshow tests*

| | | Organizational trust = Low | | Organizational trust = High | | Total |
|---|---|---|---|---|---|---|
| | | Observed | Expected | Observed | Expected | **Observed** |
| **Step 1** | 1 | 28 | 26.212 | 12 | 13.788 | 40 |
| | 2 | 33 | 34.646 | 23 | 21.354 | 56 |
| | 3 | 28 | 25.293 | 18 | 20.707 | 46 |
| | 4 | 19 | 22.449 | 26 | 22.551 | 45 |
| | 5 | 18 | 19.842 | 28 | 26.158 | 46 |
| | 6 | 14 | 17.744 | 35 | 31.256 | 49 |
| | 7 | 19 | 14.686 | 29 | 33.314 | 48 |
| | 8 | 14 | 11.018 | 31 | 33.982 | 45 |
| | 9 | 7 | 8.114 | 38 | 36.886 | 45 |
| | 10 | 3 | 2.996 | 25 | 25.004 | 28 |

*Table 9. Classification table of the established regression model*

| **Observed** | | | **Predicted** | | **Percentage Correct** |
|---|---|---|---|---|---|
| | | | **Organizational Trust** | | |
| | | | Low | High | |
| **Step 1** | Organizational trust | Low | 102 | 81 | 57.5 |
| | | High | 62 | 203 | 76.6 |
| | Overall Percentage | 68.1 | | | |

The coefficient estimates and odds ratios of the logistic regression analysis are presented in Table 10. The "B" is used in logistic regression to determine the probability that a person will do one job or the other (Özkan, 2013). Wald statistics was used for the statistical significance of the regression coefficients. The "Exp (B)" represents the odds ratios. Odss ratios show how many times more or less the dependent variable is likely to be observed under the influence of the independent variable. If the odds ratio is greater than 1, the probability of occurrence of an outcome is interpreted as increasing, if it is less than 1, the probability of occurrence of the outcome is interpreted as decreasing (Sprerandei, 2014; Şamkar et al., 2016). The last categories were taken as the reference categories of the variables.

When the coefficient estimates in Table 10 are analyzed, the following results were obtained.

Gender: The organizational trust levels of female employees is 0.411 times higher than male employees. The removal of the gender variable from the model causes a significant change at the 5% significance level.

Marital: The organizational trust levels of single employees is 0.767 times higher than that of married employees. The removal of the marital status variable from the model does not cause any significant change.

Age: The organizational trust level of employees aged 42 and over is 0.860 times higher than that of employees aged 18-25. Organizational trust levels of employees aged between 26-33 and 34-41 are 1.812 and 1.170 times higher than employees aged 42 and over, respectively. The removal of the age variable from the model does not cause any significant change.

Position: Organizational trust levels of employees in managerial positions are 2.049 times higher than those of employees as workers or administrative staff. The removal of the position variable from the model causes a significant change at the 10% significance level.

Income: Organizational trust levels of employees who are paid 4500 TL and below 4500 TL are 1.782 times higher than those of employees who are paid more than 4500 TL. The removal of the income variable from the model does not cause any significant change.

Education: The organizational trust level of primary, secondary, high school and associate degree graduates is higher than that of undergraduate and graduate graduates. As the education level increases, the organizational trust level of the employees decreases. The removal of the education variable from the model does not cause any significant change.

Working time: The organizational trust level of those working in the company for 10 years or less is 0.855 times less than that of those working in the company for 16 years or more. The organizational trust level of those working in the company between 11-15 years is 1.334 times higher than that of those working in the company for 16 years or more. The removal of the working time variable from the model does not cause any significant change.

Sector: The organizational trust level of employees in the furniture industry is 2.744 times higher than that of employees in the wood-based board industry. The removal of the sector variable from the model causes a significant change at the 1% significance level.

*Table 10. Coefficient estimates*

| **Variables in the Equation** | **B** | **S.E.** | **Wald** | **df** | **Sig.** | **Exp(B)** | **95.0% C.I. for Exp(B)** | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | **Lower** | **Upper** |
| Gender(1) | -0.890 | 0.393 | 5.141 | 1 | 0.023 | 0.411 | 0.190 | 0.886 |
| Marital(1) | -0.265 | 0.306 | 0.754 | 1 | 0.385 | 0.767 | 0.421 | 1.396 |
| Age | | | 5.279 | 3 | 0.152 | | | |
| Age(1) | -0.151 | 0.476 | 0.101 | 1 | 0.751 | 0.860 | 0.339 | 2.185 |
| Age(2) | 0.594 | 0.370 | 2.580 | 1 | 0.108 | 1.812 | 0.877 | 3.741 |
| Age(3) | 0.157 | 0.312 | 0.254 | 1 | 0.614 | 1.170 | 0.635 | 2.157 |
| Position(1) | 0.717 | 0.379 | 3.582 | 1 | 0.058 | 2.049 | 0.975 | 4.306 |
| Income(1) | 0.578 | 0.436 | 1.760 | 1 | 0.185 | 1.782 | 0.759 | 4.185 |
| Education | | | 0.492 | 4 | 0.974 | | | |
| Education(1) | 0.381 | 0.555 | 0.471 | 1 | 0.493 | 1.464 | 0.493 | 4.348 |
| Education(2) | 0.234 | 0.482 | 0.237 | 1 | 0.626 | 1.264 | 0.492 | 3.250 |
| Education(3) | 0.220 | 0.400 | 0.303 | 1 | 0.582 | 1.246 | 0.569 | 2.727 |
| Education(4) | 0.206 | 0.475 | 0.188 | 1 | 0.664 | 1.229 | 0.485 | 3.117 |
| Working time | | | 4.483 | 2 | 0.106 | | | |
| Working time(1) | -0.412 | 0.325 | 1.612 | 1 | 0.204 | 0.662 | 0.350 | 1.251 |
| Working time(2) | 0.288 | 0.406 | 0.502 | 1 | 0.479 | 1.334 | 0.601 | 2.957 |
| Sector | | | 23.616 | 2 | 0.000 | | | |
| Sector(1) | -0.157 | 0.330 | 0.225 | 1 | 0.635 | 0.855 | 0.447 | 1.633 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Sector(2) | 1.009 | 0.283 | 12.743 | 1 | 0.000 | 2.744 | 1.576 | 4.776 |
| Constant | 0.568 | 0.352 | 2.613 | 1 | 0.106 | 1.765 | | |

## CONCLUSION, DISCUSSION AND RECOMMENDATIONS

In this research, it was aimed to give information about the use of logistic regression in the forest industry with an example. For this purpose, a survey was conducted with employees working in the forest products sector. The effect of the demographic characteristics of the employees on the organizational trust levels of the employees with the data obtained as a result of the survey study was investigated by logistic regression. The organizational trust level of the study sample members in the forest products sector was high. In terms of the sub-dimensions of organizational trust, the participants trust their co-workers the most and the organization the least. In the research conducted on health personnel, it was determined that health personnel trust their co-workers the most (Filiz and Bardakçı, 2020). In another study, the organizational trust level of employees in accommodation enterprises was found to be 3.68 (Çiçek and Şahin Macit, 2016). Tekingündüz et al. (2017) stated that it is important for employees to trust the knowledge and competence of managers in terms of commitment. Redha et al. (2022) found that the organizational trust level of employees of the Central Library of Mohammed Seddik Ben Yahia University is high. These studies seem to be similar to our study.

When the logistic regression results are analyzed, gender and sector affect the organizational trust levels of the employees participating in the research at the level of 5% significance. That is, the organizational trust level of female participants is higher than male participants. In terms of the sector, the organizational trust levels of the employees in the furniture industry are higher than the organizational trust levels of the employees in the timber and wood-based board industry. The positions of the participants in their companies also affect their organizational trust levels at the 10% significance level. In other words, employees in managerial positions trust their organizations more. On the other hand, demographic characteristics such as age, education, marital status, income level, education level and working time no affect the organizational trust level of the participants significantly. There are studies in the literature that show similarities and differences with this study. In the study conducted for employees in the finance sector, no significant relationship was found between demographic characteristics such as age, education, working time and position, and organizational trust and its sub-dimensions (Halis et al., 2007). In his doctoral thesis, Vineburg (2010) determined that there is a significant relationship between organizational trust and demographic characteristics such as age, education level, administrative experience in the current institution, participation in the implementation of innovation, institutional type, gender, race and area. Chathoth et al. (2011) reported that education is the significant covariate, while the demographic variables such as age, gender, total working time, working time in the hotel are not significant. In another study conducted in the textile industry, the organizational trust level of female employees was higher than male employees and married employees compared to single employees. Moreover, it was determined that as the education level increases, the level of organizational trust also increases and the organizational trust levels of employees who have worked 11 years and more are higher (Akkoyun and Kalkın, 2015). Like in this study, in the study conducted by Işık et al. (2020), it was found that the working time did not have a significant effect on organizational trust, and the level of trust increased as the working time increased. Islam et al. (2021) conducted a study on employees in the Bangladesh banking sector and said that gender, education and experience did not have a significant effect on trust. Akpolat and Oğuz (2022) reported that teachers' organizational trust levels vary according to gender and working time.

In the literature review, there is little or no study on the determination of the effect of demographic characteristics on the organizational trust level of employees in the forest products sector with logistic regression. However, research on the application of logistic regression in the forest products sector in Turkey is quite limited (Çınar, 2018; Basılgan, 2020; Ersen, 2021). In this context, it can be said that the study is an original study that contributes to the literature. Organizational trust is one of the important factors that will increase the success, performance and productivity of the enterprises in the forest products sector and the employees in these enterprises. The fact that organizational trust is low or high according to demographic variables can be turned for favor of the employees and therefore, this positive situation may also provide positive results for companies.

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# Chapter 4

## MATHEMATICAL MODELS FOR PATHOGENIC BACTERIA RISK AND CONTROL ASSESSMENTS OF SEAFOOD PRODUCTS

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## INTRODUCTION

Bacterial diseases in fish and fishery products are rapidly spreading, having a negative effect on fish populations as well as human health. These bacterial diseases have an impact on many fishes. *Aeromonas*, *Mycobacterium, Flavobacterium*, *Streptococcus*, and *Edwardsiella* are some of the bacteria present in fish that cause bacterial diseases. These microorganisms are responsible for illnesses like cholera, tuberculosis, leprosy, syphilis, anthrax, and plague. People can be afflicted with illnesses of the cardiovascular system, gastrointestinal, kidneys, reproductive organs, and others due to consuming contaminated fish and seafood, and death can be possible (Verma et al., 2022). Pathogens associated with seafood consumption are indicated as *Staphylococcus aureus*, *Clostridium botulinum*, *Shigella spp., Listeria monocytogenes, Salmonella spp.,* and *Vibrio spp.* (Elbashir et al., 2018; Verma et al., 2022). Not only the species of bacteria but also Hepatitis A and noroviruses have already been identified as the most common source of acute gastroenteritis outbreaks for all age ranges and are strongly linked to shellfish consumption (Elbashir et al., 2018; Li et., 2023). Microorganisms and parasites observed in seafood can have a negative impact on the products in two main ways: reducing the quality or making compromises security via gastrointestinal infections, intoxications, or food allergies (Lunestad et al., 2011). Innovative management systems aid in eliminating environmental contamination of foods as well as avoiding the consumption of unsanitary or low-quality products (Freitas et al., 2020). Both hazard and risk-based management strategies for food quality and safety have been employed. Each method has many advantages and disadvantages. Nevertheless, the disparities in research methods and definitions can make public understanding and risk monitoring difficult. The widespread use of hazard analysis and critical control points (HACCP) in conjunction with chemical and microbial risk analysis is an important component of a current food system that supplies very healthy foods (Brien, 2023). Risk management, risk assessment, and risk communication are the three factors of risk analysis. Risk assessment is the scientific part of the procedure that identifies risks and danger factors and calculates the dangers presented by a particular pathogen or process. Quantitative risk evaluation is a scientific technology that links the probable incidence and concentration of potential danger in a food serving to a potential to apply health outcome. The Codex Alimentarius Commission defines the fundamentals of risk evaluation and the four stages implicated: hazard identification, risk assessments, hazard characterization, and risk characterization (Duffy, 2005). It is critical for microbial risk assessment and predictive microbiology to obtain quantitative information on the relative impact of many different factors that may influence bacterial growth (Besse et al., 2006). Food microbiology modeling has developed into an important contribution to food safety for generating estimations about microbial behavior. One of its drawbacks is a scarcity of relevant and reliable statistical information for predicting modeling. Growing data sets and advanced modeling tools have the possibility to supply necessary details on potential danger, exposure, and monitoring reports. They can be integrated to shorten the time required to conduct a risk assessment, thereby helping to improve the management of food safety decisions (Allende et al., 2022). Even as models are extremely useful outcome methods, it is important to remember that they are, effectively, the simplest version of reality. For this reason, estimated values should be taken with caution, taking into account other microbial ecology principles that may not be part of the model. Notwithstanding, it is believed that successful validation of predictive analytics in accordance with specified assessment criteria will be an essential component of exposure levels within proper quantitative risk evaluation (Ross et al., 2000). Food-borne illness outbreaks related to the high consumption of fresh and processed food products occur all over the world. Numerical microbiological risk evaluation can be applied to increase the safety of all of the food products during manufacturing, transmission, and consumption. Many mathematical microbiological models, such as execution, analysis, and experimental design. 'Time-to-inactivation' models or end-point 'time-to-growth', kinetic growth, death, and survival models also indicated as 'boundary models,' have been given examples of models (Legan et al., 2009). When the sophistication of *L. monocytogenes* growth models corresponds to the complexity of the foods of interest, i.e. the many obstacles to bacterial activity, estimated pathogen bacteria growth responses can be exact. The reliable and valid models can be used to evaluate the control of *L. monocytogenes* in ready-to-eat (RTE) food products (Mejlholm et al., 2010). Additionally, mathematically determining risk assessments of these products can be possible with a focus on epidemiological and clinical history as well as the strategies in food-borne infectious diseases (McLauchlin et al., 2004). Predictive modeling has many advantages in terms of organizing, analyzing, and visualizing huge amounts of information since the introduction of the internet, and it has also got to be extremely easy to distribute the resulting predictive software products. The authors expect that mathematical advances can also result in additional advancements, such as difficult and complicated different scenarios, probability distributions, and innovative models (Munoz-Cuevas et al., 2012). Predictive modeling not only can be used to aid in the improvement of estimation methods and the quantification of food safety hazards but also can be used to evaluate risk assessment prevention strategies (Foegeding, 1997). Therefore, this review discusses the prevalence and contamination of pathogenic bacteria in seafood products, potential microbial contamination routes, and pathogenic bacteria behavior and control in fresh and processed seafood products. The purpose of this review is also to ensure an important guide to mathematical modeling, specifically pathogenic bacteria growth in seafood products. It not only goes over the fundamentals of developing useful predictive models but also each of these predictive models has been addressed as well as model applications in seafood products and future developments are also explained.

## PATHOGENIC BACTERIA AND CONTROL IN SEAFOOD PRODUCTS

Pathogenic viruses, bacteria, and harmful algae that produce biotoxins can accumulate in bivalves and many other seafood and lead a wide range of illnesses in humans. Seafood consumption causes a significant percentage of foodborne illnesses and outbreaks worldwide (Baker-Austin and Martinez-Urtaza, 2023). The species of *Salmonella, Vibrio, Escherichia, Campylobacter, Plesiomonas, Aeromonas, Staphylococcus, Listeria, Shigella,* and *Clostridium* are the pathogenic bacteria found in seafood products (Kılınç, 2001; Taminiau et al., 2014; Elbashir et al., 2018; Kılınç, 2019; Kılınç, 2020; Kafa and Kılınç, 2022). The presence of pathogenic *Salmonella* in foods is a globally recognized human serious health risk. Even though this bacteria is responsible for too many food-borne disease outbreaks, there is some indication that cross-contamination is a major contributor. Moreover, the considered significant factor of preventing cross-contamination and recontamination in keeping food safe is very essential (Carrasco et al., 2012). *Vibrio* is a genus of marine bacteria that is commonly found in warm coastal areas and waters. *Vibrio* species such as *V. vulnificus* and *V. parahaemolyticus* can cause illness through the intake of contaminated shellfish. The spread of *Vibrio* infectious outbreaks is continuously increasing as the temperature of water rises (Ferchichi et al., 2021). *C. botulinum* can cause food-borne illness botulism (Peck et al., 2008). In developing countries, pathogenic *Escherichia coli* contamination of seafood poses a significant public health risk (Parakasan et al., 2021). *Listeria* is the potential cause of listeriosis, a serious disease with a very high mortality rates. These pathogenic bacteria reduce the safety of food products posing a risk to human health (Gandhi and Chikindas, 2007). The genus Arcobacter includes Campylobacter-related species, which are zoonotic new emerging pathogenic bacteria species whose appearance in water has been linked to fecal pollution. Additionally, discharges of fecal-contaminated water into the sea have been identified as one of the primary causes of Arcobacter contamination in shellfish, which might also pose a threat to public health (Salas-Masso et al., 2018).

Various preservative techniques have been established to increase the shelf-life of food products while preventing the growth of pathogens. Food production and preparation techniques are thought to be the most efficient techniques for removing pathogenic bacteria from food (Jarvis et al., 2016). The findings suggested in one study that the possible danger of cross-contamination of food infected with low levels of *L. monocytogenes* should be investigated further. Ultimately, lowering the preliminary level of contamination of raw meat and using hotter tap water to clean chopping boards were discovered to be successful in reducing the possibility of *L. monocytogenes* cross-contamination in food products (Zhang et al., 2022). Pathogens can survive in very lightly processed products, and thus the quality of the initial materials is critical. For safety and quality, food products not for direct consumption require a pasteurizing process preceded by refrigerated storage. Sous vide food products with a storage period of 10 days might be applied heat treatment at 70 °C for 2 minutes for *L. monocytogenes*. Additionally, products with a storage period of more than 10 days might be applied to thermal processing at 90 °C for 10 minutes for *C. botulinum* Group II (nonproteolytic) (Stringer and Metris, 2018). The possibility for non-proteolytic *C. botulinum*, a threatening foodborne pathogen, to develop and release toxins in commercial refrigerated food products with a short shelf-life indicated (10 days). Non-proteolytic *C. botulinum* can be developed and formed toxins in food products in 10 days at 8 °C (Peck et al., 2008). Additionally, vacuum and modified atmosphere packaging containing 100% nitrogen are environments that might also easily and quickly enable the development of psychrotrophic pathogenic bacteria *(L. monocytogenes, A. hydrophila,* and *Y. enterocolitica*). However, using $CO_2$-enriched surroundings for food product packaging conditions has been reported more safety than aerobic storage conditions (Fernando et al., 1995). Microbiological spoilage of food can result in significant losses in addition to health problems and/or be linked with outbreaks caused by food-borne pathogenic organisms. Attempts are being made to reduce the negative influences of pathogens in food and also for producing foods safer with a longer shelf-life. Innovative food processing technologies have been developed for these purposes such as high-pressure processing (HPP), cold plasma, etc. (Buys et al., 2023). HPP applications have primarily been used for decontamination and also used for keeping food safe. In addition to this, the quality and shelf-life of seafood can be prolonged (Duranton et al., 2014).

The advancement of food security from "farm to plate" has frequently been influenced by human pathogens, techniques, or processes (Topalcengiz et al., 2021). Microbiological exposure evaluation is critical in food safety and public potential health risk assessments because it estimates both the possibility and level of microbial potential danger in a particular consumer amount of food and considers the behavior of microorganisms (Besten et al., 2018). In relation to risk management, big food industry groups have collaborated to create excellent standards and guidance on the control of pathogenic bacteria in a non-competitive way. Furthermore, food safety regulations have made significant progress to aid in the control of pathogenic bacteria (Farber et al., 2020). Overgrowth of pathogenic bacteria such as *Salmonella spp*., *E. coli,* and *L. monocytogenes* followed by undercooking or inadequate preparation give rise to an increase in the risk of illnesses. Despite the increasing number of food safety regulations and the implementation of safety management systems like HACCP, risk evaluation research suggests that food-borne disease continues to remain a major concern in the last decade (Koutsoumanis and Taoukis, 2005).

## COMMONLY USED MODELS FOR GROWTH KINETICS

The Huang, No-lag phase, Ratkowsky square root, Huang square root, Cardinal, Gompertz, Weibull, First-order, Biphasic, Log-logistic, Log-linear, Baranyi and Jameson-effect which are the commonly used mathematical models explaining bacterial growth rates in seafood, are introduced, and explained.

**Table 1.** Commonly Used Models for Growth Kinetics in Seafood Products

| Models | Equations |
|---|---|
| Huang | $Y_t = Y_0 + Y_{max} - ln\{e^{Y_0} + [e^{Y_{max}} - e^{Y_0}]e^{-\mu_{max}B_{(t)}}\}$ <br> $B_{(t)} = t + \frac{1}{\alpha} ln \frac{1 + e^{-\alpha(t-\lambda)}}{1 + e^{\alpha\lambda}}$ |
| No-lag phase | $Y_t = Y_0 + Y_{max} - ln\{e^{Y_0} + [e^{Y_{max}} - e^{Y_0}]e^{-\mu_{max}t}\}$ |
| Ratkowsky square root | $\sqrt{\mu_{max}} = a(T - T_0)[1 - e^{b(T-T_{max})}]$ |
| Huang square root | $\sqrt{\mu_{max}} = a(T - T_{min})^{0.75}[1 - e^{b(T-T_{max})}]$ |
| Cardinal | $\mu_{max} = \frac{\mu_{opt}(T - T_{max})(T - T_{min})^2}{[(T_{opt} - T_{min})(T - T_{opt}) - (T_{opt} - T_{max})(T_{opt} + T_{min} - 2}$ |

| | |
|---|---|
| Gompertz | $log_{10}R = A_g * \ exp\left\{-exp\left[\mu * \exp(1) * \frac{\lambda - t}{A_g} + 1\right]\right\}$ |
| Weibull | $logN_t = logN_0 - (\frac{t}{\delta})^{\rho}$ |
| First-order | $log\frac{N_t}{N_0} = -\frac{t}{D_T}$ |
| Biphasic | $logN_t = logN_0 + \log(k * \ e^{-\alpha t} + (1-k) * \ e^{-\beta t}$ |
| Log-logistic | $log\frac{N_t}{N_0} = \frac{A}{1 + e^{4\sigma(\tau - logt)/A}} + \frac{A}{1 + e^{4\sigma(\tau+6)/A}}$ |
| Log-linear | $logN_t = logN_0 - k * \frac{t}{\ln(10)}$ |
| Baranyi | $Y_t = Y_0 + \mu_{max}t + \frac{1}{\mu_{max}}\ln\left(e^{-vt} + e^{-h_0} - e^{-vt-h_0}\right) - \frac{1}{m}\ln(1 + \frac{e^{-m\mu_{max}t + \frac{1}{\mu_{max}}ln\left(e^{-vt}+e^{-h_0}-e^{-vt-h_0}\right)-1}}{e^{m(y_{max}-y_0)}}$ <br> $\mu_{max} = \frac{\sqrt{z_2^4 + 3z_3^2 - 2z_2z_4}}{z_2}$ <br> $h_0 = \frac{\ln(2)}{\frac{z_2^2 + -z_3}{\sqrt{z_2^4 + 3z_3^2 - 2z_2z_4}} + 1}$ <br> $Y_{max} = z_1 - \frac{\ln(2)}{\frac{z_2^2 + -z_3}{\sqrt{z_2^4 + 3z_3^2 - 2z_2z_4}} + 1} - \ln(\frac{1}{2} - \frac{z_2^2 + -z_3}{\sqrt{z_2^4 + 3z_3^2 - 2z_2z_4}})$ |

| | |
|---|---|
| Jameson -effect | $$\frac{dN_1}{dt} = \mu_{max} N_1 \left(1 - \frac{N_1}{N_{max1}}\right)\left(1 - \frac{\gamma_{12} * N_2}{N_{max2}}\right)\frac{Q_1}{1+Q_1}$$ $$\frac{dQ_1}{dt} = \mu_{max1} Q_{1t-1}$$ $$\frac{dN_2}{dt} = \mu_{max2} N_2 \left(1 - \frac{N_2}{N_{max2}}\right)\left(1 - \frac{\gamma_{21} * N_1}{N_{max1}}\right) + \frac{Q_2}{1+Q_2}$$ $$\frac{dQ_2}{dt} = \mu_{max2} Q_{2t-1}$$ |

The terms in the models $Y_t$, $Y_0$, and $Y_{max}$ represent microorganism counts at time t, natural logarithms of initial microorganism counts and maximum microorganism counts, respectively. $\mu_{max}$ represents the specific growth rate ($h^{-1}$); λ is the lag phase duration (h). The lag phase transition coefficient α is 4.

Moreover, $\mu_{max}$, maximum growth rate, m is a skew parameter to define the transition from the exponential phase, v is a curvature parameter to define the transition to the exponential phase, $h_0$ is a dimensionless parameter, $Y_0 = \ln(x_0)$, $Y_{max} = \ln(x_{max})$, $x_0$ initial and $x_{max}$ asymtotic cell concentration, A is the difference upper and lower asymtotes, σ is the maximum inactivation rate, τ is the log time, a and b are regression coefficients, T is temperature, T0 is the notational minimum temperature for the Ratkowsky square root model, $T_{min}$ is the estimated biological minimum growth temperature, and Tmax is the estimated maximum growth temperature (°C), $\mu_{opt}$ is the optimum growth rate at the optimum temperature ($T_{opt}$), $T_{min}$ and $T_{max}$ are the estimated minimum and maximum growth temperature, R shows relative population, $N_t$ describes the microbial cell density at a time, $N_0$ defines microbial cell density, DT (min) is the decimal reduction time, b and n are the scale and shape parameter.

## COMPARISON OF MODEL FITTING

The goodness of fit of the models are important as well as the mathematical modeling of pathogenic bacteria growth in seafood products. Therefore, some criteria (adjusted coefficient of determination ($adjusted - R^2$), sum of squared errors (SSE), root mean square error (RMSE), accuracy ($A_f$), bias ($B_f$) and The Akaike information criterion (AIC) are used for the assessment of prediction degree and validation of the models as below:

$$adjusted - R^2 = 1 - (\frac{j-1}{m-j})(\frac{Sum\ of\ squares\ of\ error}{Total\ sum\ of\ squares})$$

$$SSE = \sum_{0}^{j-1} (predicted\ value - observed\ value)^2$$

$$RMSE = \sqrt{\frac{\sum(predicted\ value - observed\ value)^2}{j-m}}$$

The higher $R^2$ and adjusted $R^2$, lowest SSE and RMSE values were show as the best model to predict data set.

$$A_f = 10^{\frac{\sum \left|\log(\frac{predicted\ value}{observed\ value})\right|}{j}}$$

$$B_f = 10^{\frac{\sum \left|\log(\frac{observed\ value}{predicted\ value})\right|}{j}}$$

In these equations the j denotes the number of observations, m denotes the number of parameters. The Accuracy value (Af) shows the measure of the distance of the predicted values from the observed values, with values close to 1 indicating slight deviations from the observed values.

The bias value (Bf) shows that if it is greater than 1, there is an estimate above the observed values, and if it is less than 1, there is a lower estimate than the observed values.

In addition to these, the Akaike information criterion (AIC) value is also a criterion used to select the most suitable model. Smaller AIC values indicate models that better describe the dataset (Esua et al., 2022b).

$$AIC = jlnSSE - jlnj + 2m$$

## THE IMPORTANCE OF USING MATHEMATICAL MODELS FOR PATHOGENS

The purpose of one research was to model the prospective future *Vibrio* development risk all along coastal areas, where the shellfish industry was well developed. This was accomplished by employing an appropriate machine-learning model with an independent variable such as air temperature and wind velocity to forecast future sea surface temperatures.

Computer models demonstrated that the number of days with the lowest temperature (15°C) could very well increase spatial and temporal depending on the season and that regardless of the climate change scenario, all shellfish beds might very well reach the temperature condition for *Vibrio* growth (Ferchichi et al., 2021). In one report, using (XGB) extreme gradient boosting machine learning algorithms were applied to create estimation models for *V. parahaemolyticus* concentrations in oysters, sediment, and seawater. The results revealed by the authors that XGB was able to forecast *V. parahaemolyticus* levels in oysters and seawater. This study's findings could be beneficial in handling oyster safety at the agricultural stage, allowing for the preventing disease of *V. parahaemolyticus* infections (Ndraha et al., 2021). Another study used predictive models to estimate the development of *Vibrio vulnificus* (VV) and *Vibrio parahaemolyticus* (VP) in oysters, and the results were used to create enzymatic TTI smart labels with response kinetics adequate for identifying the potential growth of *Vibrio* spp. in the stages from the harvest to the sale. The study's findings suggested that the VP and VV-TTIs developed in this study could be useful and inexpensive tools for confirming improved processing and cooling practices, as well as monitoring oyster transportation (Tsironi et al., 2017).

The ability to determine the development of a species of bacteria within food products for a specific set of integral and environmental factors provides many benefits and advantages to food industry experts (Mahony and Seman, 2016). Based on probabilistic concepts, the produced model identified the minimum processing conditions needed to achieve the considered necessary log decrease, irrespective of the actual inactivation kinetics. The conditional probability of the inactivation impact can also be provided by the models. The updated MRV (Microbial Responses Viewer) web tool not only gave information on no growth or growth boundary conditions but also the specific rate of growth of microorganisms. Additionally, the MRV allowed users to intuitively retrieve microbial no growth or growth information and also food processors could correctly recognize proper food design and processing conditions using the MRV (Koseki, 2013). Categorization of the harvesting and production process enables the advancement of a dynamical mathematical model, a process risk model (PRM), that estimates the possible range of shelf-life for food under optimal distribution and retail conditions. The risk under consideration is the inability to meet the approximate "use by" date (Rasmussen et al., 2002). The application of computational modeling software products may significantly improve the understanding of microbial behavior in food products. The research and testing of a tertiary model that forecasts the growth of microorganisms in foodstuffs under static or dynamic conditions of temperature. The Unified Growth Prediction Model (UGPM) software products, in particular, employs the primary model Baranyi and Roberts (BR) (1994), in conjunction with a secondary temperature model, to predict the development of given micro-organisms throughout the storage of a specific food (Posamas et al., 2011). Estimation methods provide effective methods for managing the safety and quality of consumable seafood. Fish is a popular seafood that depends on well-managed both domestic and international supply chain processes to limit pathogenic bacteria growth. In supply chains, the models can be used to predict the quality, contamination, and safety of these products (Churchill et al., 2016). Extrinsic (atmosphere, temperature), intrinsic (water activity, pH) or process factors (preservatives), and environmental changes all influence the growth of microorganisms in food products (Ünlütürk and Turantaş, 2003). Laboratory experiments are used to fit 'primary models' to determine the length of the lag phase and the slope of the log phase. These data information are then described in terms of very few exteriors as possible variables. These 'secondary models' enable microbial responses to be 'predicted' in response to different combinations of external factors. Software packages and databases make evaluation possible of food shelf-life and food safety as well as they are required for the establishment of Food Safety Objectives and the performance of Quantitative Microbial Risk Assessments (QMRA) (Paulsen and Smulders, 2014). This QMRA also includes the formulation of the problem for pathogenic organisms as well as risk assessments for seven microorganisms, along with pathogenic *E. coli* 0157:H7, *Salmonella* spp*, Pseudomonas* spp, *S. aureus*, norovirus, *L. monocytogenes*, and *E. coli* (Ryan et al., 2014). Foodborne illness outbreaks related to the consumption of foods are found all over the world. QMRA for these products has an important potential to improve the safety of the products during manufacturing, transferring, and also consumption (Koseki, 2014).

## THE MATHEMATICAL MODELS USED IN SEAFOOD PRODUCTS FOR THE ESTIMATION OF PATHOGENIC BACTERIA GROWTH AND CONTROL BY DIFFERENT TECHNIQUES

The primary goal of one study was to create primary and secondary models to explain the growth kinetics of *Salmonella* and other microorganisms in raw, shucked oysters. For assessing the impact of temperature on pathogenic bacteria growth rates, three secondary models (Cardinal parameter models (CPM), Ratkowsky square root (RSR), and Huang square root (HSR) were evaluated. The HSR model was determined better than the RSR model for presenting the impact of temperature on the *Salmonella* population increase, whereas the RSR model was better for evaluating the background microbes. The lag phase's logarithms were demonstrated as linear equations of logarithms of special growth rates for *Salmonella* and background microorganisms (Fang et al., 2015). The HSR model was created to define the expansion of *L. monocytogenes* in salmon with and without the appearance of native microbiota. This model was not only used to evaluate the influence of temperature on *L. monocytogenes* of growth rates, but also lag times as well as the native microbiota. For the proposed model and kinetic parameter estimation, a one-step analysis method was also used. The findings of this study could be beneficial for future identifying risks of *L. monocytogenes* (Jia et al., 2020). In another study, the observed growth curves were used to determine the maximum rate of increase using the BR model. Additionally, the RSR model was also used to simulate the influence of the storage temperature on max. The models developed were reinforced using the experimental growth information of *L. monocytogenes* in fillets of sea bream and sea bass fish stored at different conditions. Overall, FBJ models ensured fail-safe estimations for the growth of *L. monocytogenes*. (Bolivar et al., 2018). The goal of one study was to create kinetic models that predicted *Vibrio parahaemolyticus* growth in Pacific white shrimp (*Litopenaeus vannamei*) as a function of storage temperature. To predict the kinetic models, the growth curves were assessed with two different primary models (No-lag phase and Huang models) in combined effect with a one-step kinetic analysis approach using a suboptimal HSR model as well as the USDA-IPMP Global Fit software. The models developed in this study can be applied to estimate *V. parahaemolyticus* significant growth in shrimp throughout post-harvest cold storage and temperature-changing conditions (Chen et al., 2019). To predict the growth or inactivation kinetics of *V. parahaemolyticus* during storage, the modified Gompertz (MG) and Weibull equations (WE) were used to regress survival and development curves, respectively. Both equations resulted in a satisfactory fit to the measured data. The average $R^2$ value equals 0.920 for the WE and 0.990 for the MG, respectively. (Yang et al., 2009). The primary and secondary model analyses revealed in another study that the cocktails performed single strains in terms of the growing activity of *V. parahaemolyticus*, with a shorter lag time and higher maximum growth rate. The findings suggested that simulating the growth of this bacteria with a cocktail of *V. parahaemolyticus* strains could be a better alternative for predicting growth in the real world. This research would be significantly increased the accuracy of microbiological risk evaluation and also closed a gap in predictive microbiology reported by (Ma et al., 2016). The CPM were used to determine the impact of environmental variables on biofilm development. This model provided a promising predictive microbiology method for *S. aureus* growing population and survival ability on food processing surfaces (Tango et al., 2018). Predictive growth models for *A. hydrophila* on raw tuna (*Thunnus orientalis*) as a function of different storage temperatures were created in this study. The primary Baranyi model (BM) and the second nonlinear regression analysis (RA) were determined to fit well with the BM at this refrigerator temperature to acquire lag time (LT) and specific growth rate (SGR). These predictive models were indicated to be used for predicting *A. hydrophila* growth on raw tuna at different cold temperatures. Finally, the developed models were reported to be beneficial in keeping safe levels of *A. hydrophila* during raw fish distribution and processing (Kim et al., 2022). In another study, mathematical models were created to predict the development of *Salmonella enterica* in sushi at varying temperatures using data from various restaurants in Brazil. The sushi type selected for the models had the highest overall total aerobic counts among the sushis obtained in the facilities. The BR models were used to show *Salmonella* growth. Based on these findings, the authors recommended that sushi should be distributed at conditions (15 °C for 6 h) (Silva et al., 2020). The purpose of another study was to model the progress of *L. monocytogenes* CTC1034 and *Latilactobacillus sakei* CTC494, as well as their interaction, in two very different RTE fish products (tuna pate and surimi-based products) at 2 and 12 degrees Celsius. To assess the impact of bacterial interaction, the Jameson-effect (JE) model and newly expanded Jameson-effect (EJE) models were assessed. According to the goodness-of-fit indexes, the newly expanded JE model performed much better and correctly defined the various competition general patterns in the tests performed on seafood products. Based on their effect on lag time, the suggested extensive competition model granted the explanation of not only antagonistic but also mutualistic interactions (Bolivar et al., 2021).

Studies done about the inhibition of pathogens have been summarized in the below sentences. Predictive models evaluated for a specific food type, while accounting for the inhibitory influence of various factors in hurdle technology (HT), presented estimations of *L. monocytogenes* growth possibility relating to observed growth in challenge testing. Salads and cooked meat products were classified as intermediate-risk foods, while smoked fish was a high-risk food, based on the combination of prevalence data and potential growth (Uyttendaele et al., 2009). The authors reported in one study that future applications of mathematical modeling in seafood processing had the potential to improve general processing conditions and cooking methods for various food types and sizes (Onyeaka et al., 2022). The goal of one study was to develop a mathematical model for inhibiting *V. parahaemolyticus* on cooked shrimp with three variables by acidic electrolyzed water (AEW). The aim of this study was to improve bactericidal effectiveness and decrease the risk of illness caused by this bacteria using response surface methodology (RSM). The current findings could be beneficial in predicting the inhibition of *V. parahaemolyticus* on cooked shrimp by AEW (Wang et al., 2014). A 4-factor response surface (RS) model based on the Box-Behnken experimental design (BBED) was also used in another study to evaluate the impacts of lactic acid, chitosan, rotational rate, and cleaning time on the decrease of *V. parahaemolyticus* inoculated in raw shrimps. The combined use of lactic acid and chitosan resulted in a significant inactivation effect according to the analysis of variances (Wang et al., 2013). In one study, non-linear (Log-logistic, Biphasic (B), and Weibull (W) and linear (L) (first-order) models were used to predict the inactivation kinetics of *Listeria monocytogenes* and *Escherichia coli* on grass carp dealt with a novel technique (UPFB) that combined ultrasound (US) with plasma functionalized buffer (PFB). The authors confirmed that the three non-linear (NL) models used in their study had comparably good results and they were better suited to describe the inactivation kinetics. Additionally, the B model was indicated as the best-fit model when compared with others (Esua et al., 2022a). The aim of one study was to quantify the impact of *Lactobacillus sakei* CTC494 on *Listeria monocytogenes* in fish juice. For this purpose three microbial interaction models (Lotka Volterra (LV), Jameson (J), and modified Jameson (MJ) models) were tested with gilthead sea bream (*Sparus aurata*) fillets stored in modified atmosphere packaging at thermal and non-thermal conditions. The Acceptable Simulation Zone (ASZ) approach was used to evaluate the performance of the tested interaction models. The LV model fits the data better than the J-based models, indicating good model performance. The analyzed interaction models might be used as a predictive modeling tool to simulate the concurrent behavior of *L. monocytogenes* and bacteriocin-producing *Lactobacillus* strains in highly processed fishery products, thereby assisting in the optimization and design of bioprotective culture-based techniques against *L. monocytogenes* in highly processed fishery products (Costa et al., 2019). The antimicrobial property of a light-emitting diode (LED) in combined effect with riboflavin on the inhibition of *Listeria monocytogenes* on smoked salmon was examined by (Josewin et al., 2018). The kinetics curves were fitted using three conceptually different mathematical models: Baranyi (B), log-linear (LL), and modified Weibull (MW). Mathematical modeling revealed in this study confirmed that the B and BW models best fit the kinetics curve, so the W model was used to determine the dose needed for the initial log reduction of *L. monocytogenes*. The findings of this study showed that 460 nm LEDs when combined with riboflavin, have the potential to lower the *L. monocytogenes* risk connected with smoked salmon throughout storage at food outlets (Josewin et al., 2018). The impact of brine marination at cold temperature changes on pathogenic bacteria growth and survival throughout handling and long-term storage of RTE shrimp (*Pandalus borealis*) was investigated. *S. aureus, V. parahaemolyticus*, *Salmonella spp., L. monocytogenes*, and *L. sakei* were studied for growth and survival. Notably, usable mathematical models successfully predicted the rates of growth of *L. sakei* and *L. monocytogenes* in brined MAP shrimp. As a result, these models can be applied to new products for RTE shrimp while considering both safety and quality (Mejlholm et al., 2012). As a novel non-thermal method, high hydrostatic pressure (HHP) processing has shown great promise in developing microbiologically safer products. In a risk management context, the tools and mechanisms currently in place to observe, optimize, and justify the process, as well as the processes for evaluating and modeling the treatment's lethal effect, were examined (Rendueles et al., 2011). The mathematical models, designed to be used by both experienced professional and non-expert users, could serve as a beneficial tool for supporting decisions for the food industry by providing assistance in the monitoring of food products based on their real shelf-life and microbiological safeness. The former has frequently been solely based on observational data and is subject to a high level of uncertainty. Because of the influence of temperature-abusive behavior on microbial action and consumer safety, this could also result in the rejection of huge quantities of unspoiled or safe food products, as well as the delivery of spoiled and risky foodstuffs (Posamas et al., 2011).

**Table 2.** Some of The Mathematical Models Used in Seafood Products

| Pathogen Microorganisms | Mathematical Models | Prediction | References |
|---|---|---|---|
| *Salmonella spp.* | Ratkowsky square root (RSR) model, Cardinal parameter (CP) models, Huang square root (HSR) model | Impact of temperature on the *Salmonella* population increase | (Fang et al., 2015) |
| *L. monocytogenes* | HSR model | Evaluation of the influence of temperature on *L. monocytogenes* rates of growth, also lag times, and the native microbiota | (Jia et al., 2020) |
| *V. parahaemolyticus* | Huang (H) and No-lag phase (NLP) models | Determination *V. parahaemolyticus* growth in post-harvest, and temperature-changing conditions | (Chen et al., 2019) |
| *V. parahaemolyticus* | Gompertz (G) model and Weibull equations (WE) | Predict growth or inactivation of *V. parahaemolyticus* during storage conditions | (Yang et al., 2009) |

| | | | |
|---|---|---|---|
| *V. parahaemolyticus* | Box-Behnken experimental (BBE) model | Evaluation of the chitosan and lactic acid effect on the decrease of *V. parahaemolyticus* inoculated in raw shrimps | (Wang et al., 2013) |
| *L. monocytogenes* and *E. coli* | Non-linear (Log-logistic (LL), Biphasic (B) and Weibull (W) and linear (first-order) models | Prediction of the inactivation kinetics of *Escherichia coli* and *Listeria monocytogenes* on grass carp | (Esua et al., 2022b) |
| *L. monocytogenes* | Baranyi (B) model, Ratkowsky square-root (RSR) model | Explanation the growth rate of *L. monocytogenes* in sea bream and sea bass fillets stored at static and dynamic temperatures | (Bolivar et al., 2018) |
| *Lactobacillus* strains and *L. monocytogenes* | Lotka Volterra (predator-prey, LV), Modified Jameson (MJ), and Jameson (J) models | Predictive models for the development of *L. monocytogenes* and bacteriocin-producing *Lactobacillus* strains | (Costa et al., 2019) |
| *A. hydrophila* | B model | Prediction of *A. hydrophila* development on raw tuna at different cold temperatures | (Kim et al., 2022) |
| *S. enterica* | B and R models | Determination of the development rate of *S.enterica* in sushi at various temperatures | (Silva et al., 2020) |
| *L. monocytogenes* and *L. sakei* | Jameson-effect (JE) model | Evaluation of the development of *L. sakei* and *L. monocytogenes* in tuna pate and surimi-based product at different conditions | (Bolivar et al., 2021) |

## THE MATHEMATICAL MODELS FOR PATHOGENIC BACTERIA RISK AFTER SEAFOOD CONSUMPTION

More aquaculture is being employed to supply the rising demand for seafood items on a global scale. The usage of aquaculture for fish and seafood production, on the other hand, poses potential risks to human health, particularly from enteric bacteria such as *Salmonella spp.* QMRA was conducted to notify safe aquaculture procedures, integrating probability variance in bacterial growth for advanced manufacturing shrimp handling before consumption. According to the findings of this study, limiting *Salmonella* spp. to low levels may even be required in environments where appropriate food proper management and handling cannot be assured indicated by (Hamilton et al., 2018). Serment-Moreno et al. (2015) found that HPP conditions should be chosen based on seasonal pathogen load and environmental temperature. Eventually, the process highlighted that variance in the *V. vulnificus* population at harvest, before and after HPP treatments, which reflected in part the microbiological estimation methods used, had a significant impact on the expected number of septicemia cases. As a result of this study, enhancing bacteriological quantitative measurement should result in more accurate guesses of the number of septicemia cases (Serment-Moreno et al., 2015). According to another study, A significant correlation was discovered between the concentrations of *Arcobacter spp* and *E. coli*. Additionally, the incidence of *E. coli* can assume the occurrence of pathogenic bacteria *Arcobacter* species in shellfish obtained from water temperatures lower than 26.2 °C. Consuming shellfish acquired at extremely high temperatures, might not enable *E. coli* expansion but does permit *Arcobacter spp*. the development could present a hazard to consumers reported by Salas-Masso et al., (2018). In another report, using estimated pathogenic bacteria population sizes and actual coastline sea surface temperatures, authors created a mathematical model that linked *V. vulnificus* occurrence to the temperature of the water. Developed *V. vulnificus* population numbers in marine ecosystems could rise the possibility of infection among humans, who dine at coastal restaurants. Besides that, the model used in this study to forecast the number of patients infected in the coming days, which could aid in the development of a public-health policy to lower the burden of diseases (Chu et al., 2011). *C. botulinum* type E growth and toxigenesis in raw pickled, vacuum-packaged unprocessed, and cold-smoked rainbow trout (*Oncorhynchus mykiss*) stored at fractionally abusive temperature changes were studied in another study. Compared to predictions generated by Food MicroModel (FMM) and Pathogen Modelling Program (PMP) were applied to generate growth and time-to-toxicity estimation. The results of microbiological analyses were confirmed by authors that the majority of the results of the models' estimations were not correlated with each other (Hyytia et al., 1999). The findings of one study verified the effectiveness of *L. sakei* CTC494 in monitoring pathogenic *L. monocytogenes* growth on the tested fish product. According to the statistical achievement of this study, the LV competition model fit the measured *L. monocytogenes* growth response comparatively better than the J-based models. The suggested estimation method could benefit the evaluation and implementation of bioprotective culture-based techniques intended to reduce the risk of listeriosis associated with the eating of (RTE) hot-smoked sea bream (*Sparus aurata*) (Bolivar et al., 2021). The goal of another study was to determine the probability of staphylococcal enterotoxin (SE) exposure from Nile tilapia consumption. The unprocessed (fresh) and processed (filleted, salted, smoked and sun-dried) fish supply chains were modeled from landing to consumption. Data on the prevalence of *S. aureus* in fishery products were obtained from recently concluded research in Kenya, taking into consideration survey results on handling, processing, manufacturing, and intake of Nile tilapia. Using @Risk software, a probabilistic exposure model was created using Monte Carlo simulation in Excel add-in software. The model showed that the time needed to sell the fishery products at street markets under ambient temperatures and cold stored fish fillets at retail stores had the biggest influence on the dose of SE for each serving, followed by cross-contamination from the fish handlers (Onjong et al., 2021).

Predictive microbiology is a very important tool for microbial food safety and quality assurance that can be used alone or in conjunction with HT, HACCP, and also QMRA (Ross et al., 2014). The focus should be on developing an efficient chill chain management program that aims to optimize quality transfer while minimizing risk at the point of consumption. The objective is to substitute the traditional First in, First out (FIFO) approach with an important structure based on real-life risk evaluation at key points in the chill chain via continuous product temperature observation and quality processing of data (Koutsoumanis and Taoukis, 2005). Risk assessment provides the critical scientific foundation for these critical risk management decisions. Risk assessment is growingly aimed at improving safety. Disease characteristics, dosages evaluation, risk assessments, and risk evaluation are all part of risk assessment. However, the occurrence of pathogenic organisms or toxic metabolites in food products, dosages knowledge, the occurrence of acute food-borne illness, the occurrence of chronic side effects, and the cost of foodborne illness are quantifiable or forecasts are questionable (Foegeding, 1997). Depending on the type of product, model estimations were accurate to within a different factor from two to four. As a result, estimations should not be taken as absolute; it is critical to know the limitations of model performance. The assumptions and results should be scrutinized, but in many cases, the accuracy will be adequate to create these models as a tool in the decisions of the management (Giffel and Zwietering, 1999).

## CONCLUSION

Many techniques have been used for inhibiting a large variety of pathogenic organisms in seafood for a long time. By lowering the growth of pathogens, these advanced technologies can be employed to actively prevent seafood-related diseases even while improving the shelf-life of seafood without affecting its quality. The processing of seafood has been affected by a number of factors, including the operating conditions of these advanced technologies, microbiological qualities, nutritional composition, etc. Thereby, the use of these advanced processing technologies is essential for decontaminating and eliminating the pathogenic microorganisms from seafood products. The effectiveness of these advanced technologies on the growth of pathogenic microorganisms in seafood products can be monitored easily, by choosing the best proper mathematical model. In the future, these mathematical models would be used and preferred to evaluate the risk assessments of different species of pathogenic microorganisms in different types of seafood products.

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# Chapter 5

## SEAWEED VALUE-ADDED FUNCTIONAL FOOD PRODUCTS

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## INTRODUCTION

Omega-3 polyunsaturated fatty acids, essential amino acids, proteins, minerals, vitamins, and carotenoids are abundant in seafood, which includes marine algae, shellfish, and finfish. Furthermore, seafood processing industry byproducts such as skin, fin, shell, bones, and intestines contain useful bioactive components such as gelatin, peptides, collagen, glycosaminoglycans, chitin, fish oils, carotenoids, chitosan, and trace elements. These elements have antimicrobial, anticancer, antioxidant, immunomodulatory, cardioprotective, anti-inflammatory, neuroprotective, anticoagulant, and antiobesity properties (Stephen et al., 2022). Seaweeds are marine photosynthesis macroalgae that grow in coastal regions and also have economic and ecological importance (Sarker et al., 2021a). Considering the current effort for sustainable protein resources, macroalgae proteins could be used in nutraceutical, pharmaceutical, cosmetic industry, feed, and food applications. Some species have been found to have high amounts of protein with their original amino acid composition, which is significant compared to the levels found in other plant-based proteins. Furthermore, seaweeds are high in protein, including phycobiliproteins, glycoproteins, enzymes, peptides, mycosporine-like amino acids, as well as cell wall-attached proteins. Seaweed-derived proteins may well have antiviral, antioxidant, antimicrobial, anti-inflammatory, and also have anti-cancer properties (Piego-Cortes et al., 2020). Seaweeds have a normally salty taste because of their high mineral composition, including potassium and sodium, and can be used as a healthy sodium replacement in foods. Furthermore, some seaweeds involve a wide range of potential food components that can be released through mild processing and applied to naturally improve food aroma (Jensen et al., 2022). Because of their functional, nutritional, and/or organoleptic properties, many seaweeds are commercially important, with some consumed directly or used as an ingredient. Consumer perception of food is highly correlated to its sensory properties, the most important of which is flavoring. Aromatic volatile compounds are a major contributor to flavor profile (Vilar et al., 2020a). So, seaweeds have a good potential for producing value-added products in the drink and food sector (Badmus, 2021).

Seaweeds are photoautotrophic multicellular macroalgae that play an important role as food. For this reason, it is very essential to first comprehend proximate compositions, the illness, metal contamination, and bioactive components of seaweeds (Sarker et al., 2021b). They are a mainly underutilized source of food in the Western world, despite their popularity in Asia. However, attraction is growing, and seaweeds have a high potential in European markets for both primary and functional additives. Food hygiene, product protection, and optimization, as well as food intolerances, are the present obstacles for seaweeds as foodstuffs (Blikra et al., 2021). Furthermore, the potential benefits of seaweed-enriched food products and seaweed extracts on lifestyle-related diseases such as obesity, dyslipidemia, hypertension, and diabetes have been mentioned. The findings showed that adding seaweeds as a powder or an extract form can enhance the nutritional and textural characteristics of food products. Seaweeds can also be used to make low-fat products with fewer calories as well as fewer saturated fatty acids. The addition of seaweed or seaweed extracts to food products can improve their quality (Roohinejad et al., 2017). In addition to this, macroalgae and seaweed are relatively unknown but encouraging resources of novel compounds for the food industry, such as carbohydrates and peptides for the production of food products and health supplements. A few algae-derived bioactive components have demonstrated a variety of biological activities, including anti-hypertensive and antioxidant activities, in vivo and in vitro, which are highly related to the chemical properties of carbohydrates or peptides. Several advancements in purifying and analytical tools for characterizing these substances have really been made in recent years, with the goal of gaining a better understanding of the sophistication of various molecular structures of bioactive carbohydrates and peptides (Lafarga et al., 2020). Polysaccharides (50 percent of the algae) such as laminarin, fucoidan, agar, alginate, and carrageenans are among the molecules of interest found in seaweeds. Most of these polysaccharides have been used as thickeners, gelling agents, and emulsion stabilizers in food products, whereas others are best known for their biological functions. Food-grade and nonfood polysaccharides have been found in algae. Food enriched with seaweed extracts or containing purified algal polysaccharides can also be used to enhance the functionality of food on the market (Rioux and Turgeon, 2015). Aside from being utilized as a supply of human food, nutraceuticals, pharmaceutical drugs, biofuels, cosmetic products, animal feed, and as well as fertilizers. Fast-growing seaweeds can also be utilized to avoid environmental problems, biological treatment of polluted areas, and environmental biomonitoring (Michalak, 2019).

Consumers have recently times regarded animal products as unhealthy foods. To prevent this disadvantage, the new formulation is a useful solution that enables the production of specially made animal products that contain substances with these useful properties for health while eliminating other characteristics deemed negative. In this context, edible seaweeds have indeed been recommended to provide exciting options in the meat industry to create functional foods and they're great bio compounds as well as a natural source of nutrients with diverse features and functions (Gullon et al., 2020). Therefore, the demand for preference of algae-containing foods in human nutrition by consumers has increased day by day. Numerous seaweed-value-added food products have been produced such as *Lemna minor*-added bread (Tekogul et al., 2011) and *Ulva rigida*-added bread (Turan et al., 2011), Additionally, products from seaweeds have been produced such as *Ulva rigida* marinades (Kılınç et al., 2011), vegeterian *Ulva rigida* seafood menu (Kılınç et al., 2013a), seaweed soup using red and green seaweeds (Kılınç, 2013b). In this study, the antibacterial and antioxidant properties of edible seaweeds, algal biotechnology, food and fishery products enriched with seaweeds, the usage of seaweeds as flavor ingredients, and also the health benefits and problems associated with seaweed consumption were reviewed.

## EDIBLE SEAWEEDS / ANTIBACTERIAL AND ANTIOXIDANT PROPERTIES

Most commonly used as food sources are the species of green seaweed; *Ulva, Monostroma, Caulerpa, Codium*, and *Enteromorpha*. The species of brown seaweed including *Laminaria, Undaria,* and *Hizikia* are used for the production of 'kombu,' 'wakame,' and hiziki', respectively in Asian countries. The species of red seaweed; *Gracilaria, Gelidium, Pterocladis*, and other numerous red seaweed species are used for the production of agar, which is widely utilized as a growth medium for microorganisms, as well as other biotechnological and food applications. Some species of red seaweed are used for the production of carrageenans such as *Eucheuma denticulatum, Kappaphycus alvarezii, and Betaphycus gelatine* (Kılınç et al., 2013c). Many essential nutrients, such as minerals, vitamins, omega-3 fatty acids, bioactive compounds, and amino acids are found in seaweeds. For many years, they are cultivated and used directly for human consumption or as animal feed. Although seaweeds are consumed in many Asian and European countries, there are some barriers to their inclusion in the general diet in many parts of the world. Seaweeds can be made more appealing organoleptically through advancements in food technology and culinology (Mahadevan, 2015). In one study, five brown edible seaweeds were collected and evaluated for their chemical and volatile composition, as well as their sensorial characteristics. Higher antioxidant activities were found in *Ascophyllum nodosum*, *Fucus vesiculosus*, and *Fucus spiralis*. Oleic acid dominated the fatty acid profile, followed by myristic and palmitic acid. The most common amino acids were glutamic and aspartic acids. Additionally, sensory and volatile analyses revealed that *Laminaria* species had the strongest taste and aroma of macroalgae (Peinado et al., 2014). Polyphenolic compounds found in macroalgae and seaweed extracts have been shown to have antioxidant effects. They also have antibacterial properties against main food spoilage microorganisms and microbial pathogens in foods. Thereby, the potential of adding aquatic plants to food products as both an antimicrobial and antioxidant source is the primary focus of this interaction. Furthermore, macroalgae have important nutrients, particularly sodium, potassium, iodine, and fiber. Another greatest potential where algae are being used more frequently is to improve the textural quality of food products, which is also covered extensively (Gupta and Abu-Ghannam, 2011). The antibacterial properties of live seaweed (*Gracilaria Blodgett*, *Pelvetia siliguosa,* and *Ulva fasciata*) on three *Vibrio* strains (*V. parahaemolyticus, V. alginolyticus*, and *V. parahaemolyticus* ATCC17802) was investigated in one study. Three seaweed species all revealed remarkable inhibition of *Vibrio* species. *U. fasciata* was investigated further as a representative seaweed, and it also inhibited the biofilm formation all of three strains (Feng et al., 2022). The effect of seaweed powder on bacteria load of fresh fish was examined by (Kılınç et al., 2012). Seafood is very perishable and also has a limited shelf-life. Several more reactions take place throughout storage that causes quality changes, such as enzymatic reactions, microbiological, and chemical activities. The occurrence of pathogenic and food spoilage microorganisms affects food safety and storage stability. Edible coatings can improve the shelf-life of all fresh and frozen food products by lowering lipid oxidation, inhibiting the growth of microorganisms, and moisture loss, and acting as a barrier for food products like antimicrobial and antioxidant agents. Biodegradable edible coatings have several advantages over synthetic coatings, including the fact that they are safe to eat as well as generally quite ecologically friendly (Dehghani et al., 2018). In one research, active edible films were formed from microalgae-based exopolysaccharides (EPS) nourished with various concentrations of red seaweed extract (RSE) (1.5, 1.0, and 0.5% (w/v), and their impacts on shrimp quality with chilled conditions were researched over an 8-day duration. EPS coatings containing RSE at concentrations of 1.5 and 1.0 % were most capable of inhibiting the enumerated species of bacteria, particularly spoilage microorganisms. Furthermore, until the end of the shelf-life, EPS + RSE-covered samples had reduced polyphenol oxidase activity as well as improved the oxidative stability of shrimp (Balti et al., 2020). In another study, the influence of marine sulfated polysaccharides obtained from seaweeds on the oil stabilization of *Oncorhynchus mykiss* under storage temperatures was studied. The authors indicated that sulfated polysaccharides derived from *Sargassum boveanum* can be used as a source of antioxidants (Vardizadeh et al., 2021). For the creation of active edible coatings, seaweed extracts were prepared from different seaweeds (*Palmaria palmate* and *Himanthalia elongate*). The use of edible films nourished with seaweeds in fish burgers was sufficient to manage water activity and pH changes during storage conditions. Additionally, these edible films also lowered the growth of microorganisms, especially in the case of edible coatings developed with *H. elongata* versus control. Furthermore, the incorporation of seaweeds into edible coatings appeared to be a viable strategic approach for extending the shelf-life of fish burgers, which were susceptible to rapid oxidation process and spoilage (Albertos et al., 2019). The possibility of covering seafood with omega-3 seaweed extracts as a source of antioxidants was studied in another study. The addition of seaweed extracts had an effect on oxidative rancidity and the quality of the products. There was no off-flavor observed among any of the samples, as well as rancid odor and flavor (Dellarosa et al., 2015).

## ALGAL BIOTECHNOLOGY

Algal biotechnology has also recently developed novel technologies for nutrient biotransformation that could be used as a raw material for the recovery of industrial chemicals as well as biofuels. Biological conversion processes in conjunction with a bio-refinery strategic approach have the possibility of allowing for environmentally sustainable and cost-effective seafood waste management. The processing of these wastes via sustainable bioprocessing interventions has the potential to create a variety of circular bioeconomics within the seafood processing sector. Furthermore, an innovative analysis of the developed solid waste processing lines and their subsequent impact on the environment could help with commercial viability (Singh et al, 2022). With the development of processes such as enzymatic hydrolysis, saccharification, and fermentation, the relevance of using algae as protein sources for consumption can be re-examined. These biotechnological approaches, which help in improving algal protein availability by attempting to remove anti-nutritional factors, also allow for the production of oligosaccharides and other food compounds. The impacts of these processes on the changes in edible seaweed organoleptic properties reveal intriguing opportunities for new flavor development. All of these recent advancements are favorable to the development of new algae-based foods and ingredients (Fleurence, 2022). Seafood-like flavor derived from the enzymatic hydrolysis of seaweed (*Gracilaria sp.*) protein by-products. The precursor for thermally processed seafood flavor was identified as an enzymatic bromelain seaweed protein hydrolysate (BSWPH). The thermally processed seafood flavor derived from BSWPH tasted like roasted seafood (Laohakunjit et al., 2014). Current food industry trends, informed by customers ’ preferences for better and healthier, nutritionally balanced, and environmentally friendly products, include the incorporation of plant and vegetable ingredients in place of animal-derived products. Consumers may perceive the integration of new of algal biomass (seaweed as well as microalgae) in food products to be healthy, and algal production is much more sustainable than agricultural uses. Furthermore, seaweeds and microalgae are a largely unexplored source of biologically active compounds like carbohydrates and proteins that can be utilized as functional foods or nutritional supplements and that have a greater market value than the full original organic matter (Meng et al., 2022).

## FOOD AND FISHERY PRODUCTS ENRICHED WITH SEAWEEDS

Consumption of meat products has been linked to a rise in the prevalence of people with high blood pressure and heart disease in recent years. 'Seaweeds' exceptional nutritionally rich and biologically active compound profiles make them potential candidates for the formulation of healthier alternatives. As a result of the growing consumer interest in new functional foods and healthier food habits, numerous research studies have focused on the successful integration of seaweeds into food products that enhance some of their qualities that are known to be harmful (Gullon et al., 2021). Consumption of these food products not only can be affected by a wide range of factors, including health impacts but also various approaches to improving meat-based functional foods can be efficient. These necessarily involve lowering the appearance of substances with adverse health effects while increasing the occurrence of beneficial compounds. The development of meat-based functional foods based on a presentation of research resulted in the design and development of qualitatively and quantitatively modified meat products (frankfurters, patties, and restructured steaks). These were restructured to include nutrition linked to three varying seaweeds as sources of bioactive compounds (sea spaghetti-*Himanthalia elongate*; wakame-*Undaria pinnatifida*; and nori-*Porphyra umbilical*) while lowering salt and fat as well as enhancing fatty acid profiles (Cofrades, et al., 2017). There has been an increase in demand for vegetarian and vegan products in recent years, and edible seaweeds are a resource used in developing new food products. Consumption of edible seaweeds is growing in popularity around the world, not only because of their abundant supply and distinctive flavor profiles but also due to their nutritional content and umami flavors (Milanovic et al., 2021). Two types of edible seaweeds, red (*Palmaria palmate*, *Porphyra umbilicalis*) and brown (*Undaria pinnatifida*, *Himanthalia elongate*) were examined for the production of seaweed-added reformulated frankfurters. In comparison with the control group, the reformulated frankfurters that included the seaweed were lower in ash, higher in moisture, and protein, darker in color, and had altered textural properties; primarily, they were less hard and chewy. The reformulated frankfurters had different volatile as well as sensory profiles than the control group. Nevertheless, the reformulated frankfurters containing *H. elongata* were the most favorable (Vilar et al., 2020b). In one research, some functional and value-added seaweed food products were experimentally produced, and those products were observed to be commercially viable. Sensory attributes evaluation was used to determine the approximate composition and also the shelf-life of four value-added seaweed food products (seaweed soup, ice cream, jelly, curd, and two functional food products (seaweed samosa, singara). All functional and value-added seaweed products had a shelf-life of no more than three days when kept open in atmospheric conditions, whereas in the freezer, these food products had a shelf-life that was at least one month (Sarkar et al., 2019). Throughout cold storage, the properties of restructured poultry steaks were researched as a result of the addition of Sea Spaghetti seaweed (3% dry matter) combined with NaCl reduction as well as a microbial transglutaminase/caseinate system as a cold binding agent. Products containing Sea Spaghetti had relatively high levels of total viable counts and lactic acid bacteria, as well as higher levels of tyramine and spermidine. A sensory panel deemed all products acceptable. There were no major changes in the properties in terms owing to composition throughout cold storage (Cofrades et al., 2011). In another study, the production of various valuable seaweed-value-added food products (seaweed jelly, soup, ice cream, and curd) were produced. The consumer acceptance of these products was 66.67%, 50%, 41.67%, and 83.34%, respectively (Sarkar et.al., 2017). The protein concentrate of *Kappaphycus alvarezii* was derived and tested for functional characteristics. The findings of this study point to *K. alvarezii* PC's suitability as an extremely cheap source of protein; thereby, this PC could be used in a variety of value-added food products (Kumar et al., 2014).

Many studies have also been carried out about the production of seaweed value-added fishery products. Some of these studies have been summarized in the below sentences. One study sought to ascertain the sensory qualities of fish balls at various levels of seaweed (*Eucheuma spinosum*). According to the findings, different combinations of fish and seaweed have a significant impact on the sensory qualities of fish balls. The sample with the lowest level of algae was reported to be the most accepted in terms of general acceptance (Loso and Pascual, 2020). By-products of pangasius fillet processing can be used to develop a new value-added product, such as an appetizer. To determine the best product quality, the impacts of seaweed ratio, ingredients ratio, frying as well as drying processes on the properties of water holding capacity, sensory, moisture, and texture were examined in this research. The findings revealed that seaweed-added fishery products had a better texture than seaweed-free products. Nevertheless, seaweed additions greater than 3% weakened the texture of the product. However, the product was fried for 20 seconds at 180$^0$C, resulting in the highest sensory properties (Le and

Truong, 2019). Numerous research findings have shown that incorporating entire microalgae and their bioactive components into meat products reformulation is a great way to enhance certain nutritious aspects deemed "bad." Nevertheless, several challenges still remain in terms of the sensory attributes and organoleptic properties of the final products, which affect the consumer acceptance level. To summarize, so much research is required to close these gaps, allowing the market to accept seaweed-based meat and fishery products (Gullon et al., 2020).

## THE USAGE OF SEAWEEDS AS FLAVOR INGREDIENTS

Even with its incredible biodiversity, marine food is a treasure trove of novel healthy food ingredients and biologically active molecules such as fish oils, fish proteins, bioactive peptides, seaweeds, macroalgae, and microalgae. Despite their numerous health benefits, marine functional ingredients are underutilized in the food industry. Bakery and pasta products, which are the most commonly consumed foodstuff worldwide, are the greatest source for integrating marine functional ingredients and achieving the population of interest (Kadam and Prabhasankar, 2010). Additionally, macroalgal derived proteins and bioactive peptides, and their potential use in functional foods and cosmeceuticals (Hayes, 2015). The worldwide focus on environmental responsibility has accelerated research into non-animal sources of food protein and functional food ingredients. Amphiphilic peptides are a promising class of biomolecules for replacing synthetic emulsifiers in food emulsions. This research clearly demonstrated the lowest part approach's possibility and broad potential application for identifying widely available and effective emulsifying agent peptides (Yesiltas et al., 2021). The goal of one study was to determine the shelf-life of minced tilapia when synthetic additives were replaced with natural Nori and Hijiki seaweed extracts. The seaweed extracts inhibited the total volatile base nitrogen in a study of minced tilapia with nori and hijiki seaweeds as natural ingredients. The panelists observed no difference in the rancid aroma of the fish products and only minor differences in the color of these products. The authors stated that the frozen minced tilapia with added seaweed extracts met quality standards throughout frozen storage (Ribeiro et al., 2014). Seaweed polysaccharides (carrageenan, agar, alginate) are important tools for colloidal stabilization, fat reduction, texture modification, the development of new food products, and shelf-life extension in the food industry (Alba and Kontogiorgos, 2019). Additionally, Agar, alginate, and, carrageenan have distinct biophysical properties that are extremely valuable in the advancement of functional food products. Thickening, gelling, and emulsifying characteristics are extremely effective in the application fields of seaweed hydrocolloids in food products as food ingredients (Qin, 2018a). In one study the authors' findings revealed that

1.5% carrageenan and 0.5% modified starch significantly increased the shear force of sausage gels made from red tilapia muscle. Carrageenan and starch were effective additives for enhancing the sensory and physicochemical characteristics of fish sausage. The sausage had a high holding water capacity because the paste was ground in 3 minutes. Under sterilization conditions, fish sausage received a high consumer evaluation score. Red tilapia sausage was reported to be a low-cost, high-protein source that can be used as a convenient meat source in food product formulation (Minh et al., 2019). The goal of another study was to determine the percentage of carrageenan flour added to catfish "otak-otak" and to enhance public consumption of fishery products. The results showed that adding 1.5% carrageenan flour to catfish was the most recommended treatment by panelists when compared to other treatments (Iffa et al., 2018). In another study, carrageenan was obtained from red seaweed and examined for its potential use in food formulation. The findings showed that the fish soup not only can be prepared with a 5% carrageenan supplementation without influencing the stability and aroma characteristics of the soup but also can be caused to increase the nutritional content of fish soup for human consumption (Jeyakumari et.al., 2016). Algal flour (*Ulva intestinalis)* and sulfated polysaccharide were used to extend the shelf-life of functional fish surimi in another research. Overall, this study found that using algal flour in the formula of fish surimi-based products to extend shelf-life without causing side effects was beneficial, but dosages should be considered for sensory acceptance. This study also suggested that such natural marine ingredients could be used to preserve the quality and prolong the shelf-life of surimi-based products with health benefits (Jannat-Alipour et.al., 2019). In addition to this, the study found that *Gracilaria* seaweed can be used to replace wheat flour in noodle products as a fiber source. The addition of 3% Gracilaria seaweed to the noodle additives improved their total dietary fiber content significantly (Keyimu et al., 2013). This current study looked at the impact of seaweed inclusion on the physiochemical properties and technological quality of pasta. To that end, enriched wheat pasta containing various seaweeds (wakame—*Undaria pinnatifida*, nori—*Porphyra tenera*, and sea lettuce—*Ulva Lactuca*) was created. Regardless, these additions enhanced the nutrient and dietary fiber content of these food products. Finally, pasta enriched with marine additives improved this nutritional content, and modifications in technological properties had no significant impact on the product's quality (Ainsa et al., 2022).

Flavor ingredients derived from brown seaweed for use as a food component were created during this research. Enzymatic processing was used, with freeze-dried and milled *Saccharina latissima* and *Ascophyllum nodosum* seaweed organic material being treated with an arginase (Alg3) and Umamizyme. The main goal of this study was to provide innovative processing solutions and new healthy flavor additives using seaweed to achieve the salt target of reducing and flavor-enhancing properties. The results produced umami and salty flavor additives that have the possibility of replacing sodium and producing flavor-improving additives with certain food products (Jensen et al., 2022). In another research, natural antioxidants from various types of marine seaweeds have been derived and defined for the development of new food-grade functional ingredients and drugs. *Durvillaea incurvate* (*D. incurvate*) brown edible seaweed was used in this study to produce a food-grade bioactive ingredient (FGBI) containing functional bioactive carotenoids. As a result, *D. incurvate* had reported a great potential for use as a source of nutritional supplement compounds (Burgos-Diaz et al., 2022).

## HEALTH BENEFITS AND PROBLEMS OF SEAWEEDS

Food's contribution to public health has grown in importance. The worldwide food supply chain's difficulties, such as antimicrobial resistance, climate change, and food contamination, may jeopardize food safety on a global level. Substances with high antioxidant and antimicrobial activity can be extracted from a variety of natural and sustainable sources, and they may help to prolong the shelf-life of meat and seafood products, improve food quality and safety, as well as nourish food products with more bioactive and functional flavorings (Simat et al., 2021). Macroalgae and their biologically active compounds, especially phenolics, and polysaccharides can be considered excellent dietary supplements with gut health and prebiotic properties (Charoensiddhi et.al., 2020). Additionally, seaweeds include a variety of bioactive components that provide health advantages that are difficult to come by from land-based foods. Even though consumers become more interested in healthy ingredients, seaweed-derived bioactive components have a variety of uses in functional foods and nutraceuticals (Qin, 2018b). Seaweeds are well known for their bioactive chemical components that promote health. Seaweed-derived polysaccharides like agar, carrageenans, alginates, fucoidans, and Floridian starch have been shown to have potential health benefits (Wijesekara and Karunarathna, 2017). Seaweeds have been used in recent studies not only as gelling and thickening agents but also in the pharmaceutical and food industries. Anticancer, antihypertensive, antidiabetic, antihyperlipidemic, antioxidant, anticoagulant, anti-inflammatory, antiobesity, immunomodulatory, antiestrogenic, thyroid-stimulating, neuroprotective, antiviral, antifungal, antibacterial, and tissue healing properties have been demonstrated in vitro cell. Sulfated polysaccharides, peptides, carotenoids (e.g., fucoxanthin), minerals, phlorotannins, and sulfolipids are examples of bioactive components with anti-degenerative metabolic disease attributes (Mohamed et.al., 2012). Fucoxanthin (Fx), a major carotenoid found in brown seaweed, has been shown to have a diverse range of biological activities. Fx is metabolized to fucoxanthin and amarouciaxanthin after absorption, and these metabolites primarily accumulate in visceral white adipose tissue (WAT). Fx, like other carotenoids, can suppress associated with multiple oxygens and scavenge a variety of free radicals (Miyashita et al., 2020). In one research, natural ingredients derived from seaweed such as phlorotannin stability throughout the extraction, passage through the gastrointestinal tract, storage, and possible incorporation into functional foods were studied. Phlorotannin could be used as a healthy food ingredient in place of synthetic ingredients reported by (Cassani et.al., 2020). Seaweeds are high in nutrients such as protein and minerals, and when incorporated in small amounts in common food, they can be used to create seaweed-based products for the improvement of human nutrition (Mwalukumbi, 2022). One study revealed that seaweed-based soup combinations can be supplied the iodine demand of the thyroid. Two functional soup mixtures containing vegetables, protectives, legumes, grain, dried *Ulva* powder (2.5%) with agar (3.0%), and carrageenan (2.0%) were formulated. These formulated products have the possibility to enter the commercial sector as innovative medicinal health foods. The soup mixture could be preferred as a therapeutic food for dietary iodine and mineral deficits. (Jayasinghe et.al., 2016). The purpose of one study was to see whether or not mixed catfish meatballs and seaweed flour can be decreased digestive problems. The authors indicated that dietary fiber has functions such as decreasing intestinal transit time and rising stool mass which may be used to avoid constipation (Sugitha et al., 2019). Additionally, phlorotannins are a class of therapeutic agents. However, their low stability prevents them from expressing their full bioactivity in the human body. As a result, this research concentrated on preserving their vitality through encapsulation. The chitosan-tripolyphosphate carrier was used to encapsulate phlorotannins isolated from *Sargassum ilicifolium*. They were tested for processing and storage stability, and also bioactivity retention after in vitro digestion (Kaushalya and Gunathilake, 2022).

Seaweed is used to generate functional foods as a control and prevention agent for coronary heart disease. The use of edible seaweeds to replace salt in food products may lower the risk of chronic disease by reducing dietary sodium (Vilar et al., 2020b). Kumar et al. (2015) found that regular intake of *Ulva ohnoi* and *Derbesia tenuissima* might cause a significant reduction in blood pressure and also an advancement in glucose metabolism for the human disease diabetes mellitus. Based on the chemical composition of the two seaweed, the authors reported that *Ulva ohnoi* was higher results compared to those prompted by *Derbesia tenuissima* because of its high concentration of soluble fibers and magnesium. Ramirez-Higuera et al. (2014) reported that the antihypertensive effects of seaweeds *Ulva Linza* and *Lessonia trabeculate* were determined. In addition to this, Lim et al. (2013) demonstrated that chicken and pork patties enhanced with *Laminaria japonica* improved glycaemic plasma glucose and serum cholesterol in borderline hyperlipidemic humans. According to Hall et al. (2012) adding *Ascophyllum nodosum* to bread could even help decrease the number of calories in a subsequent test diet and total energy ingestion in the one-day duration. The authors suggested that the consumption of the *A. nodosum-enhancing* bread, even as distinctions in blood glucose and cholesterol were not considerable. Nevertheless, the researchers also indicated that endoscopic research to be carried out to determine the true potential of *A. Nodosum-enhanced* bread energy intake together with glucose and lipid metabolism (Hall et al., 2012).

In addition to the benefits provided by foods substituted with seaweed, there are considerations to be taken into account in the consumption rate. Toxic contaminants present in the surrounding waters, such as pesticides, ammonium, trace elements, and dioxins are accumulated by seaweeds. Provided that knowledge of seaweed consumption is needed to evaluate exposure and the risks to human health associated with toxic substances (Ficheux et al., 2022). In coastal areas, seaweeds are dominant organisms. Heavy metal contamination, however, threatens the integrity of these organisms in light of environmental change (Varquez-Arias et al., 2023). Numerous seaweed species can collect heavy metals and cause health issues when consumed. Researchers looked at how heavy metal (Cd, Hg, Pb, and As) concentration and polyphenol levels changed over time in terms of three safe-to-eat algal species. According to a risk evaluation, consuming these seaweed species (*Saccharina latissima*, *Palmaria palmate*, *Alaria esculenta*) challenges little danger to health in terms of heavy metals (Roleda et.al., 2019). The addition of seaweeds for the production of biscuits was studied in one study. The authors showed that the levels of seaweed (*Dictyota sp.*) in biscuits were recommended to be 3%. Consuming 100g of seaweed biscuits would contribute immensely to the recommended daily intake levels of iron and zinc, thereby combating iron and zinc shortcomings in disadvantaged people. But even though the biscuits with 1-3% seaweed content had acceptable levels of cadmium and lead and were well-accepted by consumers, there was consideration about cadmium absorption in humans over time (Mwalukumbi, 2022). In another research, 34 seafood samples including seaweeds were taken from several markets in China and tested for total and speciated As both before and after boiling. Seaweeds accumulated far more As than fish and shellfish in all of the tested seafood samples, particularly the brown seaweed *Hizikia fusiforme*. This research could shed new light on the variances in As bioaccessibilities from different food sources, as well as the changes in As species during intestinal absorption, particularly in the presence of intestinal microbiota. The authors reported that humans were exposed to arsenic (As) through seafood consumption (Fu et al., 2021). Although seaweeds are high in nutritional and functional compounds, they can be also collected from heavy metals in water. The health risk assessment concluded that eating seaweed meals posed little risk. The mean values of Pb, Hg, and As were all lower than the maximum limits established for nutritional supplements and feed additives. Although the seaweeds investigated had an appropriate chemical composition for application as food and feed ingredients, Cd levels were indicated to be monitored, particularly in brown seaweeds (Veliz et al., 2023). In another report, the overall hazard index (HI) of seaweed consumption to adults was less than one, while the HI of *Sargassum polycystum, Sargassum oligocystum*, *Sargassum thunbergii*, and *Turbinaria ornate* consumption to children was higher than one, indicating a moderate or high risk to children. Furthermore, the amount of exposure and the cancer-causing risk parameter revealed that As and Cr were the limiting factors for seaweed consumption. Ultimately, the author's findings heavily supported their research hypotheses that heavy metal bioaccumulation behavior and health risk differed greatly between species (Peng et al., 2022). Even though defining healthcare outcomes or trying to assess the requirement for regulatory requirements for organic As exposure was indicated as premature. The widespread consumption of seaweed and seafood products worldwide, combined with preliminary toxicological profiles of these compounds and their confounding effect on assessing exposure to inorganic As, suggested that more research and process-level studies on organic As were required to fill the present gaps in knowledge (Taylor et al., 2017). Microplastics have been also observed attaching to marine macroalgae, which serve as a vector for microplastic transfer in the marine food web. The edible seaweed nori (*Pyropia spp.*) was preferred as the study's target species. Microplastic contamination in nori was investigated in both its final commercial applications and intermediate products at various stages of processing. The study demonstrated the presence of microplastics in commercial seaweed nori and linked them to possible sources during the processing phase (Li et al., 2020).

Consumers are increasingly concerned about the heavy metal contamination and microplastic particles in seafood. In an effort to deal with these issues, the latest trend in the food industry is the production of imitation seafood from plant ingredients. These imitation products attempt to replicate the appearance, taste, texture, and nutritional value of specific seafood (Leonard and Fang, 2023). Seaweeds include a wide range of bioactive components that provide health benefits that are difficult to get from land-based food products. As consumers become more interested in healthy organic ingredients, seaweed-derived bioactive components have a wide variety of uses in functional foods as well as nutritional supplements. Biologically active seaweed substances (BASS) can help to design functional food products that can resolve micronutrient deficiencies, encourage healthy health, and lower the risk of illness because of their diverse range of structures and properties. Furthermore, the use of modern science and technology in the development and research of BASS can be used to produce a wide variety of new functional foods, and future technological and scientific advances assure an even broader variety of health advantages for consumers (Qin et al., 2018b).

## CONCLUSIONS

Food resources are gradually decreasing due to population growth and climate changes. In order to avoid hunger problems in the future, the importance of ensuring the effective use of food resources and producing new nutritionally valuable products is gradually increasing. For this reason, seaweed is considered to be a very important food source. Seaweed can be consumed directly, as well as consumed in pill form as a dietary supplement. In addition, it is also used in the production of nutritionally valuable functional products by taking part in the formulations of various food products. Studies aimed at ensuring, controlling, and processing, the production of seaweed in a healthy way should be encouraged. It is considered that it is quite necessary to attach importance to the studies aimed at increasing the production and consumption of seaweed and functional food products containing seaweed in our country. The more given the importance of the improvement of seaweed aquaculture and processing technology in our country, the more increasing of demand for seaweed-value-added and functional seafood products would provide an opportunity to increase seafood consumption. It is estimated that seaweed and all kinds of functional food products that can be produced using seaweed will be the solution to food shortages that may occur in the future.

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# Chapter 6

## EFFECT OF STEM HEIGHT ON THE FIBER PROPERTIES OF WOOD: A LITERATURE REVIEW

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## INTRODUCTION

Softwoods have only two types of cells (ray parenchyma cells and longitudinal tracheids). Longitudinal tracheids compose more than 90% of the softwood volume. Hardwoods differ from softwood in that they have vessel elements. They have longitudinal cells such as vessel elements, tracheids (vasicentric tracheids and vascular tracheids), axial parenchyma, and fibers (fiber tracheids and libriform fibers). Average fiber and vessel element volumes in hardwoods are approximately 50% and 30%, respectively (Panshin and de Zeeuw, 1980). Wood fiber properties depend on tree species, tree age, longitudinal and radial location at the stem, geographical location (latitude, altitude, and longitude), and climatic and environmental conditions (Smook, 1992).

One of the important factors in evaluating the suitability of raw materials for pulp production is fiber properties. The main fiber properties of wood are fiber length, fiber width, cell wall thickness, and lumen width. The other fiber properties of wood are fiber coarseness, curl index, and kink index. On the other hand, derived fiber properties, such as the Runkel ratio, slenderness ratio, and flexibility ratio, have been considered important properties for pulp and paper properties (Ohshima et al. 2005).

The paper machine runnability, paper strength, response to refining, and fiber-water interactions directly affect by the fiber properties. Long fibers tend to create a less uniform paper and porous structure, rough paper surface. On the other hand, high paper strength is obtained by using long fibers. Cell wall thickness and lumen width of fibers affect fiber flexibility. Folding endurance, tensile and burst index of paper produced from thick-walled fibers are lower than those of thin-walled fibers. Tear index and bulk of papers have a positive correlation with cell wall thickness (Gülsoy and Şimşir, 2018).

Sapwood, heartwood, mature wood, juvenile wood, top wood, base wood, compression wood, tension wood, stem wood, and branch wood have different fiber properties. One of the most significant influence on the use of wood as a final product is its fiber properties. The small diatemer woods at the top position of a tree has generally been used as firewood due to their low economic value. However, these tree parts can be converted into high-value-added products such as pulp and paper. Therefore, this review gives a detailed summary of fiber morphology differences throughout the stem height (SH) of various tree species.

## EFFECT OF SH ON WOOD FIBER PROPERTIES OF WOOD

Several investigations have been carried out the relationship between fiber properties and SH of softwood and hardwood species. The results of these studies are reviewed in chronological order.

Bailey and Shepard (1915) evaluated the influence of SH on fiber length of red spruce (*Picea rubens* Sarg.). They found that fiber length values at 1 foot, 6 feet, and 12 feet from ground of 20$^{th}$ annual ring were 2.21 mm, 2.49 mm, and 2.22 mm, respectively. The fiber length values in 40$^{th}$ annual ring were 3.17 mm at 1 foot, 3.00 mm at 6 feet, 3.48 mm at 12 feet, 3.31 mm at 18 feet, 3.23 mm at 24 feet, and 2.71 mm at 30 feet.

Kribs (1928) aimed to determine effect of SH (1 foot, 11 feet, 21 feet, 31 feet, 41 feet, 51 feet, 61 feet of SH) on fiber length at different annual rings of jack pine (*Pinus banksiana* Lamb.). The author noted that fiber length values of 5$^{th}$, 10$^{th}$, 15$^{th}$, 20$^{th}$, 25$^{th}$, 30$^{th}$, 35$^{th}$, and 40$^{th}$ annual rings were irregularly changed with increasing SH. Fiber length of 45$^{th}$, 50$^{th}$, 55$^{th}$, 60$^{th}$, 65$^{th}$, 70$^{th}$, 75$^{th}$, and 80$^{th}$ annual rings had positively correlated with SH.

Kienholz (1930) studied the relationship between fiber length and SH (2 feet, 12 feet, and 22 feet above ground) western hemlock (*Tsuga heterophylla* (Raf.) Sarg.). The author found that fiber length was 2.09 mm at 2 feet, 2.35 mm at 12 feet, and 2.32 mm at 22 feet. On the other hand, Bisset and Dadswell (1949) reported that fiber length values at 2 feet, 50 feet, and 98 feet of mountain ash (*Eucalyptus regnans* F. Muell.) were measured as 1.13 mm, 1.34 mm, and 1.24 mm, respectively.

Nylinder and Hägglund (1954) observed the relationship between fiber properties and SH of Norway spruce (*Picea abies* (L.) Karst.) wood. Fiber length and fiber width was slightly decreased with increasing SH. Fiber length was 3.13 mm at 25% height, 3.12 mm at 50% height, and 3.03 mm at 75% height. Fiber width was 39.0 µm at 25% height, 38.7 µm at 50% height, and 38.3 µm at 75% height. Slenderness ratio of fiber was also irregularly varied with SH.

Kennedy (1957) investigated the axial (4.5 feet, 18 feet, and 36 feet of SH) and radial (ring 2, ring 5, ring 10, and ring 15) variation in fiber length of fast-grown and slow-grown black cottonwood (*Populus trichocarpa* Torr. and Gray) trees. He reported that fiber length was significantly affected by axial and radial direction. It was also noted that fast-grown trees of black cottonwood had longer fibers than that slow-grown trees. The longest fibers were observed in 18 feet, ring 15 samples of fast-grown trees with 1.45 mm. The shortest fibers were determined in 4.5 feet, ring 2 samples of slow-grown trees with 0.52 mm.

Liese and Ammer (1962) determined the fiber length at 40 cm and 240 cm above ground of Scots pine (*Pinus sylvestris* L.). They noted that fiber length of earlywood and latewood in the different annual rings (20$^{th}$, 110$^{th}$, and 130$^{th}$) had positive correlation with SH. The longest and shortest fibers were observed in the latewood sample in the 130$^{th}$ ring at 240 cm above ground with 3.46 mm and earlywood sample in the 110$^{th}$ ring at 40 cm above ground with 2.32 mm, respectively. On the other hand, Bannan (1964) found that the relationship between fiber length and SH of Douglas fir (*Pseudotsuga menziesii* (Mirb.) Franco) was positively correlated.

Schultze-Dewitz (1965) investigated the effect of SH (1.3 m, 5.3 m, 9.3 m, and 13.3 m above ground) on fiber length at north and south side wood samples of Scots pine (*Pinus sylvestris* L.). Wood samples were taken from predominant and medium-sized trees. The fiber length at north side samples of predominant trees increased up to 5.3 m of SH, then decreased to 13.3 m of SH. The fiber length at south side samples of predominant trees had a negative correlation with SH. The fiber length at both side samples of medium-sized trees irregularly changed with increasing SH. The longest and shortest fibers were measured in 1.3 m SH south side samples of predominant trees with 3.22 mm and 5.3 m SH north side samples of medium-sized trees with 2.80 mm, respectively.

Bannan (1966) found that fiber length of redwood (*Sequoia sempervirens* (D. Don) Endl.) was 5.04 mm at stump height, 4.78 mm at breast height, and 6.46 mm at 20 feet above ground. Taylor (1968) noted that fiber length of yellow poplar (*Liriodendron tulipifera* L.) wood was 1.91 mm at 4.5 feet, 1.77 mm at 20 feet, 1.61 mm at 40 feet, and 1.45 mm at 60 feet. On the other hand, Higgs (1969) reported that the fiber length of swamp gum (*Eucalyptus regnans* F. Muell.) was slightly increased with increasing SH. Fiber length values at breast height, 10%, 20%, 30%, 40%, and 50% of SH were 1.05 mm, 1.07 mm, 1.10 mm, 1.12 mm, 1.12 mm, and 1.11 mm, respectively.

Bannan and Bindra (1970) evaluated the relationship between fiber length and SH (1.5, 6, and 12 m above ground) of lodgepole pine (*Pinus contorta* Dougl. ex Loud.), white spruce (*Picea glauca* Moench. Voss.), and eastern white pine (*Pinus strobus* L.). Wood samples were obtained from the east, west, south, and north sides of eastern white pine and white spruce, and only from the east and west sides of lodgepole pine. In white spruce samples, the longest and shortest fibers were observed in near bark and east side samples at 6 m of SH (3.98 mm) and in near pith and south side samples at 1.5 m of SH (3.18 mm), respectively. In lodgepole pine samples, the longest fibers were observed in near bark and west side samples at 6 m of SH (3.49 mm), while the shortest fibers were observed in near pith and east side samples at 1.5 m of SH (2.77 mm). They also noted that the longest and shortest fibers in eastern white pine samples were observed in near bark and west side samples at 6 m of SH (4.76 mm) and in near pith and north side samples at 1.5 m of SH (3.45 mm), respectively.

Bozkurt (1971) observed the effect of SH (bottom, middle, and top of SH) on the fiber properties of oriental spruce (*Picea orientalis* (L.) Link) and European black pine (*Pinus nigra* Arn.). The author noted that the fiber length and fiber width of oriental spruce were 3.32 mm and 35.2 µm at bottom, 3.77 mm and 37.0 µm at middle, and 3.60 mm and 34.7 µm at top sample. Lumen width and cell wall thickness at bottom, middle, and top samples of oriental spruce were 22.5 µm and 6.4 µm, 25.0 µm and 6.0 µm, and 20.1 µm and 7.3 µm, respectively. It was also reported that fiber length, fiber width, and lumen width of European black pine had a positive correlation with SH, while cell wall thickness had a negative correlation with SH.

Davidson (1972) noted that fiber length of rainbow eucalyptus (*Eucalyptus deglupta* Blume) had positive correlation with SH. In the near pith samples, fiber length values at breast height and 30% of SH were 0.83 mm and 0.86 mm, respectively. These values in the near bark samples were 1.04 mm and 1.18 mm. Otherwise, Cown (1973) found that fiber length of radiata pine (*Pinus radiata* D. Don) was 2.30 mm at breast height and 1.92 mm at 6.5 m of SH.

Harris (1973) studied the variation of fiber length with SH of lodgepole pine (*Pinus contorta* Dougl. ex Loud.). Wood samples were obtained from the breast height and 15$^{th}$ internode of the stem. Fiber length was not significantly affected by SH. Vurdu (1977) noted that fiber length of black alder (*Alnus glutinosa* Gaertn.) had a negative correlation with SH.

Taylor and Wooten (1973) noted that fiber width of American sycamore (*Platanus occidentalis* L.) wood was 20.88 µm at 4.5 feet, 20.40 µm at 20 feet, 19.88 µm at 40 feet, and 19.08 µm at 60 feet. They also reported that fiber length and fiber width values at 5 feet and 75 feet of SH of black willow (*Salix nigra* Marsh.) were 1.21 mm and 20.68 µm at 5 feet of SH and 1.00 mm and 16.52 µm 75 feet of SH.

Cown (1974) carried out an investigation on the effect of SH (breast height, 15$^{th}$ internode, and 25$^{th}$ internode) on fiber length at different rings (2$^{nd}$, 10$^{th}$, and 25$^{th}$ rings) from the pith of European black pine (*Pinus nigra* Arnold). The author found that fiber length in the 2$^{nd}$ ring was 1.2 mm at breast height, 1.4 mm at the 15$^{th}$ internode, and 1.5 mm at the 25$^{th}$ internode. Fiber length values in the 10$^{th}$ ring at breast height, the 15$^{th}$ internode, and the 25$^{th}$ internode were 2.8 mm, 2.0 mm, and 2.9 mm, respectively. Fiber length in the 25$^{th}$ ring had longer fibers than those of the 2$^{nd}$ and 10$^{th}$ rings. In this ring, fiber length was irregularly changed with increasing SH. The longest fibers measured in the 25$^{th}$ ring of the 15$^{th}$ internode with 4.1 mm.

Clunie (1975) reported the effect of SH levels (breast height, 10%, 20%, 40%, 60%, and 80% of SH) on earlywood fiber properties at different annual rings from bark (3,7, and 11) of *Pinus caribaea* var. *hondurensis* obtained from Queensland, Australia. The author noted the longest and shortest fibers observed in 20% m of SH with 5.3 mm and in 80% of SH with 3.4 mm, respectively. The fiber length, fiber width, and lumen width increased up to 20% of SH, then decrease to 80% of SH. The author also reported that cell thickness gradually decreased with increasing SH.

Bhat and Kärkkäinen (1981) reported that fiber length and vessel element length of European white birch (*Betula pendula* Roth.) and downy birch (*Betula pubescens* Eahrh.) had a negative correlation with SH. Fiber length and vessel element length of European white birch were 1.20 mm and 0.60 mm at breast height samples and 1.08 mm and 0.55 mm at crown samples, respectively. In downy birch samples, they were 1.24 mm and 0.64 mm at breast height samples and 1.19 mm and 0.62 mm at crown samples.

Cown and McConchie (1981) revealed that the fiber length of radiata pine (*Pinus radiata* D. Don) tree (ring 1967) was 2.9 mm at butt-end sample and 3.9 mm at 6 m of SH. On the other hand, Bodner (1983) aimed to determine the effect of sampling height (butt-end and 18 feet) on the fiber length in earlywood and latewood of Douglas fir (*Pseudotsuga menziesii* var. *menziesii*) located in Oregon State University School Forest of USA. His study indicated that fiber length in both earlywood and latewood generally increased with height of the trees.

Cown et al. (1983) evaluated the effect of log position (breast height, 10 m, and 20 m of SH) on fiber length at different annual rings from pith (2, 5, 10, and 15) of *Pinus caribaea* var. *hondurensis*. They noted the longest fibers in all studied annual rings observed in 10 m of SH. The fibers in breast height samples were shorter than that of 20 m of SH.

Iqbal and Ghouse (1983) examined the fiber length and fiber width at different SHs (0.7 m, 1.8 m, 4.0 m, 6.4 m, and 8.8 m) of *Acacia nilotica* var. *telia* and *Prosopis spicigera* Linn. They found that both fiber length and fiber width of each species were irregularly decreased with increasing SH. In *Acacia nilotica* var. *telia* wood samples, fiber length and fiber width at 0.7 m, 1.8 m, 4.0 m, 6.4 m, and 8.8 m of SH were 1.09 mm, 1.14 mm, 1.01 mm, 1.06 mm, and 0.93 mm and 15.4 µm, 17.2 µm, 14.5 µm, 16.6 µm, and 11.4 µm, respectively. In *Prosopis spicigera* wood samples, fiber length and fiber width at 0.7 m, 1.8 m, 4.0 m, 6.4 m, and 8.8 m of SH were 0.98 mm, 0.96 mm, 0.97 mm, 0.97 mm, and 0.90 mm and 14.7 µm, 13.7 µm, 14.1 µm, 15.6 µm, and 10.4 µm, respectively. On the other hand, Markstrom et al. (1983) noted that fiber length values of ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) at 0%, 25%, and 50% of SH were 2.08 mm, 2.61, and 2.70 mm, respectively.

Jourdain and Olson (1984) reported that fiber length values at base, 17%, 33%, 50%, 67%, and 83% SH of American sycamore (*Platanus occidentalis* L.) were 1.41 mm, 1.49 mm, 1.47 mm, 1.40 mm, 1.28 mm, and 1.09 mm, respectively.

Süss and Müller-Stoll (1984) evaluated the effect of SH (0 m, 1.3 m, 6 m, 12 m, 15 m, and 18 m of SH) on fiber length and vessel element length of European beech (*Fagus sylvatica* L.). They noted that the longest fibers and vessel elements were observed in 1.3 m of SH with 1.29 mm and 0.60 mm, respectively. The shortest fibers and vessel elements were determined in 15 m of SH with 1.15 mm, and 0.56 mm, respectively.

Saranpää (1985) evaluated the axial variation of the fiber length at ring 3 from pith of lodgepole pine (*Pinus contorta* Dougl. ex Loud.). The author reported that fiber length values at 1.3 m, 4 m, 8 m, 12 m, and 16 m above ground were 1.54 mm, 1.72 mm, 1.78 mm, 1.65 mm, and 1.58 mm, respectively. The author also noted that fiber width and cell wall thickness of earlywood and latewood samples were irregularly changed with increasing SH.

Stringer and Olson (1987) studied the effect of SH (0%, 20%, 40%, 60%, and 80% of SH) on fiber length of black locust (*Robinia pseudoacacia* L.) located on Kentucky of USA. They reported that fiber length values at 0%, 20%, 40%, 60%, and 80% of SH were 1.06 mm, 1.09 mm, 1.03 mm, 0.96 mm, and 0.90 mm, respectively.

Wong (1987) aimed to determine effect of SH (0.15 m, 1.5 m, 4.5 m, 7.5 m, 10.5 m, 13.5 m, and 16.5 m of SH) on fiber length at the juvenile wood and mature wood of tamarack (*Larix laricina* (Du Roi) K. Koch) tree from Ontario province of Canada. Fiber length values at 0.15 m, 1.5 m, 4.5 m, 7.5 m, 10.5 m, 13.5 m, and 16.5 m of SH in the juvenile wood sample were 1.95 mm, 2.18 mm, 2.44 mm, 2.23 mm, 2.28 mm, 1.87 mm, and 1.61 mm, respectively. In the mature wood sample, fiber length values were 2.80 mm at 0.15 m, 3.21 mm at 1.5 m, 3.63 mm at 4.5 m, 3.46 mm at 7.5 m, 3.41 mm at 10.5 m, 2.92 mm at 13.5 m, and 2.40 mm at 16.5 m.

Laurila (1989) revealed that fiber length of Scots pine (*Pinus sylvestris* L.) was 2.11 mm at 20% of SH and 1.56 mm at 80% of SH. On the other hand, Malan (1989) revealed that fiber length of radiata pine (*Pinus radiata* D. Don) was 3.04 mm at 5% of SH, 3.38 mm at 15% of SH, 3.50 mm at 35% of SH, and 3.36 mm at 65% of SH.

Young et al. (1991) found that the longest fibers of radiata pine (*Pinus radiata* D. Don) were observed in 26 m of SH mm in ring 2 (from pith) samples, in 21 m of SH mm in ring 5 samples, in 16 m of SH mm in ring 10 samples, and in 6 m of SH mm in ring 15 samples. The longest and shortest fibers were measured in ring 15 at 6 m of SH (4.2 mm) and in ring 2 at butt-end (1.6 mm).

Ajmal and Iqbal (1992) determined fiber length, vessel element length, and fiber width at 1.08 m, 2.15 m, 4.25 m, 6.08 m, 7.84 m, 10.45 m, 12.60 m, and 14.22 m of SH of golden rumph's fig (*Ficus rumphii* Blume). They reported that fiber length values at 1.08 m, 2.15 m, 4.25 m, 6.08 m, 7.84 m, 10.45 m, 12.60 m, and 14.22 m of SH were 1.80 mm, 1.82 mm, 1.75 mm, 1.71 mm, 1.66 mm, 1.59 mm, 1.47 mm, and 1.32 mm, respectively. They revealed that fiber width and vessel element length were irregularly changed with increasing SH. Otherwise, Kang (1993) noted that fiber length of Korean pine (*Pinus koraiensis* Siebold & Zucc.) was 3.08 mm at 1.2 m, 3.24 mm at 5.2 m, and 3.20 mm at 9.2 m.

Muñiz (1993) aimed to analyze longitudinal variations in the fiber properties of loblolly pine (*Pinus taeda* L.) and *Pinus elliottii* var. *elliotti*. The author reported that fiber width and lumen width in each tree species increased up to 50% of SH, then decreased by 75% of SH. However, cell wall thickness gradually decreased with increasing SH.

Ridoutt and Sands (1993) reported that the fiber length of southern blue gum (*Eucalyptus globulus* Labill.) wood was irregularly varied with increasing SH. Fiber length values at 2.5%, 5%, and 70% of SH were 0.92 mm, 0.99 mm, and 0.85 mm, respectively.

Sahri et al. (1993) examined the fiber properties of four different stem parts (breast height, 15%, 35%, and 65% of SH) of brown salwood (*Acacia mangium* Willd.). They noted that while fiber length and cell wall thickness were decreased in the lower part of the stem towards the upper part, fiber width and lumen width were increased. Fiber length and fiber width at breast height, 15%, 35%, and 65% of SH were 1.03 mm and 20.8 µm, 0.95 mm and 24.3 µm, 0.91 mm and 26.3 µm, and 0.85 mm and 27.4 µm, respectively.

Rincoski (1994) noted that fiber length, fiber width, and cell wall thickness of *Pinus elliottii* var. *elliottii* were 3.21 mm, 41.45 µm, and 12.97 µm at 0.7 m of SH and 3.81 mm, 49.78 µm, and 9.66 µm at 6.0 m of SH, respectively.

Ishengoma et al. (1995) investigated the relationship between fiber length and SH (1.3 m, 4 m, 8 m, and 12 m above ground) of juvenile and mature wood of patula pine (*Pinus patula* Schl. et Cham.). Studied trees were taken from the Sao Hill Forest Project in Southern Tanzania. They revealed that fiber length in juvenile wood was slightly decreased (2.56 mm at 1.3 m and 2.50 mm at 12 m) with increasing SH. In mature wood samples, fiber length was significantly decreased (3.45 mm at 1.3 m and 3.17 mm at 12 m) with increasing SH.

Malan (1995) studied the effect of SH (5%, 15%, and 35% of SH) on fiber length in two sites (Tweefontein and Dukuduku) of *Pinus elliottii* x *Pinus caribaea*. Wood samples were taken from ring 2, ring 10, and last ring at each SH. The author noted that fiber length was significantly affected by SH at both sites. The longest fibers were observed in the last ring of 35% of SH of the Tweefontein site with 4.85 mm. The shortest fibers were measured in ring 2 of 35% of SH of the Dukuduku site with 2.30 mm. On the other hand, Lei et al. (1996) reported that fiber length values at breast height and 4.4 m of SH of Oregon white oak (*Quercus garryana* Dougl.) were 1.2 mm and 1.1 mm, respectively.

Matsumura et al. (1997) investigated the vertical variation of earlywood fiber length at intermediate wood, inner sapwood, and outer sapwood of Japanese cedar (*Cryptomeria japonica* D. Don) tree from the Kyushu University Forests in Fukuoka province of Japan. They reported that earlywood fiber length values in the intermediate wood sample were 2.17 mm at 1.5 m SH, 2.38 mm at 3 m SH, 2.55 mm at 4.5 m SH, 2.56 mm at 6 m SH, and 2.33 mm at 9 m SH. Earlywood fiber length in both inner sapwood and outer sapwood samples irregularly varied with increasing SH. The longest and shortest earlywood fibers were observed in the 1.5 m SH outer sapwood sample with 2.85 mm and 1.5 m SH intermediate wood sample with 2.17 mm, respectively.

Sharma (1997) evaluated the relationship between fiber length and SH of black locust (*Robinia pseudoacacia* L.). Black locust woods were sampled from different tree spacings (0.60 x 0.60 m, 0.90 x 0.90 m, and 1.20 x 1.20 m spacing). The author reported that the fiber length gradually decreased with increasing SH in all tree spacings. On the other hand, Youming et al. (1997) revealed that fiber length of Masson pine (*Pinus massoinana* Lamb) was 2.03 mm at 0.3 m, 2.21 mm at 3.3 m, 1.86 mm at 7.3 m, 1.52 mm at 11.3 m, 1.77 mm at 15.3 m, and 1.53 mm at 19.3 m.

Şahin and Ay (1999) studied the effect of SH (2 m, 7 m, and 12 m of SH) on fiber properties at earlywood and latewood of oriental spruce (*Picea orientalis* (L.) Link). They noted that earlywood fiber properties of oriental spruce except of cell wall thickness were increased at 7 m of SH, and then decreased at 12 m SH. The cell wall thickness of earlywood fibers had a positive correlation with SH. They noted that similar trends were also observed in latewood samples.

Carvalho (2000) aimed to analyze the effect of SH on fiber properties of hybrid eucalyptus (*Eucalyptus urograndis* (*Eucalyptus grandis* x *Eucalyptus urophylla*)) wood grown in Brazil. The fiber length and fiber width were found as 1.07 mm and 17.48 µm at the base and 1.08 mm and 17.14 µm at 4 m of SH, respectively. Also, lumen width and cell wall thickness of base wood samples were wider than those of 4 m of SH. The wood at 4 m of SH had more flexible fibers than base wood.

Hapla et al. (2000) aimed to analyze longitudinal variations in fiber properties at earlywood and latewood samples of Atlas cedar (*Cedrus atlantica* (Endl.) Manetti ex Carrière). Fiber length values in both earlywood and latewood were not changed with increasing SH. Fiber width had a positive correlation, while cell wall thickness had a negative correlation with SH.

Jorge et al. (2000) found that the fiber length in different samples (near the pith, 50% radius, and near the bark) in the radial direction of southern blue gum (*Eucalyptus globulus* Labill.) wood was slightly decreased with increasing SH. On the other hand, Ezquerra and Gil (2001) revealed that the fiber length of maritime pine (*Pinus pinaster* Ait.) was 5.1 mm at 4.07 m height above ground and 2.8 mm at 19 m height above ground.

Feng (2001) aimed to determine the effect of SH (0.15 m, 1.4 m, 3.4 m, 5.4 m, 7.4 m, 9.4 m, 11.4 m, 13.4 m, and 15.4 m of SH) on fiber length of jack pine (*Pinus banksiana* Lamb.) tree from Ontario province of Canada. The author noted that fiber length values at 0.15 m, 1.4 m, 3.4 m, 5.4 m, 7.4 m, 9.4 m, 11.4 m, 13.4 m, and 15.4 m of SH were 2.44 mm, 2.80 mm, 2.81 mm, 2.86 mm, 2.66 mm, 2.62 mm, 2.35 mm, 2.00 mm, and 2.08 mm, respectively.

Igartúa et al. (2002) evaluated the effect of SH on fiber length of near pith wood, intermediate wood, and the near bark wood of southern blue gum (*Eucalyptus globulus* Labill.) wood. In the near pith wood samples, fiber lengths were irregularly varied with increasing SH. The fiber length in intermediate wood and near bark wood had positively correlated with SH. The longest fibers were observed in the near bark wood of 60% of SH samples with 1.21 mm.

Rao et al. (2002) determined the effect of SH (0.5 m, 1.5 m, 2.5 m, 3.5 m, and 4.5 m of SH) on fiber length, fiber width, lumen width, and cell wall thickness of forest red gum (*Eucalyptus tereticornis* Sm.). All fiber properties were irregularly changed with increasing SH. The longest fibers were observed in 1.5 m of SH with 1.04 mm. The widest fibers were determined in 4.5 m of SH with 18.0 µm.

Hsu (2003) noted that the fiber length of 7 years-old radiata pine (*Pinus radiata* D. Don) was 1.70 mm at breast height, 1.55 mm at 2.4 m of SH, and 1.40 mm at 4.6 m of SH. Otherwise, Xu et al. (2003) studied the variation of fiber properties in the bottom, middle, and top samples of *Populus tomentosa*. Fiber length was 0.89 mm in the bottom, 1.03 mm in the middle, and 0.81 mm in the top. Fiber width and lumen width were

23.2 μm and 12.86 μm in the bottom, 23.6 μm and 13.02 μm in the middle, and 22.3.2 μm and 12.25 μm in the top, respectively. Cell wall thickness values in the bottom, middle, and top were 3.86 μm, 3.80 μm, and 3.78 μm, respectively.

Arenas (2004) revealed that short fibers in different annual rings of redwood (*Sequoia sempervirens* (D. Don) Endl.) were determined at 0.3 m of SH. The longest and shortest fibers were observed in the 20$^{th}$ annual ring at 5 m of SH with 4.59 mm and in the 5$^{th}$ annual ring at 0.3 m of SH with 2.59 mm.

Husein (2004) examined the fiber properties at different SH levels of western *Castanopsis javanica* (Blume) A.DC. The fiber length and vessel element length in the bottom, middle, and upper samples were 1.17 mm and 0.58 mm, 1.25 mm and 0.66 mm, and 1.25 mm and 0.65 mm, respectively. Fiber width, lumen width, and cell wall thickness increased to the middle level and then decreased up to the upper level. On the other hand, the slenderness ratio and flexibility ratio had a positive correlation with SH, while the Runkel ratio had a negative correlation with SH.

Calonego et al. (2005) evaluated the relationship between SH (0.3 m, 8.3 m, 16.3 m, and 24.3 m) and fiber length of juvenile wood and mature wood samples of lemon scented gum (*Eucalyptus citriodora* Hook.). They revealed that fiber length values in both juvenile wood and mature wood were erratically varied with increasing SH. Fiber length values of 0.3 m, 8.3 m, 16.3 m, and 24.3 m samples of juvenile wood were 0.94 mm, 1.04 mm, 1.14 mm, and 1.04 mm, respectively. In mature wood samples, Fiber length was 1.26 mm at 0.3 m, 1.31 mm at 8.3 m, 21.35 mm at 16.3 m, and 1.26 mm at 24.3 m.

Carrasco (2005) aimed to determine the variation of fiber length with SH of alpine ash (*Eucalyptus delegatensis* RT Baker). Fiber length values in bottom, middle, and top were determined as 0.75 mm, 0.79 mm, and 0.75 mm, respectively. On the other hand, Falcon-Lang (2005) revealed that fiber width values of balsam fir (*Abies balsamea* (L.) Mill.) were 39.93 μm at 0 m SH, 31.08 μm at 3 m SH, 32.96 μm at 6 m SH, 32.10 μm at 9 m SH, and 26.84 μm at 12 m SH.

Gryc and Horáček (2005) evaluated the effect of SH (6 m, 8 m, 10 m, 12 m, 15 m, 18 m, 20 m, and 22 m) on earlywood and latewood fiber length at compression wood, opposite wood, and side wood of Norway spruce (*Picea abies* (L.) Karst.). The authors noted that fiber length in all wood samples changed irregularly with increasing SH. They also reported that the longest fibers were detected in latewood samples of 8 m SH side wood with 4.06 mm, and the shortest fibers in latewood samples of 22 m SH compression wood with 2.84 mm.

Rlee and Kim (2005) studied the effect of SH (1.3 m, 2.3 m, 4.3 m, 8.3 m, and 12.3 m of SH) on fiber length and fiber width at the earlywood and latewood of Japanese larch (*Larix kaempferi* Sarg.). Wood samples were obtained south-side and north-side of the tree. In south-side samples, the longest and shortest fibers of earlywood and latewood samples were observed in 4.3 m of SH and 12.3 m of SH, respectively. The widest fibers of earlywood and latewood samples were determined in 2.3 m of SH with 61.85 µm and 37.70 µm, respectively. The narrowest fibers of earlywood and latewood samples were measured in 12.3 m of SH with 41.20 µm and 31.45 µm, respectively. They also noted that there was no difference in fiber length and fiber width between south-side and north-side samples.

Quilhó et al. (2006) investigated the fiber width and cell wall thickness at 5%, 25%, 35%, 55%, 65%, and 90% of SH of hybrid eucalyptus (*Eucalyptus urograndis* (*Eucalyptus grandis* x *Eucalyptus urophylla*)). They found that fiber width gradually decreased with increasing SH. The fiber width values were 18.88 µm at 5% of SH and 17.57 µm at 90% of SH. Also, cell wall thickness was decreased up to 65% SH, and then increased to 90% SH.

Krisdianto and Damayanti (2007) studied the effect of SH (bottom, middle, and top) on fiber properties of the near pith wood, intermediate wood, and near bark wood of prickly acacia (*Acacia nilotica* L. Willd.) from Baluran National Park. In all radial direction samples, fiber properties were irregularly varied with increasing SH. The longest fibers were observed in the near bark wood of bottom samples with 1.71 mm. The widest fibers were observed in the near pith wood of bottom samples with 24.86 µm.

Oluwafemi and Tunde (2008) determined the change in wood fiber properties along the longitudinal direction (0.38 m, 1.30 m, 4.30 m, and 7.13 m) of karaya gum tree (*Sterculia setigera Del.*). According to their findings, the relationship between fiber length and SH had negatively correlated. Fiber length values at 0.38 m, 1.30 m, 4.30 m, and 7.13 m of SH were 2.64 mm, 2.61 mm, 2.53 mm, and 2.36 mm, respectively. Fiber width, lumen width, and cell wall thickness were irregularly varied with increasing SH.

Rautiainen and Alén (2008) studied the effect of SH (0 m, 1 m, 3 m, 7 m, and 10 m above ground) on the fiber length of Scots pine (*Pinus sylvestris* L.). They reported that fiber length had positively correlated with SH. They also noted that short fibers (<1.5 mm) were determined in the near pith samples, while long fibers (about 2.8 mm) were observed in sapwood at SH of 2.5–5.0 m.

Rayirath and Avramidis (2008) examined the relationship between fiber length and SH (1 m, 4 m, and 7 m of SH) at heartwood and sapwood of western hemlock (*Tsuga heterophylla* (Raf.) Sarg.). They reported that fiber length in sapwood samples was 3.07 mm at 1 m, 3.09 mm at 4 m, and 3.14 mm at 7 m. They also noted that fiber length in 1 m, 4 m, and 7 m of heartwood samples was 2.09 mm, 2.14 mm, and 2.09 mm, respectively.

Florsheim et al. (2009) carried out an investigation on the effect of SH (bottom, 25%, 50%, 75%, and 100%) on the fiber properties of *Eucalyptus dunnii* wood. They noted that fiber properties were irregularly changed from the bottom to the top. On the other hand, Shashikala and Rao (2009) evaluated the influence of SH (0.6 m, 3.6 m, and 6.6 m of SH) on fiber length, vessel element length, and fiber width at different radial positions (25%, 50%, 75%, and 100%) of lemon scented gum (*Eucalyptus citriodora* Hook.). They found that fiber properties changed depending on the axial and radial position of sampling.

Gonzalez-Benecke et al. (2010) determined the fiber width, cell wall thickness, and Runkel ratio at 1.8 m of SH and crown base samples of slash pine (*Pinus elliottii* Engelm.) and longleaf pine (*Pinus palustris* Mill.). Fiber width and cell wall thickness of slash pine were 28.72 µm and 6.19 µm at 1.8 m of SH and 31.60 µm and 5.89 µm at crown base sample. The Runkel ratio of slash pine fibers was slightly decreased (from 0.22 to 0.19) with increasing SH. In longleaf pine samples, fiber width at 1.8 m of SH and crown base samples was 28.37 µm and 26.78 µm, respectively. Cell wall thickness was slightly decreased (from 5.75 µm to 5.73 µm) with increasing SH. The authors noted that there was no effect of SH on the Runkel ratio of longleaf pine fibers.

İstek et al. (2010) studied the effect of SH (bottom, middle, and top of SH) on fiber properties at sapwood and heartwood samples of European black pine (*Pinus nigra* Arn.). The authors noted that fiber length at bottom, middle, and top samples of sapwood was 2.65 mm, 2.40 mm, and 3.15 mm, respectively. Fiber length in heartwood samples was 1.44 mm at bottom, 1.58 mm at middle, and 1.60 mm at top sample. They also noted that the cell wall thickness of European black pine had a negative correlation with SH.

Pavlovičs et al. (2010) aimed to analyze longitudinal variations in fiber width and cell wall thickness of earlywood and latewood of Norway spruce (*Picea abies* (L.) Karst.). The authors revealed that fiber width and cell wall thickness in both earlywood and latewood samples were significantly decreased with increasing SH. They also reported that fiber length was negatively correlated with SH. The widest and thickest walled fibers were observed in butt-end earlywood (40.8 µm) and butt-end latewood (6.65 µm), respectively.

Hosseini Hashemi and Kord (2011) evaluated the influence of SH (5%, 25%, and 50% of SH) on the fiber properties of Italian cypress (*Cupressus sempervirens* L.) obtained from a plantation in the northern city of Ramsar, Iran. They revealed that fiber length, fiber width, lumen width, and cell wall thickness of Italian cypress were negatively correlated with SH. The slenderness ratio of fibers was 77.6 at 5% of SH, 77.4 at 25% of SH, and 78.8 at 50% of SH. They also reported that the flexibility ratio of fiber was slightly increased, while the Runkel ratio of fibers was slightly decreased with increasing SH.

Luostarinen (2011) studied the axial variation of fiber properties of Siberian larch (*Larix sibirica* Ledeb.) trees sampled from the plantations of the Finnish Forest Research Institute, Punkaharju, Eastern Finland. The author revealed that fiber length, fiber width, and fiber coarseness were increased with increasing SH.

Zingoni et al. (2011) evaluated the relationship between fiber length and SH (0.3, 3.3, 6.3, 9.3, 12.3, 15.3, and 18.3 m above ground) of ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) Wood samples were obtained from the south and north sides of ponderosa pine tree. They found that fiber length was increased up to 9.3 m of SH, then decreased to 18.3 m. The longest and shortest fibers were measured in the north side samples at 9.3 m of SH (3.74 mm) and in the south side samples at 0.3 m of SH (1.74 mm), respectively.

Essien et al. (2012) studied the fiber properties of sapwood and heartwood samples at different SH levels (butt, middle, and top) of *Cola gigantea* and *Ficus sur*. They found that fiber length of sapwood and heartwood samples in both species had negatively correlated with SH. While fiber width in *Cola gigantea* samples had negatively correlated with SH, it was irregularly changed in the *Ficus sur* samples.

Gonçalves and Lelis (2012) aimed to determine the variation of fiber properties with SH (0%, 50%, and 100%) of brown salwood (*Acacia mangium* Willd.). They found that fiber length and cell wall thickness had a negative correlation with SH, while fiber width and lumen width had a positive correlation with SH. Fiber length and fiber width at 0%, 50%, and 100% of SH were 0.95 mm and 26.59 µm, 0.80 mm and 29.14 µm, and 0.70 mm and 31.55 µm, respectively.

Ishiguri et al. (2012) aimed to determine the effect of SH (0.2 m, 2.2 m, 4.2 m, and 6.2 m above the ground) on fiber length of juvenile wood and mature wood of Japanese red pine (*Pinus densiflora* S et. Z.) and Japanese black pine (*Pinus thunbergii* Parl.). In the Japanese red pine samples, fiber length values in both juvenile wood and mature wood were gradually increased with increasing SH. The longest and shortest fibers were measured at 6.2 m above ground sample of mature wood with 4.74 mm and at 0.2 m above ground sample of juvenile wood with 3.24 mm. They also noted that fiber length values in juvenile wood and mature wood of Japanese black pine were irregularly varied with increasing SH. The longest (4.93 mm) and shortest (3.24 mm) fibers were measured at 0.2 m above ground samples of mature wood and juvenile wood, respectively.

Lemos et al. (2012) evaluated the effect of sampling position (base, 25%, 50%, 75%, and 100%) in the tree stem on the fiber properties of heartwood and sapwood samples of lemon scented gum (*Eucalyptus citriodora* Hook.). Fiber length and fiber width was slightly decreased with increasing SH. Fiber length was 3.13 mm at 25% height, 3.12 mm at 50% height, and 3.03 mm at 75% height. Fiber width was 39.0 µm at 25% height, 38.7 µm at 50% height, and 38.3 µm at 75% height. The slenderness ratio of fiber was also irregularly varied with SH.

Jeong and Zink-Sharp (2012, 2013) determined the fiber properties at different SH levels of loblolly pine (*Pinus taeda* L.) trees sampled from Reynolds Homestead Forest Resources Research Center in Critz, USA. The authors revealed that fiber length of loblolly pine wood was positively correlated with SH.

Rather (2012) reported that fiber length of forest red gum (*Eucalyptus tereticornis* Sm.) grown in India was significantly decreased with increasing SH. Fiber length was 0.89 mm at ground level, 0.87 mm at 30% of SH, 0.83 mm at 60% of SH, and 0.77 mm at 90% of SH, respectively.

Trianoski (2012) evaluated the relationship between SH (0%, 25%, 50%, 75%, and 100% of SH) and fiber properties of *Pinus caribaea* var. *caribaea*, *Pinus caribaea* var. *bahamensis*, *Pinus caribaea* var. *hondurensis*, *Pinus maximinoi*, *Pinus chiapensis*, *Pinus tecunumanii*, *Pinus oocarpa*, and *Pinus taeda* trees. The author reported that the fiber properties at different SH levels depended on the tree species.

Ali (2013) studied the variation of fiber length, fiber width, and cell wall thickness with SH (0.5 m, 2 m, 3.5 m, 5 m, and 7.5 m of SH) of sapwood and heartwood of Indian siris (*Albizia lebbeck* (L.) Benth.). Fiber length increased regularly in sapwood and irregularly in sapwood with the increase in SH. In sapwood samples, fiber width values were 9.19 µm at 0.5 m of SH, 8.91 µm at 2 m of SH, 9.91 µm at 3.5 m of SH, 10.46 µm at 5 m of SH, and 10.36 µm at 7.5 m of SH. In heartwood samples, fiber width values at 0.5 m, 2 m, 3.5 m, 5 m, and 7.5 m of SH were 10.09 µm, 9.31 µm, 9.13 µm, 9.70 µm, 10.52 µm, respectively. In both sapwood and heartwood samples, cell wall thickness of fibers was irregularly increased with increasing SH.

Ogunjobi et al. (2014) aimed to analyze longitudinal variations in the fiber properties of *Vitex doniana* (Sweet). They found that fiber length at butt, 10%, 50%, and 90% height levels of the tree was 1.50 mm, 1.64 mm, 1.48 mm, and 1.43 mm, respectively. They also revealed that fiber width, lumen width, cell wall thickness, and Runkel ratio values of fibers had negative correlation with SH. Slenderness ratio values at butt, 10%, 50%, and 90% height levels of the tree were 63.3, 71.5, 68.1, and 71.1, respectively. The flexibility ratio of butt fibers was 54.14, while the flexibility ratio of 90% SH fibers was 65.32.

Ali (2015) evaluated the influence of SH (base, 1 m, 2 m, and 3 m) on fiber properties of inner wood and outer wood of red river gum (*Eucalyptus camaldulensis* Dehnh.), European black poplar (*Populus nigra* L.), and brook willow (*Salix acmophylla* Boiss.). In all species, fiber length, fiber width, and cell wall thickness were irregularly changed from bottom to top.

Marsoem and Irawati (2016) evaluated the relationship between SH and cell wall thickness of brown salwood (*Acacia mangium* Willd.) and earleaf acacia (*Acacia auriculiformis* A. Cunn. ex Benth.) from Indonesia. They revealed that cell wall thickness in both species had negatively correlated with SH. In earleaf acacia, cell wall thickness was 2.20 µm at bottom, 2.12 µm at middle, and 2.11 µm at top. In earleaf acacia, cell wall thickness values of bottom, middle, and top samples were 2.10 µm, 2.02 µm, and 1.97 µm, respectively.

Kasim et al. (2016) aimed to determine the variation of fiber properties with SH of *Neolamarckia cadamba*. The fiber length and fiber width in bottom, middle, and top samples were 1.50 mm and 34.67 µm, 1.62 mm and 34.50 µm, and 1.56 mm and 34.00 µm, respectively.

Anthonio and Antwi-Boasiako (2017) studied the effect of SH (butt, middle, and top) on the fiber properties of sapwood and heartwood of African rosewood (*Pterocarpus erinaceus* Poir.). In sapwood samples, fiber length of butt, middle, and top samples measured as 1.24 mm, 1.01 mm, and 1.14 mm, respectively. In heartwood samples, they measured as 1.09 mm, 1.00 mm, and 1.04 mm, respectively. Fiber width and lumen width of sapwood samples had negatively correlated with SH. In heartwood samples, fiber width did not change with SH. The lumen width of heartwood fibers increased slightly with increasing SH. In both sapwood and heartwood fibers, cell wall thickness decreased with increasing SH. In sapwood samples, Runkel ratio values of butt, middle, and top samples were calculated as 0.80, 0.67, and 0.67, respectively. A similar decreasing trend was observed in heartwood samples.

Kiaei (2017) observed the effect of SH on the fiber properties of eastern cottonwood (*Populus deltoides* Marsh). It was revealed that the longest fibers were observed in breast height samples. Fiber length was gradually decreased from base to top. The widest and thickest walled fibers were determined in 50% of SH and 75% of SH, respectively. The slenderness, flexibility, and Runkel ratios of fibers were irregularly changed with increasing SH.

Kılıç Pekgözlü et al. (2017) determined the relationship between SH (bottom, middle, and top of SH) and fiber properties of European black pine (*Pinus nigra* Arn.) located in Bolu province of Türkiye. They noted that fiber length was 1.89 mm at bottom, 1.92 mm at middle, and 1.54 mm at top. The authors also noted that the slenderness ratio had a negative correlation, while the Runkel ratio had a positive correlation with SH.

Gil et al. (2018) studied the relationship between fiber properties and SH (0%, 25%, 50%, 75%, and 100% of SH) of teak wood (*Tectona grandis* L.). They reported that fiber length, fiber width, and lumen width had a negative correlation with SH. They also noted that cell wall thickness of teak wood was irregularly varied with increasing SH. Fiber length and fiber width were 0.94 mm and 26.3 µm at 0% of SH and 0.85 mm and 23.6 µm at 100% of SH.

Topaloglu and Erisir (2018) evaluated the change in wood fiber properties along the longitudinal direction of Caucasian fir (*Abies nordmanniana* (Stev.) Spach.) and oriental beech (*Fagus orientalis* L.) trees grown in Türkiye. The fiber length and fiber width of oriental beech wood were found as 1.02 mm and 21.08 µm at 1.3 m of SH, 0.96 mm and 17.10 µm at 6.3 m of SH, and 0.93 mm and 20.45 µm at 6.3 m of SH, respectively. The fiber length and fiber width of Caucasian fir wood were found as 2.67 mm and 33.88 µm at 1.3 m of SH, 2.31 mm and 36.95 µm at 6.3 m of SH, and 2.47 mm and 35.92 µm at 6.3 m of SH, respectively. In both species, lumen width had positively correlated with SH, while cell wall thickness had negatively correlated with SH.

Wate (2018) studied the effect of SH (base, 25%, 50%, 75%, and top of SH) on the fiber properties of red river gum (*Eucalyptus camaldulensis* Dehnh.). It was revealed that fiber length, fiber width, lumen width, and cell wall thickness values varied irregularly from base to top. Fiber length and fiber width values were 1.88 mm and 12.98 µm at base, 1.73 mm and 12.30 µm at 25% of SH, 1.85 mm and 12.73 µm at 50% of SH, 1.86 mm and 13.26 µm at 75% of SH, and 1.65 mm and 12.36 µm at top, respectively. Lumen width values were 7.27 µm at base, 6.55 µm at 25% of SH, 6.62 µm at 50% of SH, 7.40 µm at 75% of SH, 6.59 µm at top, respectively. Cell wall thickness values at base, 25%, 50%, and 75%, and top of SH were 2.86 µm, 2.88 µm, 3.06 µm, 2.93 µm, and 2.89 µm, respectively. A similar irregular trend in fiber sizes was also determined in *Eucalyptus grandis* (W. Hill ex Maid.), *Eucalyptus urograndis*, and *Eucalyptus urophylla* (S. T. Blake).

Ofosu et al. (2019) evaluated the influence of SH (butt, middle, and top) on fiber properties of inner wood and outer wood of *Chrysophyllum albidum*. They revealed that fiber length, fiber width, lumen width, cell wall thickness, and slenderness ratio of fibers in inner wood and outer wood decreased with increasing SH. Fiber length in inner wood of butt, middle, and top samples were 1.34 mm, 1.17 mm, and 1.15 mm, respectively. They were 1.23 mm, 1.13 mm, and 1.07 mm in the outerwood samples. The authors also noted that the flexibility ratio and Runkel ratio of fibers were not significantly affected by SH.

## CONCLUSIONS

In this study, available literature about the axial variation of fiber properties of several tree species is reviewed. Results showed that fiber properties are generally affected by SH. In some studies, fiber properties were positively correlated with SH. In contrast, some studies revealed that fiber properties were negatively correlated with SH. These conflicting findings show that the differences in the fiber properties in axial variation can be depended on tree species, environmental conditions, and other factors. The fiber properties of the wood raw material can be used to predict the quality of pulp and paper. This review hopefully provides new insights for future researchers on small-diameter top wood in the sense of wood industries.

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# Chapter 7

## THE LAST APPROACHES ON WILDLIFE CAPTURE AND CHEMICAL IMMOBILIZATION PRACTICES

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## INTRODUCTION

Sustainable wildlife management which has been improved thanks to innovative science and technology became more sensitive to ecological, economic and social gains in developed countries. It also aims to be more efficient, secure, protective and sustainable (Arpacık et al., 2017; Sarı and Arpacık, 2020; Sarı, 2022). Nature has offered various products and services to humankind since the beginning of humanity, one of the most important these being wild and domestic animal. Mankind has benefited from wild animals in order to meet their various needs and have had to capture animals using different methods throughout history. Initially, food and clothing-based benefits were seen, but today, as a result of developing technology and changing needs, the reasons for the capture of animals also differed. Restraint, capture and handling practices for both domestic and wild animals are often performed in the world for contributing to the protection of wildlife and habitats, controlling wild animal damage and disease, treatment of injured wild animals, relocating endangered or extinction threatened species, resettlement, stock raising, restoring deteriorated food chain and supplying breeding individual to wildlife farming (Fowler, 1995).

Successful capture planning and implementation are carried out in the developed countries of the world by expert scientists or qualified personnel trained in the field (Lins et al., 2009; Ivey et al., 2014). The capture of animals requires good planning, qualified team and experience (Kreeger and Arnemo, 2012). It is important to use appropriate methods and materials to reduce stress for different wild animal species (Caulkett and Arnemo, 2015; Gutema et al., 2018). Capturing methods should be planned according to the target species, the materials to be used and the experiences of the practitioner (Gutema et al., 2018). Wild animals are also far more delicate to emphasize and injury than domestic species, during all capture processes (Tribe and Spielman, 1996). While the capturing technique can be carried out by using simpler methods in bird species, mammalian species should be applied in a more planned, demanding and professional manner (McKenzie, 1993; Fowler, 1995; Kreeger and Arnemo, 2012; Silvy, 2012 CITES, 2018). The negativity in any of these stages may leave the handlers confronted with unwanted situations that will go up to the death of the captured animal (Kreeger and Arnemo, 2009; Stoskopf, 2014). Proper capture, restraint and handling techniques are essential for reducing stress in both captured animals and handler. Therefore, the aim of every capture and restraint process should be to reduce the stress for the captuıred species and at the same time increase the safety of the capture practitioners (Tribe and Spilman, 1996; Caulkett and Arnemo, 2015; Gutema et al., 2018). Essential elements should be taken into account when choosing a handling and capture technique: (1) Will it be safe for the professional who must capture the animal? (2) Does it supply maximum safety for the animal? (3) Will it be possible to accomplish the intended procedure by utilizing the suggested restraint method? (4) Can invariable watching and notice be given to the animal following capture until it has fully recovered from the physical or chemical effects? After evaluating all these factors, an appropriate technique can be selected (McKenzie, 1993; Fowler, 1995).

In addition to physical methods, chemical capture methods are frequently used in wild animal capture practices. However, researchers or technical personnel who extensively work with wild animals know that whichever wild animal capture method is chosen, it is not a completely safe method. Therefore, the method of chemical or physical capturing will vary depending on the species and the experience of the practitioner. For this, experience is very important and in case of doubt, the advice of experienced people in wild animal catching should be taken into account (Fowler, 1995).

In recent years there has been an increase in applications related to the capture of wild animals in Türkiye. Unfortunately, there is not any qualified staff with wildlife education among handlers. Because, there are few well-trained wildlife professionals in the country, and until 2009 no formal university training in wildlife management. Veterinarians are only legal handlers for capture practices in Türkiye. For restraint, capture and handling practices and other wildlife management applications (released into the environment after produced in the wildlife farms, treatment of injured wild animals, relocated wild animals etc,) millions of Turkish liras are spent and a very intensive effort is being done. However, despite the efforts made for years and the efforts of hundreds of staff, Türkiye is well behind the desired levels in terms of sustainable wildlife resource management and usage, and even in many areas, a backward trend is emerging day by day. Therefore, it is thought that putting forward a scientific, rational and feasible new approach to the proposed study will provide a great contribution to the management of our country's wildlife resources and to the national economy at the long term.

## METHOD

In this study, it was identified a two-stage study phase:

- Participating in the course of 'Wildlife Capture and Immobilization' for 12 weeks organized by Oregon State University (OSU), Department of Fisheries, Wildlife and Conservation Sciences.

- Participating in the field studies related to the study and the courses.

The aim of the course is to emphasize professional and humane animal capture and handling. It provides general background on chemical restraint of wildlife and specific physical capture examples of a limited number of traps and nets. Emphasis is placed on the capture event, darting equipment, animal and human safety, drug pharmacology, dose calculations, and species-specific recommendations.

Upon successful completion of the course, the participants will be able to the following:

- understand ethical issues relating to wildlife capture and handling
- able to convey clear communication regarding professional methods of animal care and handling to the public
- understand basic concepts and safety measure of animal capture and restraint
- learn the most significant animal and human safety concerns
- use methods to minimize stress and mortality with capture and handling
- understand how to prevent and treat capture related medical emergencies
- use and develop basic skills with remote delivery darting equipment
- learn to effectively monitor sedation and anaesthesia
- understand the legal responsibilities of using capture drugs
- become competent in calculating dose calculations based on recommended dosage recommendations
- participate in field studies to develop handling skills

**RESULTS**

The nature of capture depend upon the related law and the species included. Using capture methods can change from various physical types of physical restriction to chemical immobilization. Using physical or chemical capture methods in a research should be based upon an understanding of the behavioural and physical characteristics of the species to be captured, the working conditions, the knowledge, and skill of those persons capturing the animals, the aims of the research, and the choosing accurate materials. Researchers and professionals should choose the technic the least restraint necessary to carry out the capture in a humane and effective manner, with minimal stress to the species.

➢ General Principles of Physical Restraint

Due to many species of mammals being inflicted serious injury to themselves or capturing staff, different methods of capturing will be necessary. The health of the species should be the priority in capturing wild animals both physically and chemically. Many problems may arise for the species captured, including major physiological disturbances, hypothermia, hyperthermia, stress, shock and capture myopathy especially in physical capture techniques. Moreover, capturing some wild animals can alter their behavior and precondition them to predation. No species, domestic or wild, is uncomfortable with being physically in captivity, and often injures themselves and their handlers. Wildlife managers or researchers should not allow inexperienced professionals to capture any animal species until adequately trained to restrain and release the animals properly. Before capturing any wild animal, the presearcher should have a good grasp of the scientific literature and follow the advice of self-experienced people (RISC, 1998). Today, many different materials including dip/throw nets, mist nets, dho gaza nets, cannon/rocket nets, bow nets, helinets, snare and noose poles, drive nets and drift fences, nest traps, box and cage traps, decoy traps and enticement lures are used during the physical capture of wild animals.

- Net guns and traps

It is started to be used various tools such as net guns and traps for physical capturing practices especially in bird species and small mammals with developing capturing technology. Traps and snares traps, snares, and nets are frequently used to facilitate physical capture. When using net guns in wild animal capturing applications, serious injuries can be caused by hard hitting to the animal. Net guns can be applied from close ranges, and nowadays they are often used from helicopters. Nets have the potential to induce a crash if they are deployed into the main or tail rotor (National Transportation Safety Board, 2002). This equipment has specific advantages and disadvantages. For example, an advantage of net guns is the ability to be checked from a distance without disturbing the animal inside. A disadvantage is that the handler should be more near to the animals. When both types of equipment are in use the handler must be close to the target. Otherwise serious injuries to the captured animal may result. When using the net guns to capture large mammalian species, aircraft such as helicopter is used for a faster approach to the animal (Figure 1).

a

b

*Figure 1. a- Using net gun from a helicopter (URL-1) and b- Wildlife capture field trainings on Januray, 2020 (Photos credit by: A. Sarı)*

➢ General Principles of Chemical Restraint

The chemical capture method is to neutralize a conscious animals for a short time with the help of anesthetic drugs and the necessary materials. Although some wildlife research may involve the use of oral or intravenous materials, mostly utilizing chemical immobilization will require the intramuscular administration of drugs. Today, many different materials including stable injection systems, blow pipe systems, CO2 - air injection gun systems, CO2 - air injection rifle systems, dart syringes, injection needles, and biopsy needles are used during the chemical capture of wild animals. In some cases, these can be injected with a hand-held or jab-stick syringe with the animal physically restrained or confined. If drugs are administered by projectiles and a vital organ, a major blood vessel, or a non-target area of the body is penetrated, They can seriously wound or kill the target animal. Therefore, heavily muscled areas must be targeted when darting wild animals (RISC, 1998).

Chemical capture of wild animals is a technique that has been used since ancient times. Tribes living in the past used wild animals for their food needs. They often used arrows covered with various chemicals to immobilize these animals. This method has evolved over time with the help of technology and has taken its current form. (Sontakke et al., 2017). Modern immobilization techniques are more humane methods that greatly reduce the side effects and causes of death of drugs. In addition, the use of anesthetic antagonist/antidotes is preferred to avoid the undesirable and harmful effects of drugs and to quickly recover valuable wildlife species. (Sontakke et al., 2017).

Anesthesia applications are careful procedures that can have serious negative consequences. For this reason, the animal to which chemical capture method is applied should be monitored continuously and appropriate support measures should be offered in an emergency. Therefore, capturing practitioners or researchers should be very careful when choosing the appropriate drug and species-specific drug dosages. Each anesthetic application has its own advantages and disadvantages, and there is no single application suitable for chemical immobilization of all mammalian species in all circumstances. It should be known that safe and effective drug dosages vary according to the age, sex and body condition of each animal species. In addition, each species may have different individual and seasonal responses to chemical treatments. It should also be known that drugs used to capture wild animals by chemical methods have the potential to seriously affect both animals and the humans involved (RISC, 1998).

- Human and Animal safety

Every wildlife capture practice has risks. The important thing is to be prepared for emergencies and to plan and prepare for possible emergencies before capturing (Allen,1989). Both physical and chemical capturing applications of zoo and wild animals are inherently dangerous for both personnel and animals. These risks should be higher for the capture team if there are adverse changes in environmental conditions in case of capture. Therefore, prior to any catching practice, the caprure team should be aware of the risks that may occur to increase both their own and animal safety and should take the necessary measures to minimize any risk of injury. There should be a predetermined treatment and management plan against all possible injury possibilities (Allen,1989). If dart rifles and pistols are used improperly, they have the potential to cause serious injury (Allen,1989; Bush, 1992; Cattet et al., 2005). The use of dart rifles and pistols is a subject that requires serious experience and personnel using these weapons must have appropriate firearms training and apply firearm safety rules.

In some cases, wild animal capture practices are carried out by helicopters at low-level flights. Applications performed while the helicopter is in motion at low altitudes can sometimes coincide with harsh weather conditions. In these situations, there is a risk to helicopters, and injuries and even death may occur during wild animal capture. (Jessup et al., 1988). In most wild animal capture practices, animal loss is caused by human mistakes. For this reason, proper planning should be done before the capture application and the process should be constantly reviewed in mind and also imagine for each step what equipment is required. (Fowler, 1995). The use of many chemical capturing drugs in high doses has side effects that can lead to death, and if the dose is not adjusted properly, it may rarely cause the death of the captured animals (Fowler, 1995; Kreeger and Arnemo, 2012). The capture team should not forget that the choice of drug and drug doses to be administered,  and animal responses may differ between the species to be caught. Sometimes, wrong drug selection or overdoses can cause the death of the species to be captured. For this reason, the capture team should know the ecology of the species to be caught very well and be prepared for instant situation changes (Fowler, 1995; Kreeger and Arnemo, 2012).

- Capture and Physical Restraint of Zoo and Wild Animals

Whether it is the animal species in the zoo or the wild animal species, one of the important aspects is the physical conditions in which the animals are temporarily restrained before applying chemical capture. There are still some questions that researchers cannot fully answer. How can one get close enough to be able to capturer the appropriate drug combination effectively and safely? Is it better to capture a group of animals or isolate individuals before immobilizing? Is physical or chemical immobilization more suitable? (West et al., 2007).

In physical capture applications, cages are the most commonly used capture material designed for the target species of wild animal. However, there are some disadvantages in the use of these box traps. The most important of these is that the animals captured in the trap cannot be intervened in a timely manner. Wild animals that are not intervened in time are exposed to extreme stress in the box trap. They can cause serious physical damage to themselves depending on the material of the cage. Another disadvantage is that animals may be more exposed to adverse climatic conditions (eg snow, wind and rain) when captured. Capturing more than one species in a cages or capturing a larger species than the target species can also increase the number of injuries and deaths. (Fowler, 1995; Fowler and Miller, 2003; West et al., 2007; Kreeger and Arnemo, 2012). Another physical capture equipment is nets. Nets are typically strung between posts or trees in an area where animals can be streamed into a narrow opening or other suitable area. Once the animals are captured in the net, it is very important to have enough people to physically contain them. Usually one or two persons per animal are required, depending on the size of the animals captured(Fowler, 1995; Fowler and Miller, 2003; West et al., 2007; Kreeger and Arnemo, 2012).

There is no single ideal capture technique successfully used on a particular species. It depends on many factors such as ecological, age, sex, biological, topography, season, climate. Different techniques should be used for each wild animal for capturing (Table 1).

| Technique | Cost[a] | Capture Efficiency[b] | Portability[c] | Potential for Injury[d] | Selectivity[e] | Species |
|---|---|---|---|---|---|---|
| Corral (boma) traps | Low | High | Low to moderate | Variable | Low | Ungulates, bovids, goats and sheep |
| Drive nets | Moderate to High | High | Low | Moderate | Low | Ungulates, bovids, goats and sheep |
| Helicopter net gun | High | High | High | Moderate | High | Ungulates, bovids, goats and sheep, ursids, canids |
| Drop/rocket net | Low | Moderate | Moderate | Moderate | Moderate | Ungulates, goats and sheep, birds |
| Foot hold traps | Low | Low | High | Low to moderate | Low | Canids, felids, mustelids |
| Foot snare | Low | Low | High | Low | Low | Birds, canids, felids, ursids, mustelids |
| Box traps | Low | Low | Low | Low | Low | Birds, most mammals |
| Cage traps | Low | Low | Low | Low | Low | Birds, most mammals |
| Mist nets | Low | High | High | Low | Low | Birds, bats |

[a]Cost per animal captured on a relative basis.
[b]Number of animals that can be quickly captured in a short period of time.
[c]Ease of changing to different capture locations quickly and efficiently.
[d]Potential for injury to the captured animal.
[e]Ability to avoid capture of non-target species or individuals.

*Table 1. Comparison of capture techniques for some wild animal species (West et al., 2007).*

Trained dogs can be used to track traces of some felid species (Apps, 1996, 1999; Taylor et al., 1998; Deem, 2004). Most cat species prefer trees to hide. It is common for animals to fall from trees, especially during chemical capture (Fowler, 1995; Beier et al., 2003; West et al., 2007).

- Immobilization Equipment

Various remote injection equipment has been used for hundreds of years to capture animals. Arrows, spears, and poisoned darts were used to benefit from animals for different aims at the earliest times. Modified bows and blowpipes constructed out of wood or cane were used to project these weapons (Wenker, 2006). These primitive instruments are the basis for modern techniques that allow to immobilize, vaccinate, or administer drugs to animals (Chancey, 2006).

Various immobilisation and tranquiliser drugs are used during chemical capture of wild animals in order to be able to handle them. These drugs are usually administered in darts using a dart gun. Chemical immobilisation is predominantly used to capture individual animals in a herd or to capture large or dangerous animals. It is also a very effective capture method when working with aggressive species. This method of capture also allows for the individual capture of young animals without having to catch an entire family group. Moreover, darting is very effective when wanting to examine and treat sick animals, for removing aggressive animals from a herd, or for the collection of samples e.g. blood from certain individuals.

Different sizes of darts are available, depending on the volume of drug that is required for a specific animal species. Various needle lengths are also available, depending on the thickness of the animal's skin. Furthermore, two variants of needles can be selected from depending on the reason for darting. A needle with a wire barb is generally used when the animal must be immobilised. The dart needs to be removed by the veterinarian and will not fall out by itself. A needle with a wire dot is used in situations such as treating animals with antibiotics or vaccination of animals i.e. when the animal is not immobilised but darted with a dart containing a vaccine. The dart is thus able to fall out on its own. There are two types of darting systems. The one system has reusable darts, which requires manual pressurisation. The other system has non-reusable darts that function with a reloaded charge. The photos obtained from the field trainings are below (Figure 2).


*Figure 2. Wildlife capture field trainings on Januray, 2020 (Photos credit by: A. Sarı)*

Chemical injection equipment for handling practices are:

- Blowpipes (Lung-powered pipes and Compressed atmospheric air or gas powered pipes)
- Non-lung-powered blowpipes
- Dart Guns
- Darting pistols
- Darts
- Syringes and Tailpieces
- Dart needles
- Pole Syringe
- Drugs

➢ Species Dosages

There are many factors that affect the drugs used for anesthesia and their dosages. Factors affecting anaesthesia responses are age, size and body weight, sex, species, choice of drug, physical condition, pregnancy and season. Many different drugs are used in chemical capture applications of wild animals together with the developing drug technology today (Sontakke et al., 2017). However, an ideal drug should have the following properties: readily soluble and economical, readily soluble in water, stable in long-lasting solution, high therapeutic index, potent (required dose is given in small volume) and suitable for most species, fast-acting smooth induction onset, minimal excitement, Intravenous or intramuscular administration, non-irritating, short induction time, good muscle relaxation, minimal depression in physiological variables (heart rates and respiration), adequate analgesia at subanesthetic or lower doses, retention reflexes such as swallowing, effective antidote with minimal side effects, inactive, rapid degradation to non-toxic metabolites, can be used safely in pregnant animals.

How to calculate an ideal drug dose?

Drug doses are vital in chemical capture of wild animals. The morphological structure of each species varies for these calculations. An average drug dose calculation is as follows (Figure 3).

$$\textbf{Volume of drug} = \frac{\textbf{Body weight x Dose}}{\textbf{Concentration of Drug}}$$

For example, if a leopard weighs 100 Kg and the recommended dose of Drug 'Ketamine for this animal is 3 mg/kg. Ketamine is available in a 100 mg/ml solution. So, first calculate the total mg of ketamine required for leopard.

**mg of Ketamine needed = 100 kg x 3 mg/kg = 300 mg**

Then calculate the total volume of Ketamine solution

$$\textbf{ml of Ketamine needed} = \frac{\textbf{300 mg}}{\textbf{100 mg/ml}} = \textbf{3 ml of Ketamine solution}$$

*Figure 3. Calculating of the drug doses (Sontakke et al., 2017).*

Detailed trials related to calculations were carried out on the Wildlife capture field training, (Figure 4).

*Figure 4. Wildlife capture field trainings on Januray, 2020 (Photos credit by: A. Sarı)*

- Euthanasia

The term euthanasia is derived from the Greek terms eu meaning good and thanatos meaning death. A "good death" would be one that occurs with minimal pain and distress (AVMA, 2007). It is our responsibility as veterinarians and human beings to ensure that if an animal's life is to be taken, it is done with the highest degree of respect, and with an emphasis on making the death as painless and distress free as possible. Euthanasia techniques should result in rapid loss of consciousness followed by cardiac or respiratory arrest and the ultimate loss of brain function. In addition, the technique should minimize distress and anxiety experienced by the animal prior to loss of consciousness (AVMA, 2007).

In evaluating methods of euthanasia, the panel used the following criteria: (1) ability to induce loss of consciousness and death without causing pain, distress, anxiety, or apprehension; (2) time required to induce loss of consciousness; (3) reliability; (4) safety of personnel; (5) irreversibility; (6) compatibility with requirement and purpose; (7) emotional effect on observers or operators; (8) compatibility with subsequent evaluation, examination, or use of tissue; (9) drug availability and human abuse potential; (10) compatibility with species, age, and health status; (11) ability to maintain equipment in proper working order; and (12) safety for predators/scavengers should the carcass be consumed (AVMA, 2007).

- Emergencies

We have to be careful when the chemical immobilization applications.

- General view of the animal

- Abnormalities in your movements

- Movements at all feet

- Props and color changes that will occur on the skin

- Are there any bleeding in the head or mouth

- Are there lesions, color changes, or enlargement in the mouth, lips, or beak

- Are there any discolorations or fractures in the teeth or beak

- The color of the gums and the normality of salivation

**Respiratory Depression or Eclipse**

It develops as a result of insufficient intake of oxygen to the body and results in tissue damage. When we see the Respiratory Depression; First of all, stop the introduction of more anesthetic drugs into the body. To reduce the pressure on the respiratory organs (extending to the right side of the animal in general). Starting cardiac massage. To massage 15-20 times per minute in the types up to 200 kg in cardiac massage, to support the massage by pushing the front legs back and forth to the types of overweight. Inhaling from mouth to mouth or mouth to nose 1-2 mg / kg Doxapram etc. (Respiratory stimulant) or appropriate prodrug.

**Hyperthermia**

Excessive temperature rise in some parts of the body. When we see hyperthermia; First of all, stop the introduction of more anesthetic drugs into the body. Cooling the animal (shading, wetting, etc.)1-2 mg / kg Doxapram etc. Applying (respiratory stimulant) or appropriate countermeasure.

**Hypothermia**

Damage to cells and tissues as a result of a sudden drop in body temperature. When we see hyperthermia; Hypothermia interfere with the only requirement is to increase the animal's body temperature emergency.

**Swelling and swelling in the body**

Abnormal swelling, especially as a result of excessive accumulation of gases in the body, in double-clawed. When we see swelling; First of all, bringing the body to the correct position (turning the animal to its right side, raising the head with the esophagus in the air). Massaging the abdomen slightly, especially on the stomach and upper part. Applying the appropriate countermeasure.

**Vomiting and inability to breathe**

Vomiting and associated respiratory distress during medication, especially in newly fed animals. When we see vomiting; First of all, discontinue all medications. Eliminate obstruction in the trachea (if the animal is light, lift it up from its hind legs, if it is heavy, start from the stomach and continue through the trachea and do a fast massage to the exit canal). If necessary, do cardiac massage. Applying the appropriate countermeasure.

**Seizure or short-term paralysis**

Muscles that are allergic to the drug used temporary or permanent discomfort. When we see seizure; First of all, discontinue all medications. To ensure that the body temperature does not exceed 40 degrees. Applying the appropriate countermeasure.

**Cardiac arrest**

Sudden cardiac arrests parallel to overdose drug using. When we see cardiac arrest; First of all, discontinue all drugs. Eliminate obstruction in the trachea (if the animal is light, lift it up from its hind legs, if it is heavy, start from the stomach and continue from the trachea and do a fast massage to the exit canal). Doing a cardiac massage.

Applying the appropriate countermeasure.

## CONCLUSION AND COMMENTS

Thousands of wild animals are captured every year all over the world for the control of damage and disease caused by wild animals, supplying individuals to the hunting areas, population regulation activities, management and development studies, and scientific research. Capture and transfer operations for wild animals are often performed in Türkiye for contributing to the protection of wildlife and habitats, controling wild animal damage and disease, treatment of injured wild animals, relocating endangered or extinction threatened species, resettlement, stock raising, restorating deteriorated food chain and supplying breeding individual to wildlife farming. Every year, thousands of wild animals are bred, released and relocated into the nature in order to contribute to the protection of wild animals and their habitats, to reintroduce endangered or threatened species, and to increase stocks in hunting areas in Türkiye. For the wild animals that are treated and placed in the nature from the production facilities, millions of liras are spent and a very intensive effort is being made. However, despite the efforts made for years and the efforts of hundreds of staff, Türkiye is well behind the desired levels in terms of sustainable wildlife resource management and usage, and even in many areas, a backward trend is emerging day by day. Therefore, it is thought that putting forward a scientific, rational and feasible new method approach will provide a great contribution to the management of Türkiye's wildlife resources and to the national economy in the long term. The main reasons for the deficiencies observed in sustainability practices of wildlife resources in Türkiye are the lack of training wildlife and qualified personnel trained in these matters. Therefore, the fact that the subjects with the research proposal, seen in the areas where the correct practices are realized, will contribute to the career development of Türkiye's scientists who are continuing their career development in this field. In addition, the release of wild animals into nature is an application that requires experience and should be supported scientifically. Currently, many of the potential effects of such releasings around the world have not been adequately studied and understood. However, such releasings are known to have potential adverse effects. Some of these negative effects are; increasing numbers of predators, the transmission of diseases from breeding facilities and bred species to nature, deteriorating and changing habitat structure, decreasing invertebrate abundance, and perhaps most importantly, genetic pollution that will arise with the deterioration of gene resources. For this reason, native populations with pure genetic structure in nature should be determined first. The reasons for the decrease in the native population should be determined and protection measures should be taken. Scientific support should be obtained from the selection of breeding individuals to the production and release stages, and care should be taken not to release the produced species to areas where natural populations are concentrated.

Wild animals experience intense stress during and after capture. For this reason, all measures should be taken against this stress that will occur for a successful capture application. For this, the capture process should be planned in detail in advance, everyone involved in the capture should be informed about their duty, unnecessary crowds should not be created, and unless necessary, the capture process should be done outside the breeding, pregnancy and raising periods. Since the temperature of the animals may increase during capturing, capturing should be carried out in cold months, according to the species. Extreme heat and cold should be avoided. On hot days, capturing should start early in the morning and should not be left in the heat of the day. Animals should never be chased long distances or for long periods of time. They should be disturbed as little as possible. If animals are to be held in temporary captivity after capture, precautions should be taken to avoid harming themselves in the confined spaces. Aggressive animals and mature males should be separated from each other to avoid conflict and injury. Precautions should be taken against adverse environmental conditions. The animals should be protected from sun, cold and rain directly.

The biggest challenge in not only capturing animals but also the other wildlife management practices is the lack of well-trained wildlife professionals in Türkiye. The ecological knowledge, densities and population status for most species are very limited. Because there are few well-trained wildlife professionals in the country, and until 2009 no formal university training in wildlife management. The state agency responsible for wildlife and natural resources management in Türkiye is the General Directorate of Nature Conservation and National Parks (GDNCNP). In terms of main technical staff sources of GDNCNP, forest engineers have the highest numbers followed by biologists, forest industry engineers, veterinarians, agricultural engineers, fisheries technology engineers, geologists, and architects respectively. Although the history of education about game hunting and wildlife conservation dates back 200 years in Europe and America, the first university department in Türkiye with the term "wildlife" in its name was established in 2009 at Karadeniz Technical University. As the first step of solving the wildlife management problem, it is a good way to start working with qualified staff with wildlife education for sustainable use of natural resources. A change in the structure of the institution (GDNCNP) is essential to overcome existing challenges in natural resources management as soon as possible.

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# Chapter 8

## TOLERANCE CHARACTERISTICS OF TURFGRASSES

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## INTRODUCTION

Turfgrass plants in *Poaceae* family have more than 9000 species, including C3 and C4 plants (USDA, NRCS, 2010). With the shoots and leaves that make up its body, it has the ability to trap and clean the dust in the air, while at the same time providing refreshment with its cooling effect. It prevents erosion with its wide network of primary and secondary root systems. It acts as a filter for potential groundwater pollutants. It serves as a playground for children and as a base for professional sports facilities (Emmons, 2008; Wherley et al., 2011; Prokopiuk et al., 2019; Barnes et al., 2018).

When examined in detail, it prevents injuries that negatively affect the health of sport players by providing shock absorption, unlike weak and bare soil or synthetic surfaces in sports facilities (Curk et al., 2017; Gamage et al., 2017).

While it has a beautifying effect in green field landscapes, it provides an attractive and aesthetic appearance. It helps large park areas and hobby gardens look tidy and elegant. With its positive contributions to mental health, it affects the happiness of living things and increases the motivation of life. It plays an important role in providing order and stabilization at city terminals, highways and slopes (Raven et al., 2001). As mentioned, in addition to providing a cushioning effect in sports facilities, the intervention of the field to the game is reduced to a minimum with the grass facilities that are resistant to the form close to the base (Uddin and Juraimi, 2013). It is the most used visual element in all city centers and surrounding residential areas, especially in home gardens and commercial areas (Fan et al., 2020).

Turfgrass lawns are areas with a homogeneous appearance in relatively flat areas where short-lived perennial species are generally preferred, created by natural or artificial ways. They often form a rather unique ecosystem for a specific purpose and with specific production methods. A perfect image can be achieved if properly managed and properly maintained. In addition to having many different types according to their functions and ecologies, they can also be classified according to their characteristics and physiology (Jiuxin and Liebau, 2022).

They are very popular with their carpet-like appearance and form close to the bottom, and they can have a drainage effect against flooding and the absorption of excessive rain. In regions with hot climate, they can reduce the urban cooling energy consumption by lowering the city temperature a little bit. However, a healthy and homogeneous turfgrass field also has a very difficult process. Many of the grass species preferred to achieve a perfect appearance are susceptible to extreme weather conditions, diseases, pests and environmental conditions. These sensitive conditions can lead to various negativities and finally death in the lawn (Jiuxin and Liebau, 2022).

The irreversibility of global climate change brings about serious reductions in freshwater resources. At the same time, the increasing world population and the corresponding increase in water demand limit the use of water in crop production. The water and drought stress caused by this cause serious stress for both cool climate and warm climate grass species. In addition to temperature and drought, new stress factors such as soil salinity, increase in pests and the use of wastewater as a source of irrigation may emerge. While grass fields are an important source of recreation in many world capitals, increasing drought may cause these fields to become increasingly idle and perhaps decrease national happiness indexes. These stress conditions can occur alone, or it is possible for many factors to come together. This situation can cause irreversible damage. (Huang et al., 2014; Figure 1.).

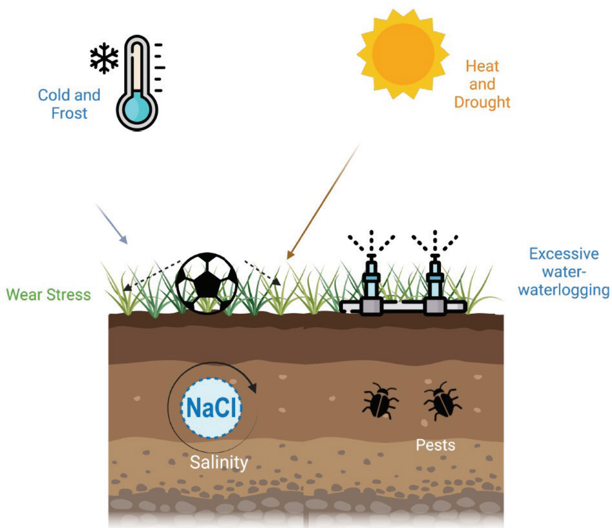


*Figure 1. Some stress factors that can cause a decrease in the quality of turfgrass lawns*

## TOLERANCE CHARACTERISTICS OF THE MAJOR TURFGRASS SPECIES

Although many species of turfgrass are preferred in lawns, it is preferred more in certain mixtures in areas such as pitches, large parks and gardens, golf facilities. Although these species are divided into two as cool and warm climate types, the tolerance characteristics of these species affect the purpose of use and the ecological condition used. Some tolerance characteristics of these species are shown in Figure 2-10. (derived from Aldous and Chivers, 2002; Açıkgöz, 1994).

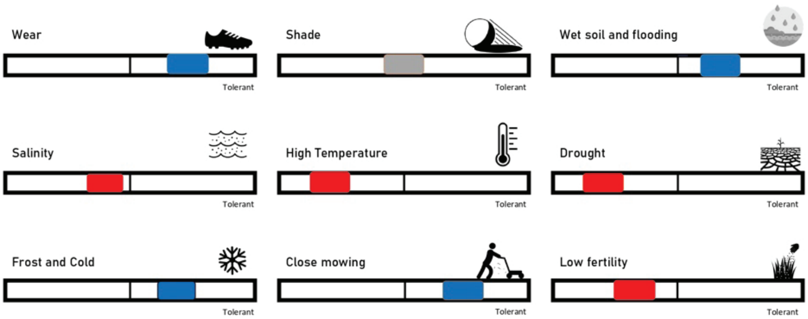


*Figure 2. Perennial ryegrass (Lolium perenne) tolerance features*

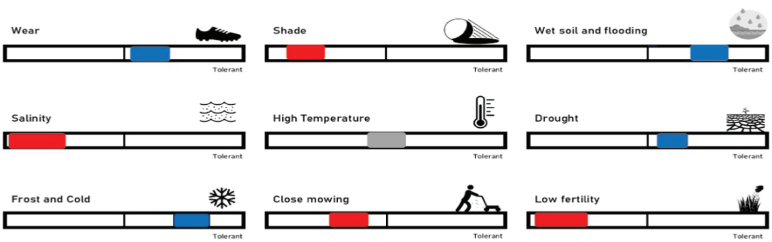


*Figure 3. Kentucky bluegrass (Poa pratensis) tolerance features*

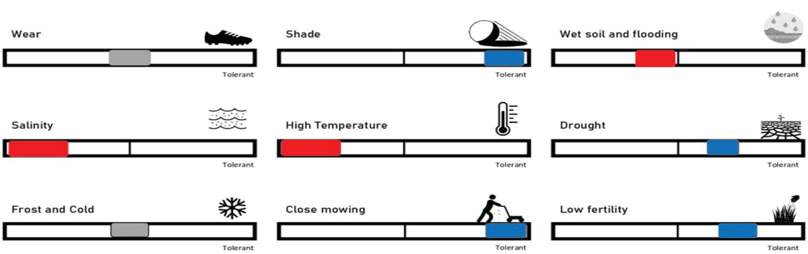


*Figure 4. Creping Red fescue (Festuca rubra rubra) tolerance features*

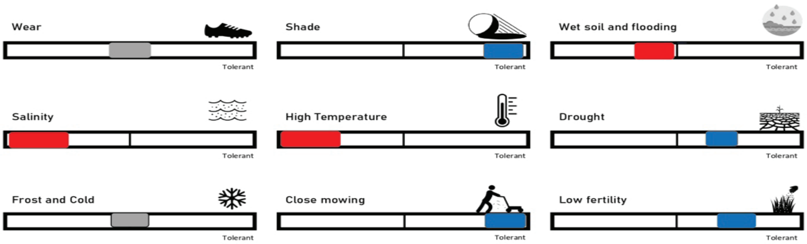


*Figure 5. Chewing's fescue (Festuca rubra commutata) tolerance features*

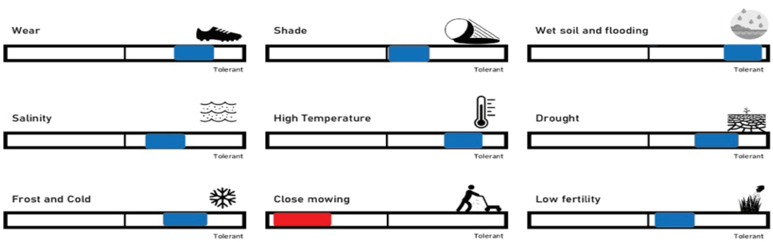


*Figure 6. Tall fescue (Festuca arundinacea) tolerance features*

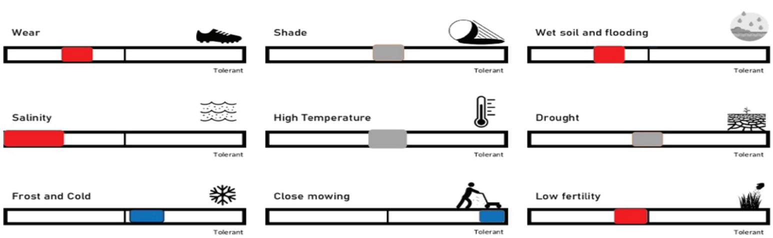


*Figure 7. Colonial bentgrass (Agrostis capillaris) tolerance features*

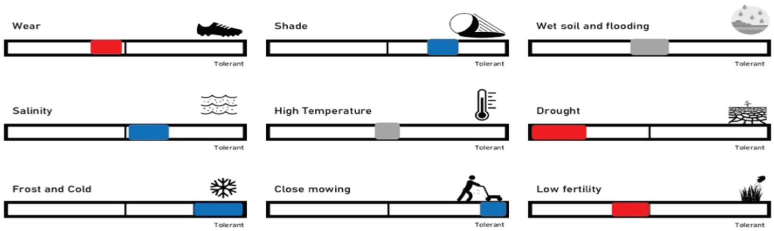


*Figure 8. Creeping bentgrass(Agrostis stolonifera) tolerance features*

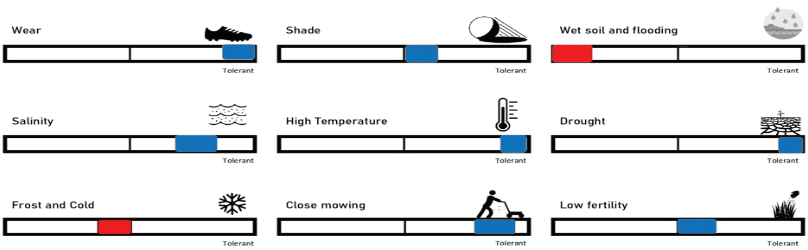


*Figure 9. Zoysiagrass (Zoysia japonica) tolerance features*

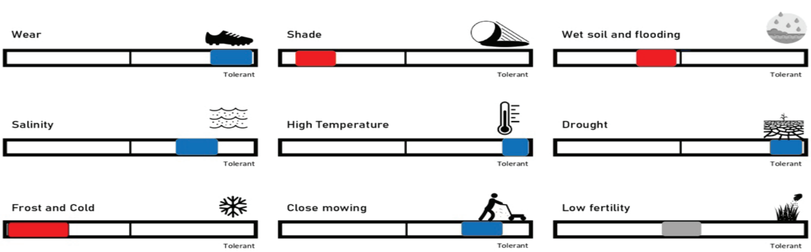


*Figure 10. Bermuda grass (Cynodon dactylon) tolerance features*

## SHADE TOLERANCE

One of the most important challenges preventing growth and development in lawns is exposure to shade stress (Esmailpourmoghadan and Salehi, 2021; Bell and Danneberger, 1999). Exposure to shade on quality turf fields (i.e. football pitches) creates quite a challenge in maintenance.

Grass species that form the bottom of the trees, which have a lot of place in the design in most landscape areas, are therefore exposed to this stress all over the world (Bell et al., 2000). It is estimated that approximately 25% of artificial turf areas in the world are shaded for these and similar reasons. (Giesler et al., 2000).

Shade-tolerant traits are genetically dependent on the species, its cultivars, and green space management. (Richardson et al., 2019). Shade environments can have even more negative effects with some factors such as reduced air circulation and competition in the root zone. This is a situation that can prevent or limit the growth of the grass (Bell and Danneberger, 1999).

The dry weight of plants grown in full sunlight is higher than those grown in shade. As the amount of light and lux decreases, the starch content in the shoot and root region may decrease (Wilkinson et al., 1975). At the same time, a decrease in the amount of new shoots can be seen in turf plants grown in shaded areas (Van Huylenbroeck and Van Bockstaele, 2001). Stomatal closure response occurs due to intense starch consumption in plants grown under limited photosynthesis and constant drought and shade stress (Asghar et al., 2020).

In terms of shade tolerance, very different resistances can be seen among grass species and varieties. The general opinion is that cool-season grass plants are more resilient than warm-season grass species. There are large differences in shade tolerance levels between grass species and varieties (Van Huylenbroeck and Van Bockstaele 2001; He and Li, 2021; Awada et al., 2003; Kubásek et al., 2013). For example, the commonly used fescues (*Festuca* sp.) are known to be relatively shade-tolerant (He and Li, 2021).

Plants have different mechanisms to adapt to shade conditions. Lower light compensation point (Van Huylenbroeck et al. 1999), higher leaf area index (LAI) (Cayssials and Rodríguez 2013) and finer leaf blades are produced. Other mechanisms include increased chloropyhll content, decreased stomatal conductance, and dark respiratory rate (He and Li, 2021).

Reducing the intensity of photosynthetically active radiation (PAR) through shading reduces the growth rate. It is also recognized that shading is associated with increased severity of turf diseases. Many leaf diseases caused by pathogens such as rust (*Puccinia* spp.), powdery mildew (*Erysiphe graminis* DC.) and leaf spot fungi (*Bipolaris* and *Drechslera* spp.) are more severe in densely shaded lawns than in sunlight areas (Giesler et al., 2000) .

Despite adequate levels of photosynthetic production, 'shade avoidance' mechanisms can occur in turf located in shade areas, diverting resources to be used for more agriculturally productive activities such as root and leaf growth (Ballaré et al., 1997).

## WEAR STRESS

Wear due to use in heavily used grass areas is a very important stress factor. A lot of time is required for eroded grass areas to naturally regain their former form. At the same time, a homogeneous image may not be formed, since it will not be possible for each species to return to its former form in the same time.

One of the main criteria in turfgrass cultivation is the resistance of the leaf blade, stem, root crown and roots, which are the morphological parts of the plant, to abrasion stress due to heavy use. In general, it can be said that grass species with high lignin and lignocellulose content are more tolerant to wear and pressing (Wei et al., 2022).

Proline and osmoregulatory substances can also be used as reservoirs for energy and ammonia sources under traffic and wear stress, as they directly participate in plant metabolism after stress is removed (Moreno-Galvan et al., 2020).

Wear stress damages the leaf, stem and root crown by compression. This leads to losses in the water content of the leaves (Samaranayake et al., 2008). In addition, the loss of relative moisture content likely causes increased evaporation rate and decreased water absorption corresponding to soil compaction (Wei et al., 2022). Decreasing canopy coverage in grass areas due to wear stress occur due to intense damage in the shoot tissue of the plant. At the same time, continued use in this area increases soil compaction and prevents grass regrowth (Trappe et al., 2011).

## HEAT AND COLD STRESS

High-temperature stress is one of the main abiotic stress conditions that can negatively affect plant growth and development in grass species (Xu et al., 2005; Larkindale and Huang, 2004; Liu and Huang, 2000). Plants have developed different physiological fighting mechanisms against high temperature stress as in other stress conditions. The most basic of these is that they send different signal warnings for heat acclimation against non-fatal high temperatures (Fan et al., 2020).

The ability of plants to maintain growth and survive periods of drought stress is generally defined as drought resistance. Drought resistance can be achieved through three main strategies. These; are escape, avoidance, and tolerance (Huang et al., 2014).

High evapotranspiration rate and water loss in plant tissues and organs are the destructive effects of high temperature stress on the plant (Hall, 2000). High temperature stress can bring along drought, which causes visual problems in cool season grass species (Su et al., 2007). In warm season species, this situation is completely different. The opposite of dormant periods reveals that these plants have low tolerance to cold stress in cold seasons (Propiuk et al., 2019). Cool season species are more resistant to cold conditions.

The perennial species used in turf fields has shown that these species can survive in a dormant state under stress conditions such as drought and high temperature. Dormancy; It is the period of brown color due to the fact that the plant minimizes some of its physiological activities in response to drought and some extreme conditions. Under these conditions, it is vegetatively stolons and alive. Species with rhizomes can generally survive from 1 week to 1 month in anhydrous conditions. After seeing the moisture for the first time, it heals quickly and tries to overcome this situation with the least damage.

When *Poa pratensis*, a rhizome species, absorbs moisture from the soil, it can form new roots and shoots and increase its durability in long-term dry conditions (Fry and Huang, 2004). Subsequently, they can develop many features such as low leaf area index and leaf feathering. At the same time, differences in stomatal activity and the number of stomata can be observed. Among these species, *Festuca arundinacea*, *Cynodon* sp. and *Zoysia* sp. exhibit drought avoidance properties (Huang et al., 2014). Damages in root growth are highly related to the duration of stress and temperature. This is particularly important than the decline in turf quality.

Deep rooting has been thought of as a drought avoidance property and allows water to be explored from deep within the soil profile to delay tissue drying (Huang et al., 2014). In addition, the way out of drought with the least damage is water use regulation. Grass species that reduce the amount of water use may survive more.

Plants with slow growth mechanisms can withstand the dry period for a longer period of time, as the need for water is determined to be less. They show minimal water use in their physiological activities. The relative contribution of stomatal and metabolic limitations to drought-induced decline in photosynthesis varies with plant species or cultivars that differ in drought tolerance and drought duration and severity. Drought-tolerant *Poa pratensis* sustained higher photosynthesis under prolonged drought stress, mainly associated with greater Rubisco activation state and higher carboxylation efficiency (Hu et al., 2010).

Plants can recover from heat stress through heat avoidance or heat tolerance mechanisms. Heat avoidance is the ability of plants to keep their internal temperatures below lethal stress levels, including transpiration cooling, changes in leaf orientation, the reflection of solar radiation, and extensive rooting as well as sunburn-sensitive tissues. Better summer stress performance of cool-season grasses such as *Poa pratensis* has been reported to correlate with sustained transpiration cooling and root elongation (Lehman and Engelke, 1993; Bonos and Murphy, 1999).

High temperature affects carbohydrate metabolism, including the use of carbon in respiration for energy production to support growth, maintenance processes and metabolic activities, and carbon production through photosynthesis. In response to increasing temperatures, overall photosynthesis rates decrease while respiration rates increase in various cold-season grass species (Huang and Gao, 2000; Liu and Huang, 2001). It suggests that adequate irrigation during hot summers may help the lawn better recover from heat stress by maintaining proper leaf water availability and photosynthesis (Jiang and Huarg, 2001).

Root growth reduction in cold-season grass species under heat stress has also been associated with reduced carbohydrate availability due to increases in respiration rate and reduced carbon allocation from shoots to roots (Xu and Huang 2000a, b). During periods of drought, leaves may die and fall from the plant, but lawns generally recover with adequate irrigation (Kanapeckas et al., 2008).

Effective drought recovery may prove to be more important than plant growth during the dry season because it allows a species to survive on lawns and develop competition with less drought-tolerant species (Kanapeckas et al., 2008).Under heat stress, oxidative stress can often be induced to generate reactive oxygen species (ROS) (Xu et al., 2005; Sun et al., 2002; Kocsy et al., 2004).

Cultivation of cool-season species in summer can be handled by high temperatures and drought. At the same time, it is known that high temperatures with drought stress can cause some very harmful changes in plant physiology. (Jiang ve Huang, 2001).

In terms of adaptation to drought stress, *Festuca arundinacea* outperformed *Lolium perenne* and *Poa pratensis* by keeping high evaporation and leaf water level in balance. Also *Poa pratensis* is better in tolerance than *Lolium perenne* (Turgeon, 1999). Although *Lolium perenne* can grow in a wide range of soil types, it is poor in tolerance to drought, extreme heat and cold (Friell and Watkins, 2021).

In one study that sticks in terms of drought adaptability, researchers found that the tall fescue performed quite well (Jiang and Huang, 2001). In

Bermuda grass, low somatal conductivity was detected in genotypes with superior drought tolerance (Zhou et al., 2013).

Various studies have been carried out in recent years to improve the heat tolerance of lawns. NO application can significantly reduce heat damage in the photosystem of tall fescues. Recently, the application of melatonin has shown a remarkable effect on stress, including the heat response of the plant (Fan et al., 2020).

Cold stress is an important factor limiting the distribution, growth and productivity of warm season grass species. Tropical and subtropical grasses are most susceptible to temperatures below 12°C, while cool-season grass species can suffer freeze damage in northern climates. Low temperature damage is generally categorized by whether it occurs as a result of temperatures above 0°C or below 0°C. At the physiological level, chill stress manifests primarily as losses in membrane function, inhibition of photosynthesis, as well as oxidative stress caused by metabolic imbalances (Suzuki and Mittler, 2006; Reulland et al., 2009). At temperatures below freezing, plants also undergo the formation of ice crystals inside the cell and between the cell walls, which can cause dehydration, mechanical damage and protein denaturation among various metabolic damages (Huang et al., 2014)

In cool-season grass species, minimum temperatures for net photosynthesis can be as low as -4°C, depending on factors such as light levels and exposure to freezing conditions (Höglind et al., 2011). However, many studies have been conducted to improve frost tolerance on Lolium perenne, which is among the most important species with economic importance (Hulke et al., 2008; Zhang et al., 2009; Hoffman et al., 2010; Hulke et al., 2012). In a study conducted for this purpose, photosynthesis losses of up to 85% could be observed in *Lolium perenne* when transferred from 22/17°C (day/night temperatures) to 8/5°C during the day (Moon et al., 1990).

## SALINITY STRESS

Salinity is an important environmental stress factor that adversely affects plant growth and development in many regions of the world close to the coast or with high groundwater. In addition to causing toxicities due to ionic imbalance, it can affect soil permeability and healthy root growth (Ashraf, 2008). Tolerance to salinity in plants can be coupled with a low uptake of Na ions that are returned to the cytoplasmic membranes and growth medium (Jacoby, 1999). Today, the demand for salt-resistant grass varieties is increasing due to the increasing salinity and alkalinization of soils. Among the reasons for this is the fact that the water preferred for lawn irrigation is preferred from low-quality wastewater and some treated sea waters. While these water sources increase the salinity in the soil, the preference of salt accumulator or salinity-resistant grass species can be important both in terms of soil improvement and visually (Uddin and Juraimi, 2013).

Plant growth in soil acidity varying between 4-8 pH, its ability to develop in compacted soils and to grow in alkaline soils has enabled *Festuca arundinacea* to be evaluated as a turfgrass in urban roads and idle areas (Friell and Watkins, 2021). *Festuca arundinacea* is known to be resistant to salinity. While it can grow in many ecological conditions in the world, it can be found especially in salt marshes in United Kingdom. This situation reveals that these regions are an important species in soil improvement (Gibson & Newman, 2001).

When the tolerance to salinity in grass species was examined, it was observed that ion accumulation was limited in new shoots (Wu and Liu, 1994). Many different criteria are used to determine tolerance to salinity in turf lawns, such as shoot and root weight, decrease in shoot weight compared to salt-free control, a number of surviving plants and seed germination percentage (Marcum, 1999). One of the salt-tolerant species is *Paspalum vaginatum*. This type is a type in which seawater or treated wastewater can be used. Although the healthy growth in this species is up to 15 dS $m^{-1}$, it has been observed that it tolerates salt up to 25 dS $m^{-1}$. This species, which gives a very good result even in irrigation where diluted seawater is used, can be used in many coastal areas with its halophytic feature in the near future. In addition, *Cynodon dactylon*, which is one of the hot climate species, is one of the species that can withstand salt water (Uddin and Juraimi, 2013). Another tolerant species is *Zoysia* sp. This species, whose varieties have been developed recently, has long been tested for its resistance to salinity. It has been found to have as good a quality as *Paspalum* species in coastal areas (Engelke, 2002).

Grass species that are resistant to salinity have the feature of minimizing the harmful effects of salinity with many morphological and physiological modifications. However, salinity causes lower osmotic potential, losses in turgor potential, ion toxicity and nutritional deficiencies (Alshammary et al., 2004). Salinity suppresses growth on plants, loss of turgor pressure, and low osmotic potential and nutrient deficiencies (Alshammary et al., 2004). The water that cannot be taken through the roots and accordingly the plant nutrients also negatively affects photosynthesis. This can lead to the death of plants under stress conditions. At the same time, the potential tolerance of each species also differs depending on the species (Huang et al., 2014). The effects of salinity on grass species were explained by Uddin and Juraimi (2013) as follows;

-Low water intake due to osmotic pressure stress

-Low nutrient intake with reduced water intake and inhibition of the absorption of some nutrients by Na+

-The slowdown that can be seen in photosynthesis and the decreasing of plant growth rate

Despite these effects, the use of some signaling molecules such as $Ca^{2+}$ ion and Nitric oxide in order to increase plant tolerance has been evaluated and positive effects have been observed in many grass species including *Festuca arundinacea*, *Cynodon dactylon* and *Festuca ovina* (Fan et al., 2020). However, if this stress is not tolerated, the plant tries to cope with salt stress with water loss from leaves and roots (Huang et al., 2014).

In their review, the researchers describe what is called the biphasic growth response. The first phase, called the osmotic phase, occurs when salt levels outside the plant's roots increase, causing an increase in osmotic pressure followed by a decrease in plant growth. The second phase, called the ion-specific phase, can be defined as further reduction in growth and disruption of cellular processes that cause aging of plant tissues. In the case of Na+, tolerant plants can respond through three different mechanisms, including osmotic adjustment, exclusion of Na+ from the leaf blade, or isolation of Na+ ions at the cellular level to avoid toxic cytoplasmic concentrations. (Friell and Watkins, 2021).

## CONCLUSION

Turfgrass fields appear in all areas of life. Since it is a plant that is easy to plant but difficult to maintain, variety and species selection should be made by considering the genotype-environment interaction. Among the environmental factors, features such as salinity, temperature, shade and abrasion affect the quality of the turf. For this purpose, in this study, species characteristics according to tolerance characteristics and the factors affecting the formation of some characteristics were examined. Every right type and mixture to be selected will reduce the expense cost and provide sustainable lawn facility management.

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# Chapter 9

## HYDROPONIC FODDER PRODUCTION FOR LIVESTOCK FARMING

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## Introduction

According to World Bank data, Turkey, whose population growth rate is above the world average, is a country whose nutritional needs increase yearly due to increasing population and especially global warming. This situation causes our country to face the problem of adequate and balanced nutrition. Our country's primary food source is carbohydrates, and our per capita consumption of meat, milk, etc., animal-derived protein is at a level that cannot be compared with contemporary countries. Although at least 33 grams of the daily protein requirement of 70 grams should be of animal origin, this value is only 13-17 grams in our country (Cevheri and Polat, 2009). Our deficiencies in adequate and balanced nutrition are due to problems related to animal husbandry and, therefore, to our animal product production. At the beginning of these problems, feed shortage and poor quality come to the fore (Soya et al., 2004). Our quality roughage production cannot meet the needs of our animals, and the resulting deficit has reached approximately 70% (Demiroglu Topcu and Ozkan, 2017). In our country, animal feeding is primarily carried out with practices based on primitive feeding conditions such as natural meadows and pastures, plant residues, stubble grazing, and straw. However, forage crop farming is the most efficient and economical way of obtaining feed (Kusvuran et al., 2011).

Green fodder is an essential component of rations in animal nutrition to increase productivity and reproductive performance. For this reason, giving quality green fodders to animals more frequently is necessary to increase the quality and quantity of livestock products (Dung et al., 2010). However, there are significant restrictions on green fodder production. The decreased amount of arable land, water scarcity, labor requirement, and high cultivation costs limit the forage crop agriculture in the world and our country. Therefore, although hydroponic fodder, which has become popular worldwide in recent years, is not a comprehensive solution for livestock farming, it is thought to be beneficial in meeting some requirements, at least at a basic level. As a solution, adding grown hydroponic fodders to the rations can regulate the diets of animals and improve performance (Rodriguez Muela et al., 2005).

## Concept of Hydroponic Fodder

The origin of hydroponic based on the combination of two Greek words meaning water (hydro) and work (ponic), respectively (Mason, 1996). Therefore, it is also defined as the growth of a plant in a soilless environment. It is also known as sprouting fodder or often sprouting grain. It is based on the principle that the seeds germinate and grow quickly in an environment such as greenhouses where environmental conditions can be controlled (Morgan, 2021).

Green fodder is the most basic input that plays an essential role in animal nutrition (Hynd, 2019). The practices of hydroponic fodder production date back to the 19th century or earlier (Kerr et al., 2014), from the "Hanging Gardens of Babylon" era, when European livestock breeders fed with sprouted seeds to their animals during winter season to improve fertility and increase amount of animal products (Anonymous, 2008). Due to the increasing human effect on agricultural area, fodder production for cereal seeds, oilseeds, and legumes cannot easily increase. The interest in hydroponic fodder production has increased in late years due to the scarcity of green fodder in some Middle East, Asian and African countries, especially with the effect of global warming (Shit, 2019; Gumisiriza et al., 2020).

Hydroponic fodder production is a primitive technique (Bakshi et al., 2017). Its basic principle is that the seeds of cereal or other plant species react to water or nutrient-rich solutions for germination and growth and produce green plants in a short period of 7-10 days (Baytekin, 2015; Farghaly et al., 2019; Wang et al., 2019). Hydroponic fodder is grown with soilless by the effect of water in the environment. It is also possible, but not necessary, to use nutrient solutions. Instead, potable water that does not contain heavy metals can be used. Also, there is often no chance that this production system will suffer from soil-borne insect, pest, disease attacks, or weed infestation because plants are fed directly from their roots under controlled conditions.

In a hydroponic environment, primarily cereals such as barley, wheat, rye, oats, corn, millet, and different plant seeds such as alfalfa, vetch, lentil, sunflower, and sunn hemp can be grown in a controlled manner (Sneath and McIntosh, 2003; Jemimah et al., 2015). Also, mixtures of these plants can be used (Akman et al., 2021; Ozdemir and Temur, 2022). However, primarily pure barley is preferred. Compared to other plant seeds, barley seed is preferred because dry farming methods can be produce it, it is widely used, it is cheap, and it is generally the grain that gives the best nutrients.

Suppose appropriate temperature, humidity, and light are provided in the growing environment. In that case, with hydroponic techniques, approximately 6-10 kg of green fodder can be produced from 1.0 kg of seed in 7-10 days in controlled conditions (Jemimah et al., 2018; Wootton-Beard, 2019; Dogrusoz, 2022). Hydroponic fodder is a mat of seeds, green leaves and roots about 20-30 cm high (Figure 1). It is a delicious, nutritious, and digestible feed for livestock animals. In addition, it is the best alternative fodder production system at a lower cost for farm animals grown in regions where conventional forage crop production is scarce (Naik et al., 2015; Girma and Gebremariam, 2018).

**Figure 1.** *Hydroponic fodders (Original, 2020)*

Livestock animals consume the green fodder produced in hydroponic farming systems with appetite and can convert them into animal products. It is reported that this method achieves 35-45% savings in feed costs. In addition, green fodder can be produced in these production systems at the cost of one-third of hay and one-seventh of the cost of alfalfa (Atici, 2012; Karaşahin, 2014; Baytekin, 2015; Sulser, 2015).

The researchers suggest that with hydroponic fodder production, obtaining fodder will no longer be a problem and livestock animals can be fed high-quality fodder at any time of the year (Baytekin, 2015; Ozcan, 2015). The amount of fodder production varies according to the size and capacity of the established hydroponic systems. In addition, there are fully automatic machine systems that can produce hydroponic fodder (Al Ajmi et al., 2009; Ozcan, 2015). Using these systems makes it possible to produce green fodder in different capacities according to the requirements of livestock enterprises. Many characteristics affect the yield and quality of the green fodder produce, such as system management, species and quality of seeds, water quality, water pH, irrigation duration and frequency, soaking time, presence of plant nutrients, temperature, humidity, light intensity, seed density, growing time. (Karasahin, 2014).

**Methodology of Hydroponic Fodder Production**

Hydroponic fodder is the cultivation of cereals, legumes, etc., without a solid growing medium but with the necessary moisture and nutrients. For this purpose, the first thing to do is to supply the seeds of the desired plant. The cost of seed corresponds to 85-90% of the total production cost in the hydroponic fodder production system (Naik et al., 2014; Jemimah et al., 2015). Therefore, consideration should be given to the supply of clean, healthy, sound, intact, and unprocessed high-quality seeds. (Cuddeford, 1989; Naik et al., 2015; Hynd, 2019). Seeds treated with chemicals such as fungicides or pesticides should not be preferred in these production systems. In addition, these types of chemicals should not be used in the production process at any stage as any residue can negatively affect animal health and people.

Seeds must first be free of non-seed matter and subjected to germination tests before production. Then, if necessary, the seeds should be thoroughly washed with potable water until all dirt and poor-quality seeds are cleaned. Afterward, they should be kept in hydrogen peroxide (1-2%) or sodium hypochlorite (0.1-1.5%) solution for at least 30-60 minutes to be free from disease (Jemimah et al., 2015; Jeton, 2016). Next, it should be removed from the cleaning solution, and the seeds should be washed with potable water.

The seeds that are cleaned and free from diseases should first be kept in clean water for varying periods depending on the thickness. and hardness of the seed coat. Researchers suggest different soaking times, such as 4 hours, 8 hours, 12-16 hours, or overnight and 24 hours (Al-Karaki and Al-Momani, 2011; Sinsinwar et al., 2012; Naik et al., 2014; Reddy, 2014; Jeton, 2016; Brownin, 2017). However, in determining this period, there is a standard view that the seeds should be kept for at least one night. On the other hand, the germination rate is also affected the water temperature. The ideal temperatures for high values are 22-23ºC (Sneath and McIntosh, 2003). Water temperatures above room temperature can cause disease factors to develop in seeds.

After soaking, the seeds should be placed with a seed thickness of 2-3 cm in plastic or stainless metal trays, preferably with holes to facilitate the discharge of the wastewater or nutrient solution, which can be collected and recycled in a water tank. The amount of seed (seed per unit area) varies according to the plant species and affects the hydroponic fodder yield. For example, the recommended seed amount for hydroponic barley, wheat, or sorghum fodder production is 4-6 kg/m$^2$ (Al-Karaki and Al-Momani, 2011; Jeton, 2016) and 6.5-7.5 kg/m$^2$ for maize (Naik and Singh, 2013; Naik, 2014; Naik et al., 2017).

In order to produce approximately 6-8 kg of green fodder, it is considered ideal to choose trays of 50x80x5 cm dimensions, in which 1-1.5 kg of seeds can be placed, as a growing medium. Plastic tray material is generally preferred in terms of providing lightness (Figure 2). However, it should not be forgotten that it can be affected by environmental conditions over time and should be replaced. Therefore, thin and durable stainless metal trays are more beneficial in terms of longevity. They must be clean, washed with disinfecting solution, and free of dust or other substances. After the seeds are kept in water for one night, they should be transferred to these trays without waiting. In environments where vertical farming is carried out while determining the distance between two trays, a space should be left so that air circulation can be provided sufficiently and the plants do not touch the upper tray as the harvest day approaches.

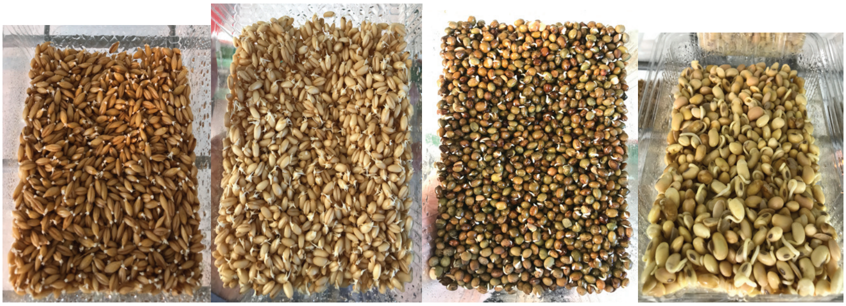

**Figure 2.** *Early stage of hydroponic fodder production (Original, 2020)*

Germinated seeds should be watered regularly with nutrient-enriched solution or potable water. Also, trays should not be kept in strong wind, heavy rain or direct sunlight. It is possible to use different irrigation methods according to the growing environment. While irrigation can be done with a hose in primitive conditions, irrigation can be done in the form of fogging in advanced systems. During the growing period, care should be taken to keep the seeds moist. However, there should be no ponding in the trays. If the irrigation water is stored in tanks and reused cyclically, the water should be changed two times every week (in other words two times every cycle) to prevent microbial contamination.

The harvest day of hydroponic barley fodder is approximately day six after sowing when it reserves the highest nutrient. Also, among all hydroponic fodders, such as sprouted barley, wheat, triticale, rye, and oats, sprouted barley has the highest fodder quality (Heins et al., 2015). For this reason, each cycle is completed in an average of 7 days, especially in hydroponic fodder cultivation (Figure 3). At the end of the growing cycle, it is recommended to disinfect the trays before reuse in the next period.

Nowadays, 17 elements, C, H, O, N, P, K, Ca, Fe, Mg, Cu, S, B, Cl, Mn, Mo, Zn and Ni are considered vital for plants (Salisbury and Ross, 1992). In addition, others such as Na, Si, V, Se, Co, Al, and I are considered beneficial to plants as they promote growth or can offset the toxic effects of other elements or, in a less specific role, replace essential nutrients (Trejo-Téllez et al., 2007). The nutrient solutions are often the preferred aqueous solution (Taiz and Zeiger, 1998). However, it is not essential. The nutrient composition of the solution determines the basic pH, EC, and osmotic potential of the solution. For this reason, yield and quality increases are obtained in feeds grown with this type of solution instead of potable water.

Environmental factors in the growing environment are important for optimizing hydroponic fodder production and quality. Suitable temperature (20±2ºC), humidity (average 60-65%), light intensity (approximately 2.000 lux), lighting time (12-16 hours), and ventilation (5-10 minutes every 2-3 hours) should be provided for sustainable fodder quality standardization in the growing environment (El-Deeba et al., 2009; Naik, 2014; Jeton, 2016; Hynd, 2019). The total energy (especially electricity) requirement of hydroponic fodder system is much less than conventional forage production. On the other hand, in some critical situations or ambient conditions, the tops of the trays can be covered with green shade nets. This is essential for ventilation and lighting to prevent the yellowing of leaves. Because the green canopy net lets in enough light and maintains the appropriate humidity and temperature for optimum photosynthesis rate, this provides higher hydroponic fodder yield and quality.

Mold is one of the most critical problems in poorly managed hydroponic fodder production. (Myers, 1974). It is known that with moldy green fodder, the performance of animals consuming these fodders decreases, and even moldy fodders cause poisoning and animal deaths. Therefore, great care must be taken at all stages of hydroponic fodder production. Otherwise, erroneous transactions can cause severe economic losses.

**Figure 3.** *Hydroponic fodders produced from different plant species (Original, 2020)*

**Nutritional Values of Hydroponic Fodder**

Different plant species can be used for hydroponic fodder production. Cereals are at the forefront of these species most of the time. Barley (Reddy et al., 1988), wheat, oat (Snow et al., 2008), sorghum, alfalfa, cowpea (Al-Karaki and Al Hashimi, 2012), corn (Naik et al., 2011; Naik et al., 2012) and sunn hemp (Jemimah et al., 2015) can be produced by the hydroponic methodology (Figure 4). However, the choice of hydroponic fodder to be produced depends on geographical and agro-climatic conditions and sustainable seed supply.

Barley grown with hydroponic feed production has a digestibility of 98%. It contains 17-22% crude protein, 16-21% dry matter, and 2.800 kcal/kg metabolic energy (Cuddeford, 1989; Akbag et al., 2014; Kilic, 2016). The nutritional contents of hydroponic fodders, generally obtained from cereal seeds, may differ according to growing conditions (Fazaeli et al., 2011). In addition, hydroponic fodder's nutritional quality is superior to common non-legume fodders in terms of organic matter, crude protein, ether extract, and nitrogen-free extract.

Sprouting catabolizes starch to soluble sugar during the biochemical processing of plant seeds. When the starch content decreases, both the organic matter and dry matter content decrease. However, the ether extract of the hydroponic fodder increases as the plant grows due to the increase in structural lipids and chlorophyll. With sprouting, there is an increase in concentration. The development of structural carbohydrates increases the concentration of acid detergent fibers (ADF), neutral detergent fiber (NDF), crude fiber and linoleic acid but decreases the nitrogen-free extract. On the other hand, sprouts are the best plants for enzyme density. They maintain these features for up to seven days after the germination stage (Sneath and McIntosh, 2003).

Hydroponic fodders are nutritious, tasty and digestible feeds for animals. Sprouting seeds converts starch to sugar. Therefore, the energy value of sprouts on a dry matter basis is less than seeds with gross energy loss (Sneath and Mclntosh, 2003; Farghaly et al., 2019). However, hydroponic fodder has an advantage in digestibility. In the rumen, its digestibility is higher than in broken seed. However, when the digestibility of shoots and root shoots is compared, shoots are easily spoiled in the rumen. For this reason, it is preferred to give it to ruminant animals with plenty of leaves (Dung et al., 2010; Kumar, 2019). On the other hand, hydroponic fodders are especially rich in terms of vitamins C and E contents. Sprouting positively changes the vitamin content of the seed (Shit, 2019). Due to intensive root growth in the hydroponic feed system, the plant increases mineral uptake from the fourth day. Therefore, the ash and protein content increases rapidly (Girma and Gebremariam, 2018). Animal breeders report that adding hydroponic fodder to rations increases milk production and improves fertility, rates of conception, fur or appearance of fleece, and the animals' overall health (Anonymous, 2012).

**Figure 4.** *Hydroponic fodders looking like a mat consisting of roots, seeds and plants (Original, 2020)*

Hydroponic fodders are rich in pigments and protein protective factors that increase animal products and reproductive performance. In addition, they help to remove phytic acid, oxalic acid, and other toxic substances from the feed (Chavan and Kadam, 1989; Sneath and McIntosh, 2003; Salisbury and Ross, 1992; Shipard, 2015). Seeds contain phytic acid. Therefore, they can remain intact for years (Naik et al., 2012). However, the suppository acid content of the seeds limits their use in direct animal feed. Because the main effect of phytic acid is to form insoluble compounds with minerals such as calcium and iron, causing inefficient absorption in the blood. When seeds germinate, phytic acid levels decrease (Girma and Gebremariam, 2018; Xia et al., 2020; Bhattacharya and Laxmi, 2021). Enzymes also eliminate other potentially harmful chemicals during the germination stage. Digestive enzymes in sprouts act as biological catalysts in the digestion of proteins, fats, and carbohydrates. The amount of enzymes contained in the sprouts is much higher than in the seeds. As is known, enzyme activities control the physiological effects of vitamins, minerals, and elements on plants (Almuhayawi et al., 2021). The period with the highest enzyme activity of the sprouts corresponds to the hydroponic production cycle (the period from germination to the first seven days).

**Conclusion**

Hydroponic fodder production is an agricultural technique that provides nutritious, tasty, and digestible feed to animals at low costs. Given the scarcity of land and water, and climate change worldwide, hydroponic fodder is a good alternative for forage production, although not a complete solution for the livestock industry. This system can help meet green fodder requirements, especially in winter seasons and in farms near urban areas where forage production areas are scarce. Furthermore, various species of plants or their mixtures, especially barley, can be produced by the hydroponic method, and the fodder can be made usable in a short time, like 7-10 days. However, determining the best forage plant is essential for obtaining the highest fodder yield and quality and considering the economic dimensions in the hydroponic fodder production process by saving seed costs. Therefore, developing special low-cost devices for hydroponic fodder production is also necessary under specific local conditions.

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# Chapter 10

## PARASITE BIODIVERSITY OF FISHES IN TÜRKİYE – I. CILIOPHORA

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## 1. INTRODUCTION

Ciliophoran parasites are among the most diverse ectoparasitic groups infesting fishes around the world. Parasitic ciliophorans are important, especially for fingerlings under intensive and extensive culture conditions. They mostly infect the skin, gills, and fins of host fishes. Host and environmental-related factors affect the severity of the pathogenicity of ciliophoran parasites. They can cause alterations in the structural and functional peculiarities of host fish organs and, when the severity is excessive, infected host fish may even die. Some of them, such as the agent of white spot disease *Ichthyophthirius multifiliis*, are well-known infectious pathogens affecting fish health seriously by causing significant pathological alterations and death.

A total of 401 and 561 fish species were registered in freshwater and marine environments in Türkiye, respectively (Faroese & Pauly, 2022). Fish are regarded as valuable food sources for human consumption and due to constant decreases in capture values, some species, such as rainbow trout *Oncorhynchus mykiss*, European seabass *Dicentrarchus labrax*, and gilthead sea bream *Sparus aurata,* are cultured in either land-based culture facilities and/or net cages in lakes and seas. Ornamental fish trade is another fast-growing industry in Turkey and either cultured individuals or imported ones are capturing more and more of the attention of hobbyists.

The number of studies by researchers on the parasite fauna of fishes have gained momentum in the last decades and several checklists of parasites of all the taxa, including Phylum Ciliophora, and their respective hosts in freshwater and marine environments have been published by Özer & Öztürk (2015, 2017), Özer (2019, 2020). Moreover, Özer (2021) has recently published a very comprehensive host-parasite, as well as parasite-host checklist book based on all previous reports in Türkiye, and this chapter on the ciliophoran parasites of fishes in Türkiye has been created based on the data presented in this recent book which all the individual publications on each ciliophoran parasite species can be found.

## 2. CILIOPHORAN parasite diversity of fishes in Turkey

According to Özer (2021), a total of 78 ciliophoran species were reported from all fish species in Türkiye. The highest number of ciliophoran parasite species was 19 from both wild marine and freshwater fishes, followed by cultured freshwater, aquarium fish, and cultured marine fishes (Figure 1). On the other hand, aquarium fish species were the host for maximum ciliophoran parasites (25), followed by wild freshwater, wild marine, cultured freshwater, and cultured marine fishes (Figure 2).

## 3. CILIOPHORAN PARASITE DIVERSITY OF MARINE FISHES

### 3.1. Wild marine fishes

Wild marine fishes inhabiting the surrounding seas of Türkiye subjected to parasitological investigations and most of the ciliophoran parasites reported from fishes came from the Black Sea and no ciliophoran parasite was reported from the Aegean Sea and the Sea of Marmara (Figure 3).

Ciliophoran parasites which were reported from wild marine fishes were dominated by trichodinids and *Trichodina domerguei* is the most reported species among others from 9 host fish species. This parasite was followed by an unidentified *Trichodina* sp. from 5, *T. heterodentata,* and *T. puytoraci* from 3 host fish species in the Black Sea (Figure 4). Some other ciliophoran species were also reported from 2 and a lesser number of fish species (see Özer, 2021 for details).

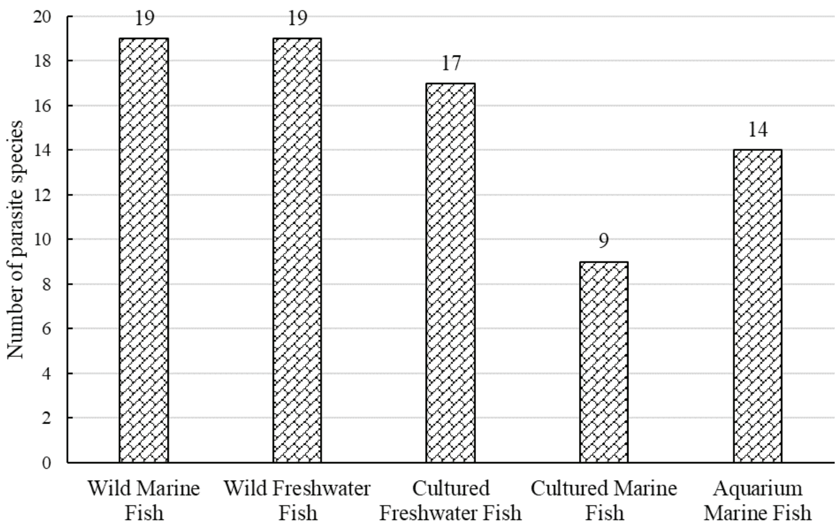


**Figure 1.** *The total number of ciliophoran parasite species reported from marine, freshwater, and aquarium fishes in Türkiye.*

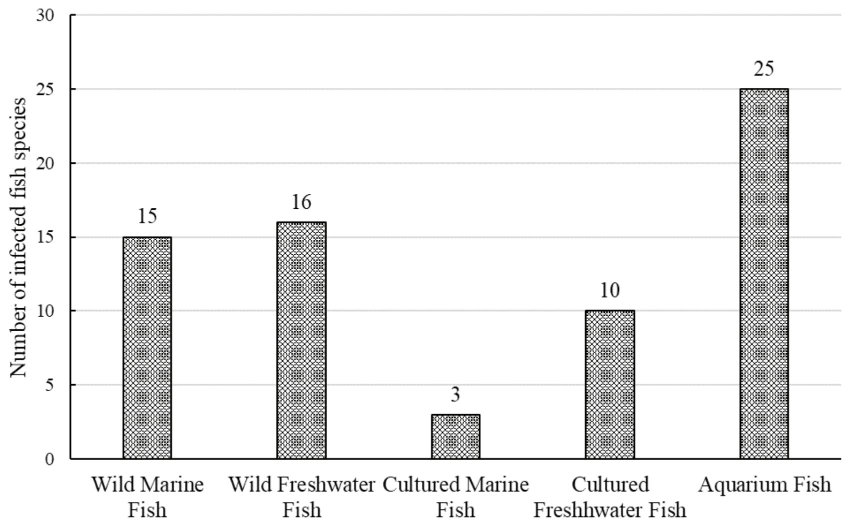


**Figure 2.** *The number of fish species infested by ciliophoran parasites in marine, freshwater, and aquarium environments in Türkiye.*

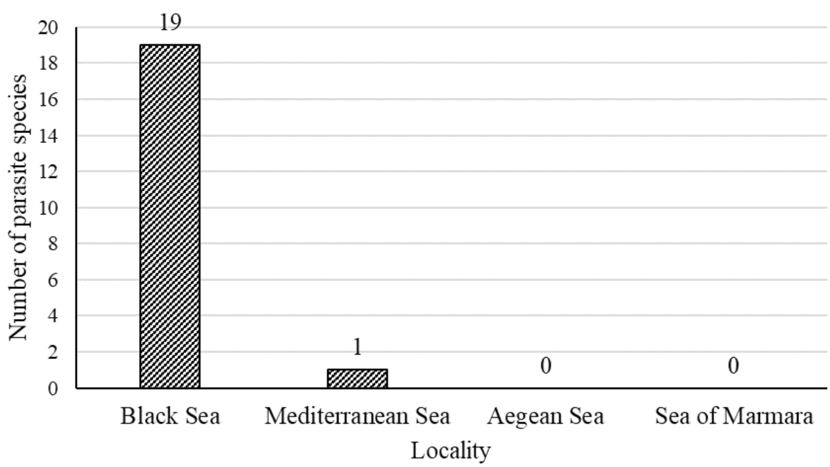


**Figure 3.** *The number of ciliophoran parasite species reported from wild marine fish species inhabited the surrounding seas of Türkiye.*

Wild marine fishes were the host for ciliophoran parasites from the surrounding seas of Türkiye and whiting *Merlangius merlangus*, golden grey mullet *Chelon auratus*, red mullet *Mullus barbatus* and European flounder *Platichthyes flesus*, all from the Black Sea, were the most ciliophoran reported host fish species (Figure 5).

### 3.2. Cultured marine fishes

Marine fish culture has gained great momentum in the last 30 years in Türkiye and statistical values indicated constant increases in their amount of production. Türkiye is the leader in the culture of seabass *Dicentrarchus labrax* and gilt-head sea bream *Sparus aurata* and there are also some other alternative marine fish species that have been subjected to cultural activities. Parasitological investigation on ciliophorans yielded a wide range of parasite species infesting cultured marine fish hosts (Figure 6). While the most occurring parasites *Epistylis* sp. and *Trichodina* sp. were reported from 3 host fish species, *Apiosoma* sp. *Ichthyopithirius multifiliis* and *Cryptocaryon irritans* were reported from 2 host fish species (Figure 6).

Owing to intensive cultural activities on gilt-head sea bream *S. aurata*, seabass *D. labrax*, as well as turbot *Scophthalmus maximus* were reported to be the host of 4 ciliophoran parasite species (Figure 7). This figure also shows that the fourth most infected fish species is common dentex *Dentex dentex* with 3 ciliophoran species.

## 4. CILIOPHORAN PARASITE DIVERSITY OF FRESHWATER FISHES

### 4.1. Wild freshwater fish

Ciliophoran parasites are among the most common parasites of wild freshwater fishes worldwide. The number of wild fish host species infested by ciliophoran parasites in Türkiye is presented in Figure 8 and trichodinids were the dominating parasite species reported from 11 different host fish species, followed by white spot diseases agent *I. multifiliis* from 6, *Apiosoma* sp from 3 and the rest were from 2 host fish species. Some trichodinids were found to infest only one specific host species and these can be seen in Özer (2021).

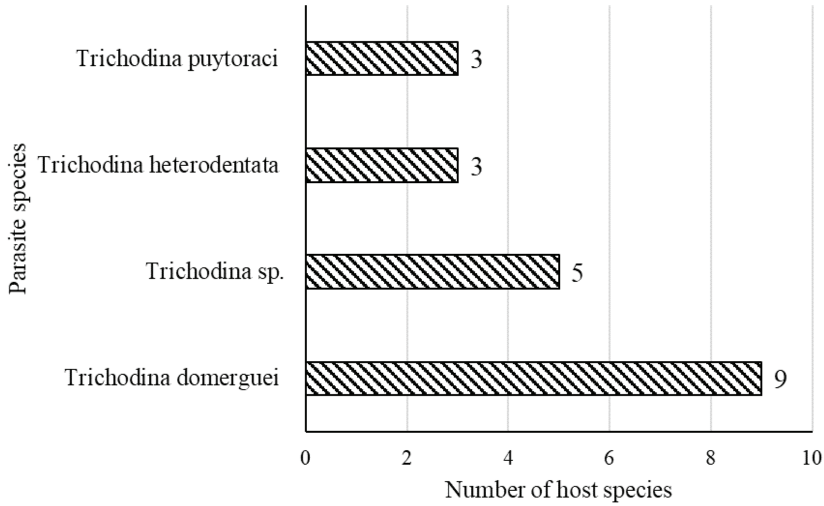


**Figure 4.** *The number of ciliophoran parasite species infesting ≥3 wild marine fish species in Türkiye.*

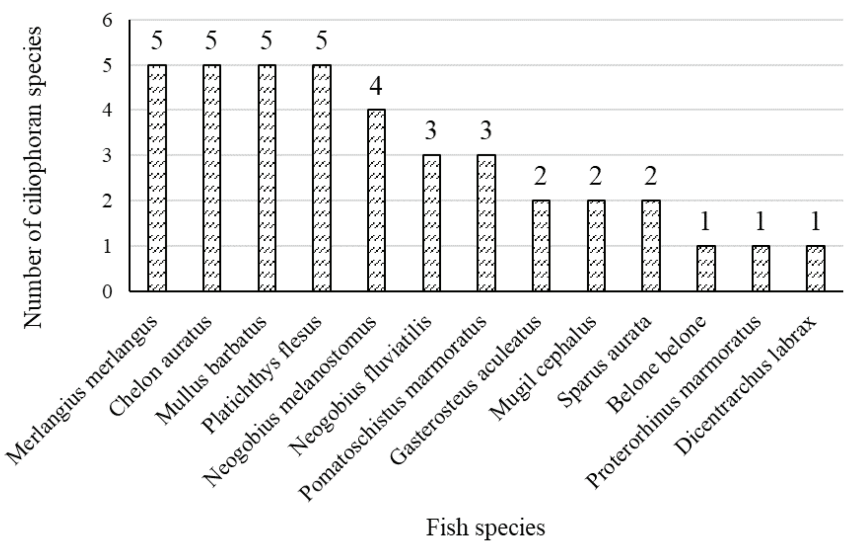


**Figure 5.** *The number of ciliophoran parasite species infesting the wild marine host fishes in Türkiye.*

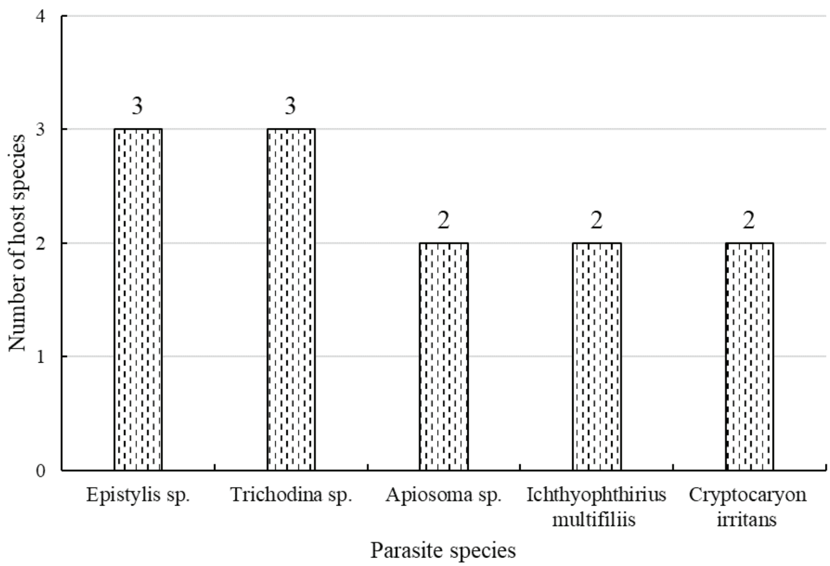


**Figure 6.** *The number of cultured marine fish host species infested by ciliophoran parasites in Türkiye.*

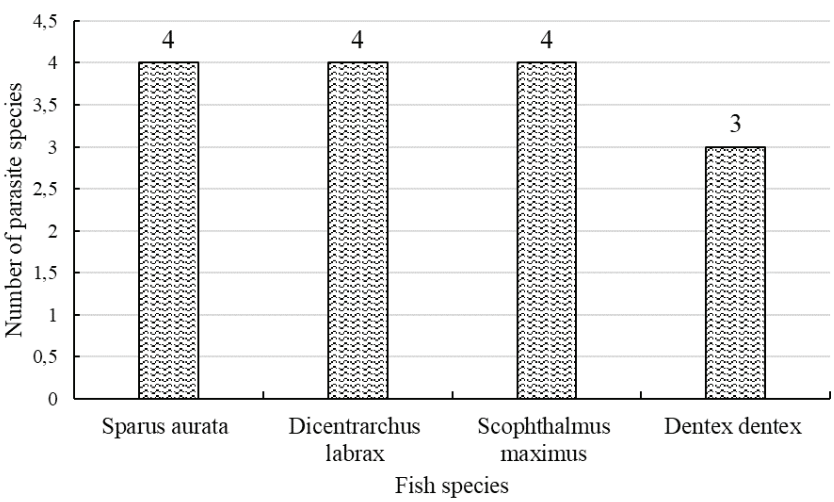


**Figure 7.** *The number of ciliophoran parasite species infesting the cultured marine fishes in Türkiye.*

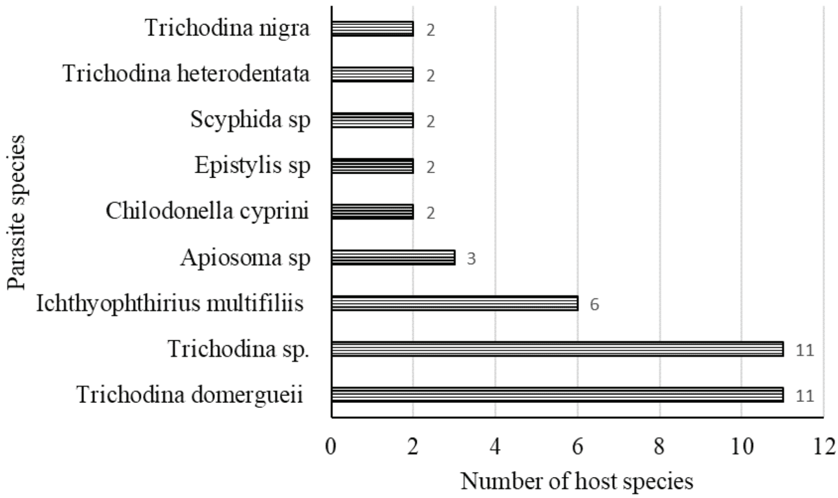


**Figure 8.** *The number of ciliophoran parasite species infesting wild freshwater fish species in Türkiye.*

Wild freshwater fishes subjected to parasitological investigation yielded a wide range of ciliophoran parasite species and the common carp *Cyprinus carpio* was the most ciliophoran-reported fish species (13), followed by a native toothcarp *Aphanius danfordii* (7) and the rest of the fish species had 3 and less ciliophoran (Figure 9).

### 4.2. Cultured freshwater fish

The rainbow trout *Oncorhynchus mykiss* and common carp *Cyprinus carpio* have been the most commonly cultured species in intensive and extensive facilities in Türkiye. Among the cultured freshwater fish infesting parasites, ciliophorans *Chilodonella cyprini, Ichthophthirius multifiliis,* and *Trichodina* sp. were the first three parasite species reported from 6, 4, 3 host fish species, respectively (Figure 10). These parasite species are cosmopolitan ones reported from a wide range of cultured freshwater fishes in different environments worldwide.

When the number of parasite species infesting cultured freshwater fishes is considered, not surprisingly, the rainbow trout *O. mykiss* is the most infested cultured fish species with 15 different ciliophoran species and the rest of the fishes had a lower number of ciliophoran parasites (Figure 11).

## 5. CILIOPHORAN Parasite diversity of aquarium fishes

Ornamental fishes and aquarium fisheries are worldwide popular sectors and are attractive to hobbyists everywhere. Of the 32 ornamental fish species in Türkiye, a total of 26 have been reported to be infested with at least one ciliophoran parasite. *Trichodina* sp. has been the most reported ciliophoran species among ornamental fish species (21) and followed by the infection agent of white spot disease *I. multifiliis* from 14 host species (Figure 12). The rest of the 14 ciliophoran species were found on several fish host species (Figure 12).

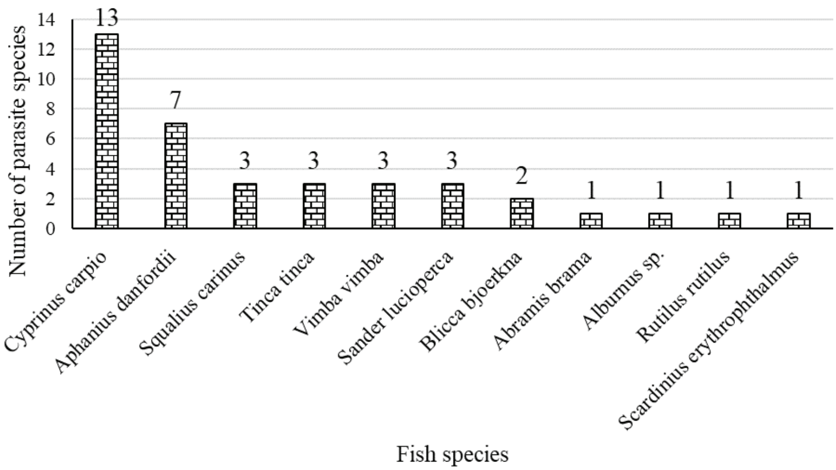


**Figure 9.** *The number of ciliophoran parasite species infesting the wild freshwater host fishes in Türkiye.*

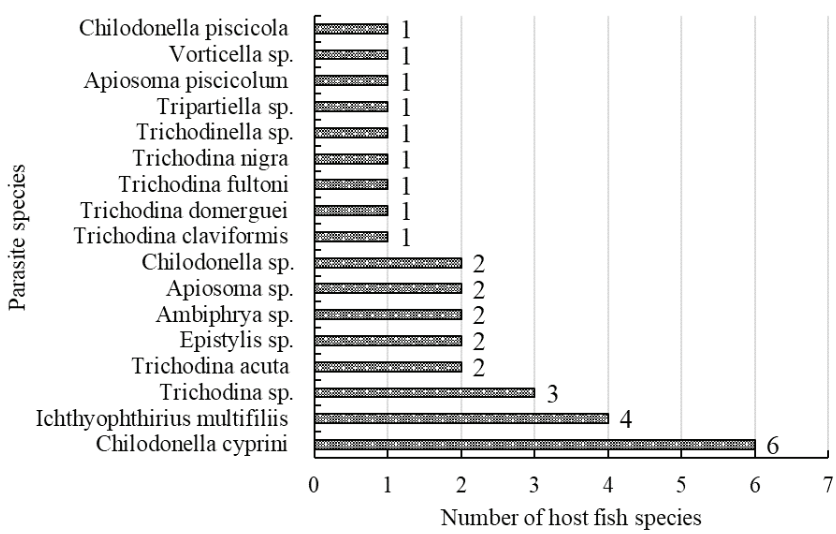


**Figure 10.** *The number of cultured freshwater fish host species infested by ciliophoran parasites in Türkiye.*

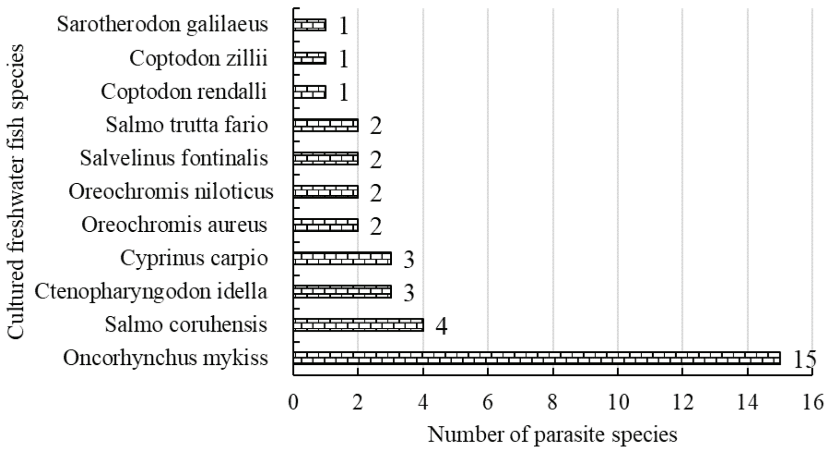


**Figure 11.** *The number of ciliophoran parasite species infesting cultured freshwater fishes in Türkiye.*

Goldfish *Carassius auratus* and guppy *Poecilia reticulata* have been reported to be the host of 6 different ciliophoran species in Türkiye (Figure 13). Another goldfish *Carassius* sp. and guppy *Poecilia sphenops* had the second highest ciliophoran species and the rest of the ornamental fish species were reported to be the host for several numbers of parasite species (Figure 13).

## 6. PARASITIC CILIOPHORAN INVESTIGATIONS ON FISHES IN TÜRKİYE AND RECOMMENDATIONS

This chapter provided comprehensive data for the ciliophoran parasites and their wild and cultured host fishes in marine, freshwater, and aquariums in Türkiye. It is clear from these data that the numbers of reported ciliophoran parasite species in these environments and their host fish species are very low when compared with metazoan parasites. A total of ciliophoran parasite-reported 15 wild marine host species and 16 wild freshwater host species are very low when considering the reported 561 marine and 401 freshwater fish species in Türkiye by Froese & Pauly (2022). Currently, we do not know the actual number of parasite species infesting their host fishes as the result of several factors; i) the investigations focused only on the target parasite groups of relatively larger-sized ones such as monogenea, nematoda, cestoda etc, and the neglection of very small sized members of ciliophoran higher taxon in the investigations ii) the limited number of professionals working on ciliophoran parasites of fishes, iii) limitations on the financial sources as well as facilities having more technological devices enabling actual ciliophoran parasite species identifications. We can, of course, increase these obligations on the revealing of the actual ciliophoran parasite compositions in investigated environments and fish hosts, I believe that more efforts will overcome this deficiency.

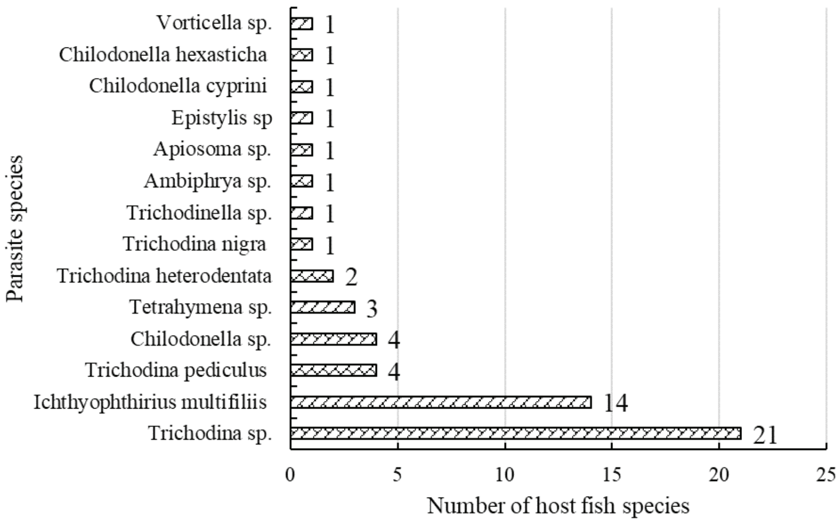


**Figure 12.** *Ciliophoran parasite species and the number of infested ornamental fish host species in Türkiye.*

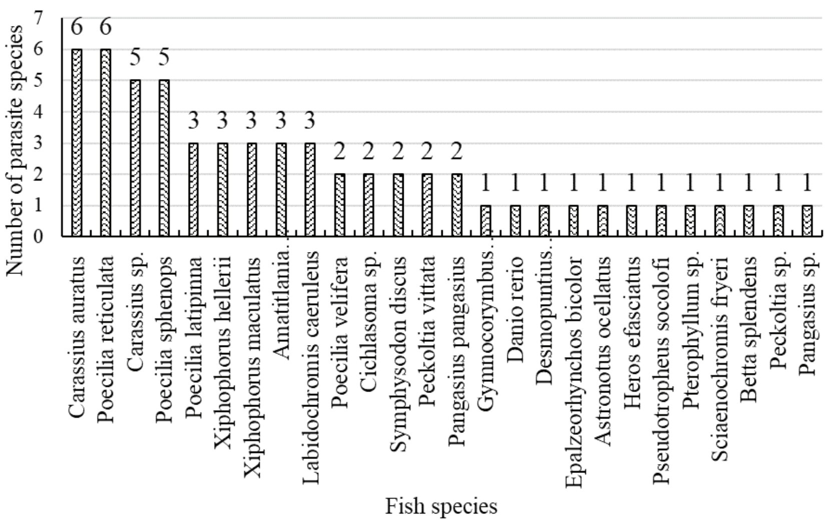


**Figure 13.** *The number of ciliophoran parasite species infesting ornamental aquarium fishes in Türkiye.*

I must state that increasing fish parasitic investigations in the recent 10 – 15 years in Türkiye yielded more reports on wild and cultured fish parasites in marine, freshwater and, aquarium environments as parallel to the great progress in fish culture activities and these enabled us a better understanding of current interactions between the ciliophoran parasitic invasions and their hosts in Türkiye. It is, however, clear that more professionals and research efforts supported by more financial sources will definitely provide more data on actual ciliophoran parasitic fauna of marine, freshwater, and aquarium environments in Türkiye.

## 6. CONCLUSION

Cilophoran parasites are among the most diverse groups of fish parasites worldwide and Türkiye has great fish diversity sources inhabiting both freshwater and marine environments. The ornamental fish trade in our country is also another source of fish diversity. It is believed that all fish species in all these sources have at least one parasite species in their lifespan and more investigations focused on ciliophoran parasites will reveal more protozoan parasite diversity in fish hosts in Türkiye.

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# Chapter 11

## ROLES OF STRIGOLACTONES IN PLANTS: A REVIEW[1]

*Emine Sema ÇETİN*[2]

*Birol KOÇ*[3]

1 This paper was prepared from a part of the master's thesis (The Effects of Strigolactone Applications on Some Physical and Biochemical Properties on Vitis Grown in Limely Media. Yozgat Bozok University, School of Graduates Studies, Department Of Hortıculture, 58 p. Supervisor: Assoc. Prof. Dr. Emine Sema ÇETİN)

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## INTRODUCTION

The term “hormone” was first employed about 100 years ago in the field of medicine to mean a stimulating factor and transported chemical messenger. The concept of plant hormones was introduced by Sachs (1981) through the observation of morphogenic and developmental correlations in plants. Went and Thimann (1937) qualified hormones as compounds transferred from one part of the organism to the other. But it was later understood that the state of the hormones being transported from their position to demonstrate their effect elsewhere does not always occur and that they can be localized in a certain part, as in animals. The definition of the hormone has therefore evolved over the years with the uncovering of different properties. Today, plant hormones are regarded as organic compounds that are produced naturally, which can be transported from the point at which they are produced to other parts of the plant, have important roles in growth- and development-related events and in gaining tolerance for stresses, and can be influential even at very low concentrations (Le Xu et al., 2018). The only characteristic of the plant hormone in its alternating and evolving description is that they have an impact on the physiological process in plants and can be operative even at very low concentrations.

The first ascertained hormone is called indole acetic acid universally, which is the compound in the group of auxins today (Wildman, 1997). Some other compounds that fit the hormone definition were added afterward. In this way, gibberellins, cytokinins, abscisic acid, and ethylene were discovered. More recently, other compounds including brassinosteroids, jasmonates, and salicylic acid have also been added to the list of plant hormones (Davies, 2010). Ascertaining new plant hormones is momentous in terms of comprehending their function, biosynthesis, and transduction pathways, illuminating different aspects of plant growth and developmental processes.

Phytohormones are recognized to play important roles at the cellular, histological and molecular levels in the entire process in plants from germination to growth and development, from efficiency to senescence (Davies, 2010; Takatsuka and Umeda, 2014). Plant hormones are also critical in gene expression, regulation, and transduction. They are efficaciously playing a role from the earliest stage of plant life to its latest stage.

Another group of hormones discovered today is a novel class of phytohormones called strigolactone (Gomez-Roldan et al., 2008; Su et al., 2017). It is a substance derived from carotenoids and produced in plant roots. It was first uncovered in studies investigating plant parasite and symbiosis relationships and was discovered in cotton roots in 1966 as an effective factor in germinating witchweed seeds called *Striga lutea* (Cook et al., 1966). Its chemical structure was discovered in 1972 (Cook et al., 1972). It was observed earlier this century that the phenotypical structures of some pea, Arabidopsis, and petunia mutants were very discrepant from the mutants of auxin or cytokine, creating more branched shoots. It turned out that a substance based on root had an important role in controlling shoot branching. It has also been revealed (Lopez Obando et al., 2015) that there are large contributions of strigolactones in symbiotic interactions of plants and they are effective in promoting hyphal branching in arbuscular mycorrhizal funguses.

Studies in this regard have gained momentum since strigolactones were ascertained as having a role in increasing plant resistance to drought, salinity, heavy metals, low temperature, and more negative stressors (Xiong et al., 2002). This review study discussed the properties of strigolactones and their role in plants.

## 1. CHEMICAL STRUCTURE OF STRIGOLACTONES

Strigolactone (SL) was first discovered as a root secretion during germination studies of witchweed parasite plant seeds. The word “strigo” comes from the genus name of the witchweed plant, while the “lacton” comes from the lacton ring in its chemical structure (Smith, 2014).

Cook et al. (1966) reported (+) -strigol isolation in cotton (*Gossypium hirsutum* L.) roots for the first time. Cotton is a plant that has a strong stimulating effect on the germination of Striga seeds and is not a host plant. Then, Siame et al. (1993) remarked that strigol is a germination-stimulating compound secreted by the most commercially important Striga hosts, primarily maize and millet. Strigol has also been ascertained in the root secretions of plants such as *Sorghum bicolor* L. Moensch and *Menispermum dauricum* DC (Yasuda et al., 2003).

SLs are classified into two groups in regard to their chemical structure, mainly canonical and non-canonical (Fig. 1). Canonical SLs consist of a tricyclic lactone with three rings (ABC ring) connected to the butenolide group (D ring) via an enol-ether bridge (Bhattacharya et al., 2009; Al-Babili and Bouwmeester, 2015; Lopez-Obando et al., 2015). The enol-ether bridge and D-ring parts are considered to be critical in the biological activity of SLs (Umehara et al., 2015). If this shifting group is a hydroxyl group, it is usually accompanied by augmented germination activity (Xie et al., 2008; Kim et al., 2010); But if it is a hydrophobic group or has acetyl, it is associated with shoot branching (Boyer et al., 2014). Canonical SL is divided into strigol type and orobanchol type according to the stereochemistry of the C ring (Xie et al., 2013).

In non-canonical SLs, unlike the canonical type, the ABC ring is missing. However, they possess both an enol-ether bridge and a D ring (Xie et al., 2017; Yoneyama et al., 2018a; Xie et al., 2019). The simplest non-canonical SL is Carlactone (CL) (Alder et al., 2012).

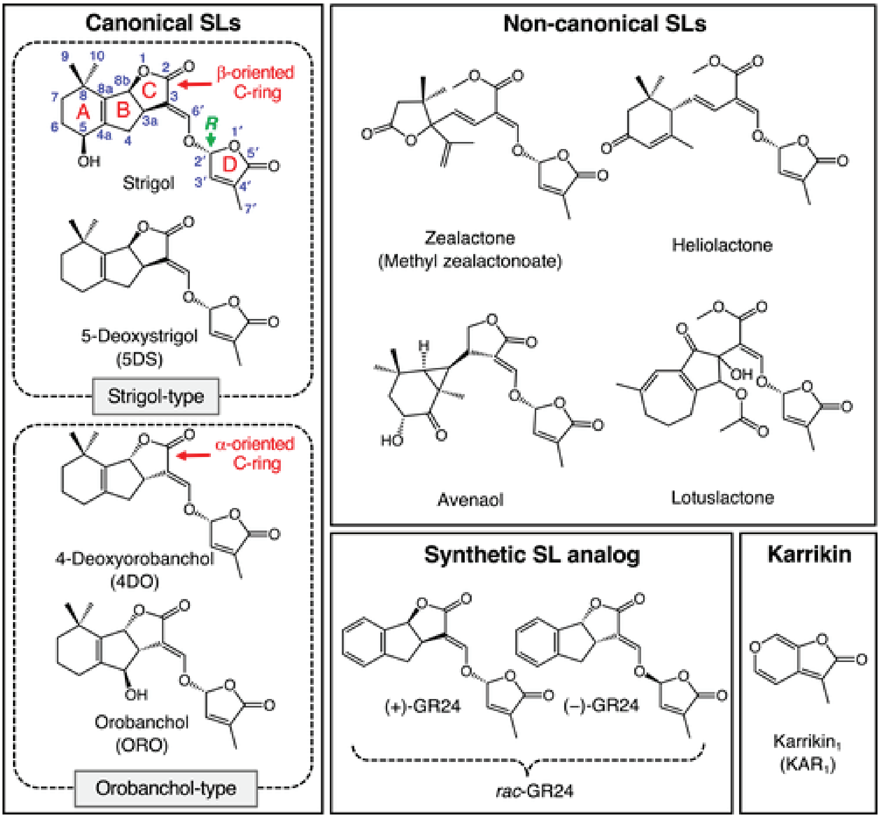


*Figure 1. Chemical structure of SLs (Mashiguchi and Seto, 2021).*

Both canonical and non-canonical SLs are secreted around the root of the plant. In tomato, *A. thaliana,* and poplar plants, the roots secrete carlactonic acid (Abe et al., 2014; Yoneyama et al., 2018b), black oat plant secretes aveanol (Kim et al., 2014), sunflower secretes heliolactone (Ueno et al., 2014), corn secretes zealactone (Charnikhova et al., 2017) and methyl zealactonoate (Xie et al., 2017), while *Lotus japonicus* plant secretes lotuslactone (Xie et al., 2019) into their surroundings, all of these substances are non-canonical SLs.

Owing to the small number of canonical SL and the fact that they are transported from the roots to the stem in a way peculiar to their structural and chemical properties (Xie et al., 2016), it is considered that SL-inhibiting stem branching may be non-canonical SL instead of canonical SL (Yoneyama et al., 2018a).

## 2. STRIGOLACTONE BIOSYNTHESIS

The biosynthesis of SL and SL-like compounds comes about in the cytoplasm and chloroplasts. The origin of the biosynthesis of all SLs is β-carotene, and the starting point of synthesis is plastids. The main place of synthesis in the plant is the root and stem. The KL molecule is synthesized following successive reactions of DWARF27 (D27), Carotenoid Cleavage Dioxygenase7 (CCD7), and Carotenoid Cleavage Dioxygenase8 (CCD8) enzymes in plastids (Fig 2).

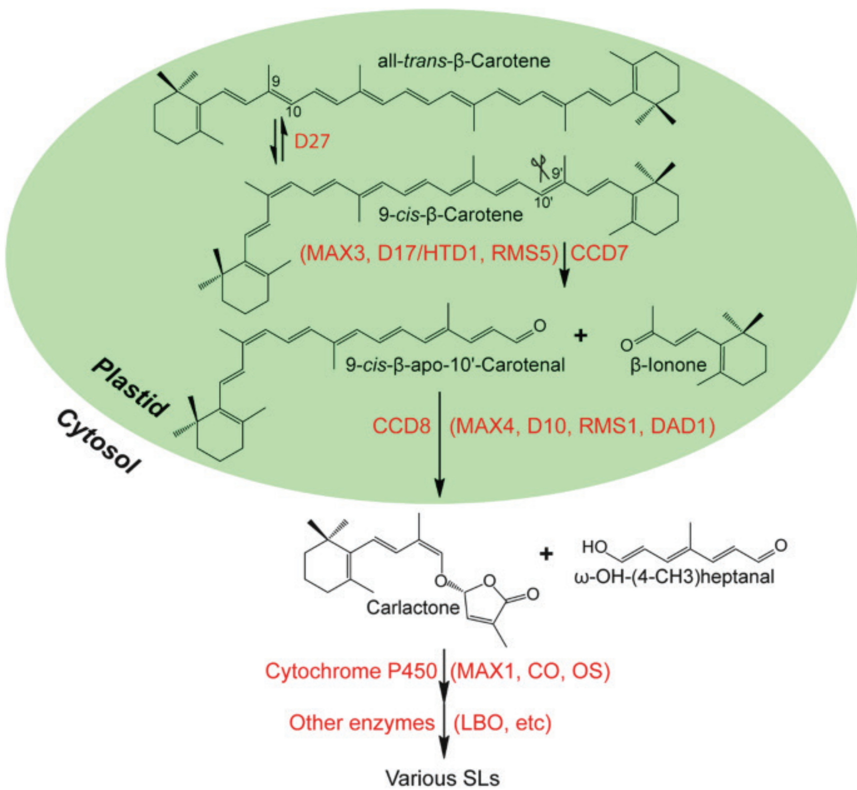


*Figure 2. Biosynthesis of SLs (Jia et al., 2019).*

*MAX1* performs 3 oxidation steps using KL as a substrate, resulting in carlactonic acid. Either 5-deoxystrigol or 4-deoxyorobanchol is made up of carlactonic acid or methylated to form methyl carlactonate (Abe et al., 2014). Methyl carlactone needs to be further oxygenated with an oxidase such as Lateral Branching Oxydoreductase (LBO) to become bioactive (Cardinale et al., 2018). To date, at least 20 naturally synthesized SL and 5 SL-like compounds are recognized to be transported inside the plant and outside the root.

It has recently been reported that a sulfotransferase is involved in the formation of 5-Deoxystrigol, a canonical SL, in the sorghum plant (Gobena et al., 2017). The loss of function of this transferase alters the type of produced SL, giving resistance to parasitic plant species (Gobena et al., 2017; Jia et al., 2018). It has also been noted that a metabolite called 3-hydroxy-carlactone is formed in paddy after D10/CCD8 in the SL biosynthesis pathway (Baz et al., 2018). These results suggest that there are still many metabolites or enzymes in the SL biosynthesis pathway waiting to be discovered.

5-Deoxystrigol, which is described as a metabolic product in the root cultures of *Lotus Japonicus* L., is considered to play another important role. Akiyama et al. (2005) stated that 5-Deoxystrigol compound is effective as a "branching factor" in the colonization of Arbuscular Mycorrhizal Fungi (AMF) in the lotus roots.

GR24 is the most widely used synthetic SL analog in laboratory studies (Humphrey and Beale, 2006). It is named after the initials of the researcher Gerry Roseberry (Cardinale et al., 2018). GR24 is the most effective synthetic SL that promotes broomrape germination (Reizelman Lucascen 2003).

In cases where carotenoid synthesis is inhibited, the events in which SL acts are adversely affected by this situation prove that SLs are carotenoid-induced. Matusova et al. (2005) investigated the effects of root extracts of corn, cowpea, and sorghum plants treated with fluridone, which inhibit carotenoid biosynthesis, on the germination of Striga and Orobanche seeds. As a consequence of the research, parasitic plant germination was reduced by up to 80% in the groups that inhibited carotenoid biosynthesis compared to the control group. Similar results were observed in extracts obtained from the carotenoid synthesis mutants of the corn plant. Based on these results, it has been reported that SL is a plant hormone of carotenoid origin that they are formed as a consequence of carotenoid degradation, and that ABC and D-ring attached to it are made up following a series of reactions.

## 3. TRANSPORT OF STRIGOLACTONES

The place of synthesis of SLs is the roots, and they are transported to the stem through the xylem (Kohlen et al., 2012).

### 3.1. SL transport from roots to shoots

SLs function as symbiotic signals for AMF and are emitted from the roots into the soil, especially under conditions of low phosphorus or nitrogen (Andreo-Jimenez et al., 2015). SLs also act as long-distance signals from the roots to the shoots. *Dad, Max,* and *Rms* mutants demonstrated that SLs produced locally in the shoot were sufficient to suppress axillary bud growth. The normal phenotypic appearance of WT scions grafted onto mutant rootstocks with SL deficiency confirms this (Turnbull et al., 2002). However, the absence of excessive branching of WT rootstocks in mutant scions with SL deficiency also suggests that SLs have acropetal movement towards shoots.

Since SLs are actively produced in the roots in conditions where phosphate and nitrogen are limited, it has also been suggested that the SLs in the root-derived shoots are signals that integrate the beneficial nutrients in the soil and alter the shoot structure (Kohlen et al., 2011; de Jong et al., 2014).

Grafting studies on SL-deficient mutants can determine SL biosynthetic intermediates and their action. It has been suggested that CL may be a mobile signal. This is because phenotypic changes in the shoot branching structure in *max1* rootstocks and *max4* scions have been observed. CL has been ascertained as the only known intermediate upstream of *max1* and downstream of *max4* (Booker, 2005). CL is extremely highly accumulated in the *max1* mutant (Seto et al., 2014).

### 3.2. ABCG/PDR-mediated SL transport

Another pathway of transport of SLs has been ascertained in the petunia plant. Kretzschmar et al. (2012) revealed that Pleiotropic Drug Resistance1 (PDR1), a G-type ABC transporter, is involved in the transport of SLs in petunia. PDR1 in the root subepidermal cells and stem-leaf transmission system have cellular SL transporters in petunia. Thanks to these transporters, SLs have an important function in determining stem branching and root structure (Kapulnik and Koltai 2014, Waldie et al., 2014).

Strong PDR1 expression was observed in the hypodermal passage cells (HPC) in the roots where AMF hyphae penetrate during mycorrhization. PDR1 expression in the roots was also upregulated in response to phosphate shortage and colonization by AMF, indicating that PDR1 had a function in the release of SLs from HPCs into the rhizosphere. Kretzschmar et al. (2012) also noted that in addition to SL transport in root tissue, PDR1 and its homologs may also play a role in SL transport in aerial parts and stated that PDR1 mutant plants exhibit hyper branching (Mashiguchi et al., 2021).

## 4. BASIC FUNCTIONS OF STRIGOLACTONES

After revealing the role of SLs in promoting germination in parasitic plant species and acting as a signal for AMF, studies have tried to reveal the other functions of SLs within the plant. These studies have determined that SLs play an important role in plant growth and development by demonstrating synergistic/antagonistic effects together with other plant hormones and that they are effective in many aspects such as shaping shoot branching, seedling morphological development, root shape formation, and protection against various stresses (Fig 3).

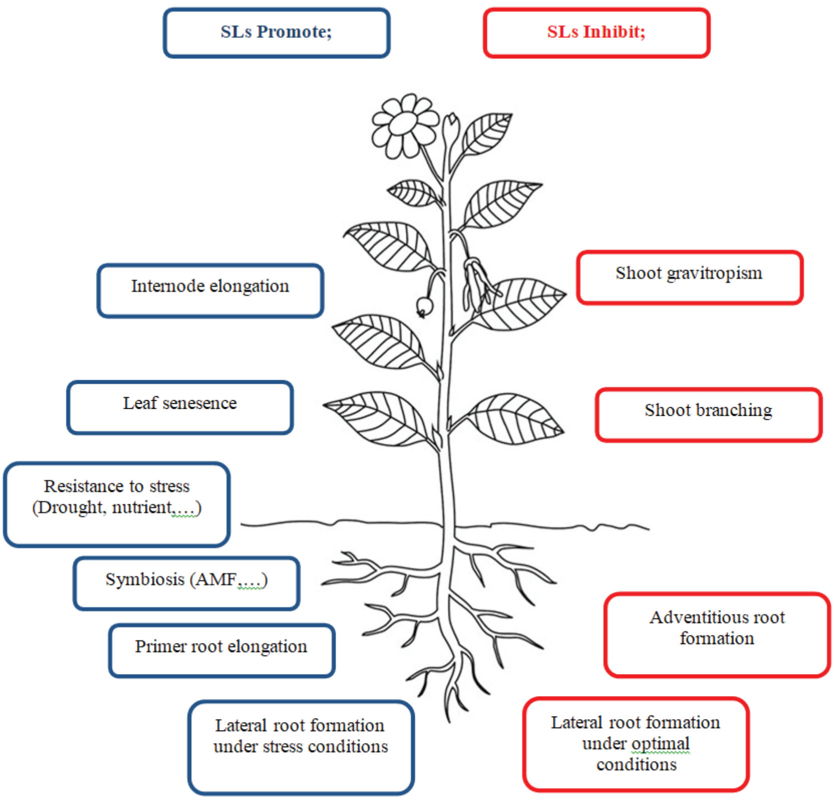


*Figure 3. Roles of strigolactones in plants (Marzec, 2017).*

### 4.1. Controlling Plant Architecture

The most important known effect of SL as a plant hormone is to control plant architecture by suppressing lateral bud development and stem branching (Gomez-Roldan et al., 2008; Umehara et al., 2008). For many years, it has been considered that auxin, cytokinin, and abscisic acid control shoot branching (Thimann and Skoog, 1993; Skoog and Tsui, 1948). However, it is now known that SL also controls the stem branching in harmony with these hormones.

It has been determined that the inhibitory effects of SLs on shoot branching are also achieved by exogen SL application in mutant types with intensive branching (Umehara et al., 2008). SLs have also been determined to augment the main root length in Arabidopsis and maize (Ruyter-Spira et al., 2011; Guan et al., 2012), elongate root hairs in Arabidopsis and peas, but suppress lateral root formation (Kapulnik et al., 2011). Apart from these, SLs are effective in increasing the merithal length, thus increasing the stem length (Guan et al., 2012; de Saint Germain et al., 2013), accelerating leaf senescence (Snowden et al., 2005; Yamada et al., 2014), thickening of the stem transversally (Agusti et al., 2011) and determining the leaf shape (Stirnberg et al., 2002). When SL is suppressed, some changes take place in shoot branching and branching angle, pectination at the leaf edges, elongation of merithals, senescence of the leaves, and secondary thickening.

### 4.2. Promoting Germination in Parasitic Plant Species

SL was first discovered in the cotton plant by Cook et al. (1966). Members of the genus Striga are parasitic weeds. The seeds of these members perceive SL secreted from the host plant roots as stimulants and germinate in areas close to the host (Fig 4). This chemical, which is secreted into the soil from the roots of the host plant and acts as a signal for the germination of parasitic plant seeds, was first called "strigol". Later, SL has been demonstrated to promote germination by secreting it in many cultivated plants such as corn, millet, and sorghum (Siame et al., 1993).

Parasitic plants make up about 1% of angiosperms and have evolved independently at least 12 or 13 times, as evidenced by their wide variability in shape, color, and parasite strategies (Heide Jørgensen, 2008; Westwood et al., 2010). Among these lineages, the only family with any parasitic strategy is the Orobanchaceae family, which is important because it includes major crop pests such as flixweed (Orobanche and Phelipanche spp.) and witchweed (Striga spp) (Brun et al., 2018). *Striga* spp. generally affects grain crops in Africa, while *Phelipanche* and *Orobanche* spp. affect legumes, tomatoes, rapeseed, and tobacco in Europe, North Africa, and Asia (Parker, 2009; Yoshida and Shirasu, 2012).

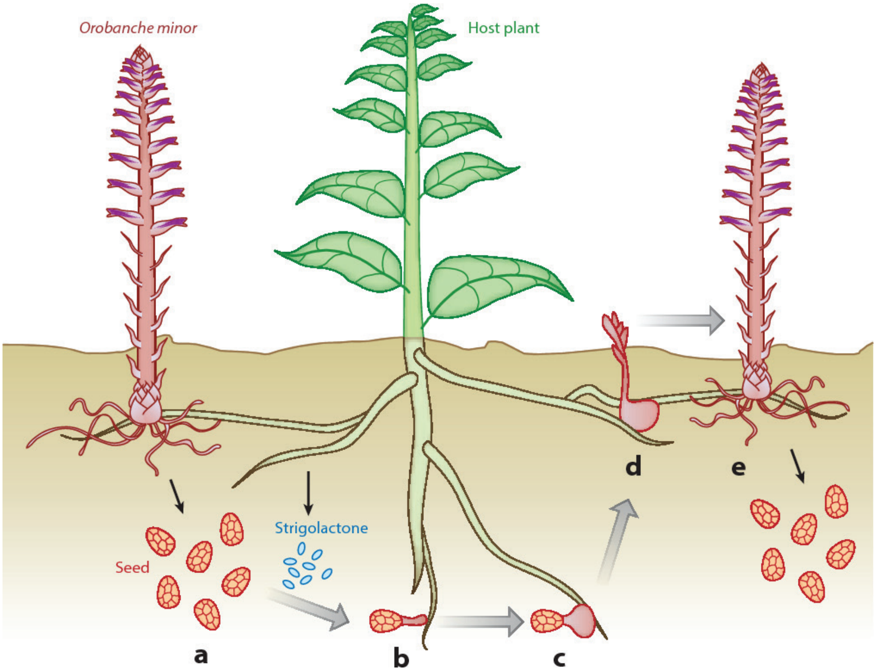


*Figure 4. The roles of strigolactones as stimulant on parasitic plant seeds (Xie et al., 2010).*

Seed germination of obligatory parasitic plant species is a two-step process in that the seeds do not initially react to stimuli and require a conditioning period initiated by seed absorption. Depending on the species, this conditioning period can last from 3 days to several weeks at a temperature of 18-30 °C in *in vitro* conditions (Matusova et al., 2004; Song et al., 2005; Lechat et al., 2012). After that, the seeds become sensitive to chemicals emitted from the surrounding host roots. Most of these stimulants belong to the SL family (Brun et al., 2018).

**4.3. Taking on a Signal Role for AMF**

The release of SL to the root periphery is important for cooperation with AMF. SLs stimulate beneficial symbiosis by triggering hyphal branching in the AMF (Akiyama and Hayashi, 2006; Besserer et al., 2008; Parniske, 2008). It acts as a signal in host recognition for AMF (Akiyama et al., 2005). Fungi, sensing this signal, begin to form a symbiosis with the plant. This interaction is actually a requirement for AMFs to be able to complete their life cycle given their dependence on the host (Parniske, 2008).

The first discovered branching factor is 5-deoxystrigol, isolated from *Lotus japonicus* plant root extracts (Akiyama et al., 2005). Although SL has been detected in root extracts in many plant species, its presence in plants that do not have a symbiosis with fungi, such as Arabidopsis, has suggested that it may have other roles (Goldwasser et al., 2008).

Most land plants establish symbiosis with AMF. In this relationship, plants provide the fungi with the products they obtain by photo assimilation, while they also receive inorganic nutrients, especially phosphate, from the fungi. Therefore, in the absence of phosphate, the synthesis of SL in the plant and its release into the soil are augmented (Lopez-Raez et al., 2008; Kohlen et al., 2012). The presence or absence of phosphate controls the transcript levels of SL genes such as MtCCD7, MtCCD8, and MtD27in alfalfa (Bonneau et al., 2013), D27, D17/CCD7 and D10/CCD8 in rice (Sun et al., 2014), and DgD27 in chrysanthemum (Wen et al., 2016).

### 4.4. Promoting Growth and Development with Other Hormones

Since plants cannot move to a different place from where they are, they have to adapt to altering environmental conditions in their life spans. Auxins, gibberellins, cytokinins, abscisic acid, ethylene, brassinosteroids, jasmonic acid, salicylic acid, nitric oxide, and SLs in the group of hormones have important functions in regulating plant growth and development in response to environmental changes. Hormones often do not act alone in performing these functions. They interact synergistically or antagonistically with each other, acting as signaling molecules to stimulate or inhibit each other's synthesis (Fig 5). For example, lateral bud growth is inhibited by auxins carried down the apex of the shoot, as well as by SLs carried upwards from the roots. Cytokinin, which is transported from the root to the stem, on the contrary, promotes the formation of lateral buds. These different signals are modulated in response to different environmental factors such as light and nutrients (Smith, 2014).

#### 4.4.1. Strigolactones and auxins

Plant development is characterized by such processes as the creation of initial models of organs in the apical meristem of shoots, branching of roots and shoots, the emergence and growth of leaves, and ensuring the connection of newly formed organs with the pre-existing conduction system (Zhang et al., 2020). In this process, events such as cell division, cell growth, and cell and tissue differentiation are especially associated with the action of auxin hormones in the plant (Adamowski and Friml, 2015). In the process called the canalization of auxin, narrow auxin transport routes are created, beginning from cells and tissues with higher auxin concentrations to the parts where auxin is consumed intensively (Bennett et al., 2016; Sauer et al., 2006). There is a self-reinforcing system to direct the canalization. In this system, auxin feeds these auxin transporters back by promoting the expression of PIN genes and inserting the PINs into the plasma membrane facing the auxin pool (Balla et al., 2011; Bennett et al., 2016). The mechanisms by which auxin controls the polarization of PINs are still conceptually unclear (Zhang et al., 2020).

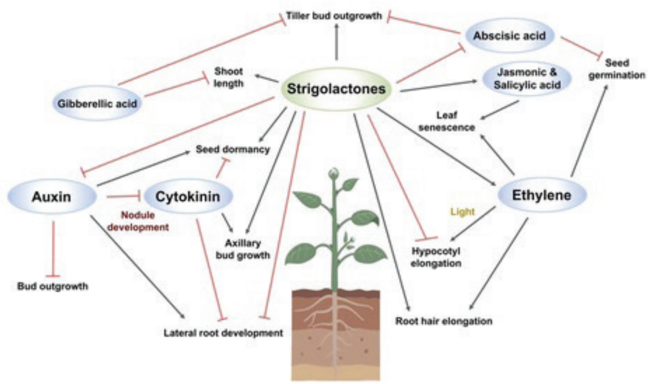


**Figure 3: Crosstalk of Strigolactones with other plant hormones**

*Figure 5. Crosstalk of strigolactones with other phytohormones (Kaniganti et al., 2022).*

Various plant hormones affect PIN-dependent auxin transport. SLs are also considered to be effective here (Crawford et al., 2010). Many of the processes targeted by SLs require the canalization of auxin (Shinohara et al., 2013). Therefore, the relationship between auxin and SL has been tried to be elucidated.

The accumulation of PIN1 proteins responsible for auxin transport in the plasma membrane is inhibited by SL (Bennett et al., 2006; Crawford et al., 2010; Shinohara et al., 2013). In this way, the transport of auxin is reduced, and shoot development is inhibited (Bennett et al., 2006; Ongaro and Leyser, 2008; Crawford et al., 2010). This is supported by the fact that the shoots of SL mutant plants are resistant to inhibition by auxins (Sorefan et al., 2003; Bennett et al., 2006). According to this theory, instead of directly inhibiting shoots, SL indirectly inhibits them by reducing auxin canalization (Waldie et al., 2014).

A study was conducted to determine the effect of SL applications on indole acetic acid synthesis in arid conditions (Çetin et al., 2022a). It has been noted that auxin synthesis is higher in vine plants treated with GR24 (10 µM). They also emphasized that regardless of whether there is stress in the environment or not, high doses of SL have a positive effect on the amount of auxin.

### 4.4.2. Strigolactones and gibberellin

Gibberellins/Gibberellic acid (GA) are hormones that have active roles primarily in stimulating seed germination, promoting stem growth, accelerating fruit growth, and regulating flower formation. There are some studies on SL and GA interactions. Toh et al. (2012) stated that GA and SLs, which regulate seed germination in Arabidopsis, demonstrate a synergistic effect. In contrast, GR24 administration did not augment the transcription of gibberellin-3-oxidase 2, a key enzyme in GA biosynthesis. From this result, the researchers inferred that the effect of SL was realized by regulating other steps in GA biosynthesis (Zhang et al., 2013).

Although various crosstalk between SLs and other hormones have been reported in physiological analyses, the relationship between GA and SLs is not fully understood. A study in peas also argued that SL and GA signaling is independent of each other (de Saint Germain et al., 2013).

However, GA has been reported to suppress SL biosynthesis in rice by suppressing the induction of SL biosynthesis genes, moreover, GA has been ascertained as a new SL regulatory molecule (Ito et al., 2017). They stated that the regulation of SL biosynthesis by GA depends on the GA receptor *GID1 (GIBBERELLIN INSENSITIVE DWARF1)* and the F-box protein *GID2*. In the same study, GA administration also reduced *Striga hermonthica* infection. For this reason, researchers have stated that GA can be used to control parasitic weed infections.

It has been stated in previous studies that the GA and SL signals demonstrate remarkable similarities at the molecular and mechanical levels (Santner et al., 2009; Waters et al., 2017). The similarity of the GA and SL signaling pathways indicates a common evolutionary origin and a possible molecular interaction between the signaling components (Lantzouni et al., 2017). GA is sensed by the *gid1* family of receptor proteins. The binding of GA enables the activation of *gid1* and the coupling of *SLY1* (SLEEPY1) or *SNE* (SNEEZY) in Arabidopsis and *gid2* F-box proteins in rice with an $SCF^{Skp1}$ (SKP1-CULLIN1-F-box protein) type E3 ubiquitin ligase complex (Ariizumi et al., 2011; Daviere and Achard, 2016).

In Arabidopsis, the D14 receptor is known to support the degradation of *SMXL7* (SUPPRESSOR of max2 1-LIKE7) and paralogous *SMXL6* and *SMXL8* by co-functioning with the F-box protein *MAX2* (*MORE AXILLARY BRANCHES2*) (Soundappan et al., 2015; Wang et al., 2015).

There are studies reporting that *DELLA* proteins are present everywhere through the SL pathway and that SL supports GA signaling (Nakamura et al., 2013). In Arabidopsis shoots, SL does not affect the degradation of *DELLA* proteins (Bennett et al., 2016).

### 4.4.3. Strigolactones and cytokinin

Cytokinin is a vegetable hormone that plays a role in stimulating cell division, being effective in bud development, and ensuring the late shedding of leaves. Cytokinins act as promoters of bud growth. In physiological studies, SLs were demonstrated to exert an antagonistic effect with cytokinin, which regulates bud growth. When the buds of the wild pea plant were compared with the buds of the SL-deficient mutant pea plant, it was determined that 6-benzylaminopurin, a synthetic cytokine, reacted in an increased manner in the axillary buds (Zhang et al., 2013).

Duan et al. (2019) studied rice SL signal mutant *d53* and pointed out that the content of cytokinin increased significantly at the base of shoots. They examined the transcript levels of genes related to cytokine metabolism in plants treated with GR24. As a consequence of the study, they stated that the *CYTOKININ OXIDASE/DEHYDROGENASE 9 (OsCKX9)* gene, the primary response gene in wild plants, was significantly upregulated within one hour of the administration, but this was not the case with *d53*. They interpreted the results as that SL induced the expression of *OsCKX9* to decrease the cytokinin content.

Zha et al. (2022) measured the transcription levels of several genes at different levels of plant growth through qRT-PCR analysis and revealed that shoot branching in rice is modulated by auxins, cytokinins, and SLs. As a consequence of the research, they stated that both nutrient deficiency and exogenous SL administration prevented bud development by reducing cytokinin content. It has also been noted that administration of the SL inhibitor may affect the level of expression of the *OsCKX* genes, but not the *OsIPT* genes (Zha et al., 2022).

### 4.4.4. Strigolactones and abscisic acid

Both SLs and Abscisic acid (ABA) is biosynthetically derived from carotenoids. Given their common origins, it is also highly likely that there is an interaction between these two hormones. A strong decrease in SL level was also demonstrated in the analyzes performed on *flacca* and *sitiens* tomato mutants obtained by a mutation at the last step of ABA biosynthesis (Martin et al., 2010). Exogen SL applications have been reported to reduce the damage of drought stress in SL-deficient mutants of Arabidopsis. It has been determined that stoma conductivity increases in drought-sensitive genotypes and stomata closure encouraged by ABA decreases (Ha et al., 2014). In the *Arabidopsis* plant, SL promotes seed germination during heat stress while abscisic acid has a suppressive effect on growth. It is known that SLs regulate seed germination by influencing other hormones (Zhang et al., 2013).

In a study, researchers determined that drought in rice simultaneously induces SL production at the root and ABA production at the shoot, as well as the expression of SL biosynthetic genes. It has been noted that the concentration of ABA in the shoots of the SL biosynthetic rice mutants *dwarf10* (*d10*) and *d17* is higher than in wild types. These differences are even more pronounced in arid conditions. However, it did not bring about an increase in leaf ABA content in rice mutant line *d27*, which carries a mutation in the gene encoding the first processed enzyme in SL biosynthesis. As a consequence of the research, they stated that SL and ABA pathways are related to each other (Haider et al., 2018).

In another study conducted to reveal the relationship between SL-ABA, Wang et al. (2018) ascertained four genes (*HvD27, HvMAX1, HvCCD7,* and *HvCCD8*) involved in SL biosynthesis in barley based on sequence homology. Two transgenic lines that accumulate ABA have been used to investigate the effect of ABA on SLs. Higher ABA levels were confirmed in the root and stem tissues of these transgenic lines by LC-MS/MS analyses. In both lines, lower 5-deoxystrigol was determined in the root, while tillering rate increased. Lower expression levels of *HvD27, HvMAX1, HvCCD7,* and *HVCCD8* have demonstrated that ABA promotes tillering rate in barley by suppressing SL biosynthesis.

A study aimed at uncovering the relationships of SLS with ABA in drought stress was conducted by Ren et al. (2018). The relationship between SL and ABA in salt stress tolerance was investigated in AMF-inoculated *Sesbania cannabina*. SL levels augmented after ABA applications and decreased when ABA biosynthesis was inhibited. The expression levels of SL-biosynthesis genes in plants were augmented with the application of exogenous ABA and $H_2O_2$. Furthermore, ABA-induced SL production was blocked by pretreatment with Dimethylthiourea, which scavenges $H_2O_2$. However, the production of ABA during this process was not affected by Dimethylthiourea. In a conclusion, researchers reported that ABA provides induction of salt tolerance by SL in *S. cannabina* seedlings.

Another study explored the relationship between ABA synthesis and SL biosynthesis in heat and cold stresses in tomatoes (Chi et al., 2021). Some parameters were used to determine the effect of SL on the heat and cold tolerance of tomatoes and these parameters were evaluated in relation to SL. These are ABA production, the accumulation of heat shock protein 70 (*HSP70*), *C-REPEAT BINDING FACTOR 1 (CBF1)* transcription, and antioxidant enzyme activity. Application of GR24 increased heat and cold tolerance. The remarkable conclusion of the research is that the deficiency in ABA biosynthesis inhibited the effects of GR24 on heat and cold stresses. This deficiency eliminated the transcription of genes associated with GR24-mediated *HSP70, CBF1,* and antioxidant enzymes.

Summarizing the results of the study, the researchers remarked that SLs have an ABA-related effect on heat and cold tolerance in tomatoes.

### 4.4.5. Strigolactones and ethylene

Ethylene, a gaseous plant hormone, has an influence on many aspects of plant life, including germination, fruit ripening, aging, and stress responses. These roles of ethylene appear in conjunction with other hormones that partially influence ethylene biosynthesis and signaling pathways. Recently, researchers determined that phytohormones such as GA, ABA, auxin, methyl jasmonate, and salicylic acid regulate the stability of ACC synthases, which are limiting enzymes in ethylene biosynthesis.

SLs interact with ethylene as well as auxins in the regulation of root hair growth (Zhang et al., 2013). In arabidopsis, SL along with ethylene regulated the growth of root hair (Kapulnik et al., 2011). The administration of GR24 up-regulated the expression of the *1-AMINO-CYCLOPROPANE-1-CARBOXYLATE (ACC) SYNTHASE 2 (ACS2)* and *ACC OXIDASE (ACO)* genes associated with ethylene biosynthesis in Arabidopsis (Kapulnik et al., 2011; Lee and Yoon, 2020).

In recent studies, KAR-mediated signaling has regulated ethylene biosynthesis by enhancing *ACS7* gene expression in both Arabidopsis and *Lotus japonicus* (Carbonnel et al., 2020; Villaecija-Aguilar et al., 2021). This outcome confirms the function of KARs in ethylene biosynthesis and perhaps the development of root hairs through ethylene (Villaecija-Aguilar et al., 2021). Researchers pointed out that SLs promote the elongation of primary roots under poor nutrition conditions, but prevent the formation of adventitious roots (Sun et al., 2022).

Lee and Yoon (2020) reported that the administration of SL in languishing Arabidopsis seedlings increases ethylene biosynthesis. They noted that SLs do not affect *ACS* stability or *ACS* gene expression, but augment transcript levels of a subset of *ACO* genes, thereby increasing ethylene biosynthesis.

Accelerated or premature leaf senescence caused by dark conditions is known to be associated with chlorophyll degradation and is also regulated by hormones. A study was conducted to examine the effects of SLs on dark-induced leaf senescence and to explore the interactions of SL and ethylene in this process. *Lolium perenne* was left in the dark for 8 days, and GR24 and aminoethoxyvinyl glycine (AVG) were administered. Also, SL and AVG were sprayed together on leaves. Chlorophyll content, photochemical activity, electrolyte leakage, and ethylene production were measured. Expressions of genes associated with leaf senescence - SL biosynthesis and signal - ethylene biosynthesis and signal-chlorophyll biosynthesis and degradation have been ascertained. The application of GR24 to the leaf supported leaf senescence of the plants in dark and the intensity of senescence increased owing to the increase in GR24. AVG suppresses dark-induced leaf senescence by down-regulating chlorophyll degradation genes and SL synthesis genes. In consequence, they noted that SL and ethylene interactively regulate leaf senescence by controlling for dark-induced chlorophyll degradation in this plant (Hu et al., 2021).

#### 4.4.6. Strigolactones and jasmonic acid

Jasmonates mediate a series of physiological processes during vegetative growth, secondary metabolism, plant-insect and plant-pathogen interactions, injury, etc. (Yan et al., 2007; Yan and Xie, 2015). Owing to the limited number of studies on the SL-jasmonate relationship, this relationship has not yet been fully elucidated. However, the expression of the jasmonic acid (JA) content and *PINII*, a jasmonate-dependent gene (responsible for the tomato's resistance to *Botrytis cinerea*), was reduced in the SL-deficient tomato mutant (*Sl-ccd8*) (Torres Vera et al., 2014). This points to a link between SLs and jasmonates in disease tolerance. Although these results are clearly insufficient to elucidate the mechanism between the two hormones, since both hormones are effective in similar developmental processes (mesocotyl prolongation, senescence, and plant-pathogen interactions), this suggests a relationship between them (Omoarelojie et al., 2019). Another study remarked that SLs promoted the nematode of bacterial crown gall in rice roots by inhibiting the JA pathway, while SL mutants were less prone to being infected by the nematode of bacterial crown gall (Lahari et al., 2019).

#### 4.4.7. Strigolactones and salicylic acid

Salicylic acid (SA) has been associated with biotic stresses by playing a defensive role against various pathogens in plants, but they have also played a role in tolerance to abiotic stresses (Askari and Ehsanzadeh, 2015; Prodhan et al., 2018; Omoarelojie et al., 2019). SA-related stress tolerance is mainly depending on its effects on reactive oxygen species in the plant (Omoarelojie et al., 2019). SA interacts with SLs in plant-fungal symbiosis (Rozpadek et al., 2018). GR24 causes SA buildup in the plant, while SA concentration decrease in SL mutants (*max2*). This indicates that SLs are involved in plant defense by stimulating the production of SA (Rozpądek et al., 2018; Omoarelojie et al., 2019). It has been found that the application of SL and SA to the leaves during drought stress in wheat reduces membrane electrolyte leakage, augments leaf relative water content and antioxidant enzyme activities, and thus creates toleration to stress (Sedaghat et al., 2017).

### 4.4.8. Strigolactones and brassinosteroids

Tillering in cereals is considered to be largely regulated by SLs. The entire SL signaling pathway from the receptor to downstream transcription factors is known to inhibit tillering. In a study conducted in this area, Fang et al. (2020) determined that brassinosteroids (BRs) augment tillering by promoting bud growth in rice, unlike its function in Arabidopsis. Genetic and biochemical analyses have revealed that both SL and BR signaling pathways control rice tillering by regulating the stability of *OsBZR1-RLA1-DLT* and/or *D53*, a transcriptional complex in the rice BR signaling pathway. They also noted that *D53* inhibits the expression of *FC1*, a tillering inhibitor, by interacting with *OsBZR1*. These results point out that SLs and BRs regulate rice tillering in a coordinated manner through the *FC1* gene.

A study was conducted to view whether SL or BRs in peas (*Pisum sativum*) interact with the AON system (autoregulation of nodulation). Double mutants were obtained between shoot-acting (*Psclv2*, *Psnark*) and root-acting (*Psrdn1*) mutants of the AON pathway and between SL-deficient (*Psccd8*) or BR-deficient (*lk*) mutants. The obtained double mutant plants demonstrated the increased shoot branching seen in classical SL deficiency and also demonstrated the extreme dwarf characteristic seen in BR deficiency. However, despite these phenotypic features, supernodulation of the roots was observed in plants with a double mutation causing both BR and SL deficiency. Disruption of the AON pathway did not have a consistent effect on SL production. But *Psrdn1* mutants produced significantly more SL. (Foo et al., 2014).

### 4.5. Gaining Resistance to Plant Stresses

Researchers reported that SLs are involved in ensuring tolerance to different stresses (Trasoletti et al., 2022). It is noticeable that the studies on SL are mostly stress-oriented studies, especially in recent years. For example; stresses such as heat and cold stress (Chi et al., 2021; Omoarelojie et al., 2020); light (low) stress (Mayzlish-Gati et al., 2010; Tian et al., 2018; Zhou et al., 2022); light (high) stress (Thula et al., 2022); heavy metal stress (Niu et al., 2021; Qiu et al., 2021) are the study topics in recent years for investigating the effect of SLs.

Chen et al. (2022) researched the effect of SL application on alkaline stress in soybeans and stated that the application of 0.5 μM SL was effective in preventing this stress. The administration of SL significantly reduced the malondialdehyde content and hydrogen peroxide content in plants and increased the activity of antioxidant enzymes. Furthermore, SL augmented the Na content in the leaves under alkaline stress and diminished the Na content in the roots. Researchers expounded on this situation as SL may have encouraged the transport of Na from the roots to the leaves. In a study conducted on the grapevine (Çetin et al., 2022b), GR24 was applied as a leaf spray to plants grown in different limy environments to determine the effect of SL on protection from stress brought about by high pH and lime. As a consequence of the study, the researchers determined that the phenolic compound contents, which are an important parameter in the stress tolerance of plants, increased with GR24 application, and GR24 application had a great positive effect on the amount of mineral substances in the grapevine leaves. In light of the results, the researchers stated that SLs may be effective in plant nutrition and stress tolerance. Another study determined that SLs positively affected high-light tolerance (Thula et al., 2022).

Although SL application is known to increase plant endurance in arid conditions, more studies are needed to fully understand the mechanism in this regard (Ha et al., 2014, Lopez-Obando et al., 2015; Çetin et al., 2022b). This condition, which significantly postpones the opening of the stoma after the water potential is recovered and is known to be promoted by ABA, has been ascertained as being promoted by SLs in tomatoes. It has been set down that administering GR24 to wild-type tomato plants 24 hours before dehydration prolongs this period (Visentin et al., 2020). Similarly, this process is encouraged by SLs in Arabidopsis (Korwin Krukowski et al., 2022).

Studies have also been executed using mutant genotypes in which SL synthesis or signal perception is altered to study the effects of SLs on stress. Overexpression of the *SsMAX2*, a *MAX2* homolog, from *Sapium sebiferum* in Arabidopsis assured resistance to osmotic stress and augmented proline and soluble sugar content, as well as antioxidant enzyme activities (CAT, SOD and POD), compared to wild type. $H_2O_2$ and MDA concentrations were found to be lower in lines that overexpressed *SsMAX2* (Wang et al., 2019).

## 5. CONCLUSION

The discovery that SLs are carotenoid-derived compounds released from the roots into the rhizosphere was the first piece of information about this hormone. It has been set down that it acts as a signaling molecule both to promote the germination of parasitic plant seeds by releasing from plant roots into the rhizosphere and for hyphal branching in AMFs. However, it is also revealed by studies that it is effective in many developmental processes of the plant and tolerance to biotic-abiotic stresses. Although SLs exhibit synergistic/antagonistic interactions with other hormones in these processes, detailed research is needed to clearly figure out their impact on stress factors.

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