CURRENT AGRICULTURAL STUDIES in TÜRKİYE RESEARCH and REVIEWS II

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PREFACE

Agriculture, forestry and aquaculture are crucial for sustaining livelihoods in rural areas and ensuring food and nutrition security around the world. A significant portion of the world's population depends on agriculture and forests for many needs such as food, feed, and shelter. The fisheries and aquaculture sector plays an important role both in providing a critical portion of animal protein and in providing a source of livelihood for people living in poor and marginalized areas. For this reason, academic studies play a prominant role in providing the necessary knowledge and skills to ensure sustainable development in the agriculture, forestry and aquaculture sectors. To this end, this book provides valuable information on a wide range of topics including new strategies in legume farming, which is an important component of sustainable agriculture, new developments in forestry and aquaculture, the relationship between forage crops and animal nutrition, and the evaluation of ornamental plant diseases.

I would like to thank the valuable chapter authors who shared precious research findings and information in the fields of agriculture, forestry and aquaculture and contributed to science in these fields, and I hope that the book will be an important resource for all stakeholders.

Editör

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CHAPTER 1

A STUDY ON CONFIRMED MAXIMUM SIZE RECORD OF BULLET TUNA (*Auxis rochei* Risso, 1810) FOR ENTIRE TURKISH WATERS

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INTRODUCTION

The family Scombridae comprises 55 species in 15 genera (Eschmeyer's Catalog of Fishes, 2024). As far as is understood, 10 of these species [*Euthynnus alletteratus* (Rafinesque, 1810), *Orcynopsis unicolor* (Geoffroy Saint-Hilaire, 1817), *Auxis rochei* (Risso, 1810), *Scomberomorus commerson* (Lacepède, 1800), *Katsuwonus pelamis* (Linnaeus, 1758), *Scomber colias* (Gmelin, 1789), *Thunnus alalunga* (Bonnaterre, 1788), *Sarda sarda* (Bloch, 1793), *Thunnus thynnus* (Linnaeus, 1758), *Scomber scombrus* (Linnaeus, 1758)] are present in Turkish seas (Fricke *et al*., 2007). Having a yearly distribution along the shore in both tropical and temperate locations, the genus *Auxis* is epi/meso-pelagic, distributed globally in tropical and subtropical waters (Uchida, 1981; Collete *et al*., 1986) and encapsulates only two species, *A. rochei* and *A. thazard* (Baeck *et al*., 2014)

The smallest species of tuna in the world is known to be the bullet tuna (*Auxis rochei* Risso, 1810) (Jasmine *et al*., 2013). Despite being regarded as a very migratory species, not much is known about its range (IOTC-WPNT08, 2008). The species' age determination, gonado-somatic index (GSI), length at first maturity and spawning time were reported by Macias *et al*. (2005; 2006) from the Spanish Mediterranean, by Plandri *et al*. (2008) from the Ligurian Sea, by Valerias *et al*. (2008) from the western Mediterranean Sea, by Bök and Oray (2001) and Karaman *et al*. (2010; 2011) from the Turkish waters. The research has also been conducted on schools' behavior patterns, spawning grounds, and fishing from various regions of the world (Sabatés and Recasens, 2001; Oray *et al*., 2005; Oray and Karakulak, 2005; etc.).

In order to monitor and conserve fish stocks, the fisheries management authorities wish to investigate some biometric data. Fish sampling programs typically yield important results, such as data on fish weight and length. Fish population dynamics require this data in order to determine length and age structures, rates of growth and other factors (Kolher *et al.*, 1995). Two very significant theoretical factors in fisheries science are maximum length and weight (Dulčić and Soldo, 2005). These measurements are incorporated, both directly and indirectly, into the majority of models used in stock evaluations (Borges, 2001). It is noteworthy that techniques for improving our comprehension of community structure and function are becoming more and more common, such as size-based assessments of fish (Jennings and Dulvy,

2005) and when primary data is scarce, it could be a useful tool for quickly evaluating growth rates (Filiz and Sevingel, 2015). These factors make it crucial to keep up-to-date data regarding the largest size of a species that could be used for recreational or commercial purposes in the future (Navarro *et al.*, 2012).

Given that ecological functions and biological rates vary with size, biologists and ecologists need to know with accuracy what the largest fish size found in a population is (Peters, 1983; Pope *et al.*, 2005). For instance, body size is positively correlated with total food consumption and negatively correlated with metabolic rate. A fish's maximum size is directly correlated with its sexual development, size at hatch, lifespan and maturation (Freedman and Noakes, 2002; Vander Veer *et al.*, 2003). This study was carried out to make a contribution to the proven maximum length of bullet tuna (*Auxis rochei* Risso, 1810), which has not been studied in the Turkish seas for more than 10 years.

1. MATERIALS AND METHODS

The Gallipoli Peninsula, the Gökceada and Bozcaada Islands, the Edremit Bay, and Saros Bay are the sub-regions that constitute Türkiye's northern Aegean coasts (Cengiz and Paruğ, 2020). At the point where Saros Bay opens up to the Aegean Sea, it is roughly 61 km long and 36 km wide (Eronat and Sayın, 2014). Since 2000, the bay has been off-limits to bottom trawl fishing (Cengiz *et al*., 2014), and Sarı and Çağatay (2001) noted that nothing industrial was going on in the vicinity, therefore it may be thought of as a virgin ecosystem (Cengiz *et al*., 2015). Due to these factors-including its scenery, geomorphology, ecology, floristic biogenetic, and tourism qualities-Saros Bay and its coastline area was granted SEPA status (Güçlüsoy, 2015) (Figure 1).

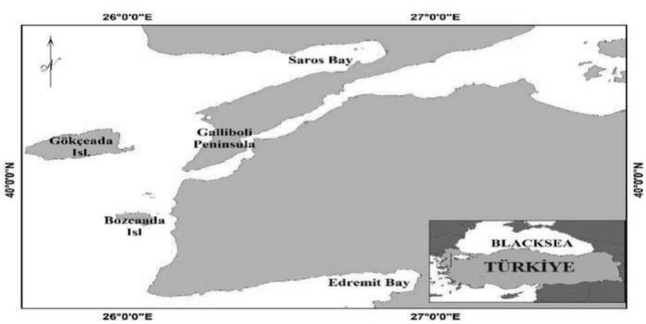

Figure 1. Saros Bay and Türkiye's northern Aegean coastlines

2. RESULTS AND DISCUSSION

A commercial fisherman captured a single *Auxis rochei* specimen on December 11, 2022, at a depth of about 15 meters. The specimen measured 45.0 cm in total length and 1200.00 g in total weight (Figure 2).

Figure 2. Bullet tuna (*Auxis rochei*)

As Turkish waters, 216 specimens were sampled by Karaman *et al*. (2011). They said that the species' length range was 34.0-48.0 cm (FL). However, Bök and Oray (2001) said that the highest size was 44.5 cm (FL). Froese and Pauly (2024) underlined its maximum size value was 50 cm (FL). According to this measurement, it is the world's largest individual.

As is widely known, populations subjected to a great deal of levels of fishing pressure are going to react by having fewer individuals reproduce at average ages and sizes, which could lead to a reduction in the maximum lengths that can be reached. But that kind of length could only be attained by the one individual who was not under the pressure of overfishing (Filiz, 2011). The availability of nutrients, oxygen, nourishment, lighting circumstances, temperature, pollution, current speed, nutritional concentration, salinity, density of predators, intraspecific social relationships and genetics are some of the variables that could effect growth, though. (Helfman *et al*., 2009). These remarks imply that the ecological circumstances and pressure from overfishing determine regional variations in maximum length and weight.

3. CONCLUSION

Given the relevance of the maximum length and/or weight in multiple models of fisheries, such as the Gompertz and von Bertlanffy models of growth (Quinn and Deriso, 1999), these natural habitat measures may provide crucial data that is incorporated into these computations and stock evaluations. So as to benefit fishery management and the global scientific literature, the data in this study could be considered.

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CHAPTER 2

DIGITAL TRANSFORMATION IN LEGUME AGRICULTURE: DATA ANALYTICS AND MODELING STRATEGIES

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INTRODUCTION

Within the recent past, there has been a tremendous adoption of digital agricultural practices aiming at increasing productivity and sustainability in agriculture. Such technological innovation includes, among others, precision farming, smart irrigation technologies, remote sensing tools, data analysis methods, and artificial intelligence, all great factors that have significantly changed the production paradigms of agriculture (Gebbers & Adamchuk, 2010). Digital agriculture can be characterized as the use of facts and communication technologies that seek to enhance agricultural processes and give better productivity indicators (Wolfert et al., 2017). More importantly, in recent years, the incorporation of sensor technologies, together with analyses powered by artificial intelligence, has established digital agriculture as one of the main tools within the decision-making frameworks used by farmers. One of the studies by Yeo et al. (2014) showed that the adoption of precision agriculture practices could bring about 20% savings in the use of fertilizers and water. It thus gives insight into the critical role played in digital agriculture, more so in addressing concerns such as climate change and the scarcity of water resources.

Remote sensing technology is an important part of digital agriculture, which enables the full monitoring of agricultural environments and the timely evaluation of data (Zhang et al., 2019). Satellite- and drone-imaging technologies are used in different ways, including monitoring plant growth and detecting diseases and pests (Li et al., 2020). This gives the farmers more informed options regarding land management, resource utilization efficiency, and sustainable production methods.

One more important technology used in digital agriculture is IoT (Internet of Things) devices. These devices will be helpful in the continuous observance of different variables, such as soil moisture, temperature, pH, etc., in the agricultural field and instant evaluation of these data (Kumar et al., 2021). So, the farmers can provide optimum productivity by instantly intervening in field conditions. Artificial intelligence and machine learning algorithms are more prominently used due to their greater importance in the analysis of such data and in predictions for future scenarios (Jha et al., 2019).

Furthermore, big data analytics in the domain of digital agriculture has revolutionized agricultural management practices. Big data analytics allows for the strategic planning of future agricultural activities by gleaning insights from past data, and it improves resource utilization (Wolfert et al., 2017). Such as, Devlin et al. (2020) showed that, through the use of big data analytics, the most favorable time of sowing in terms of meteorological and soil conditions was determined, leading to a 25% increase in crop yield.

Importance of Legume Production

Legumes are internationally recognized as the main source of proteins and play a key role in human nutrition and soil fertility improvement (Miller et al., 2015). These crops harbor nitrogen-fixing abilities that improve the natural composition of the soil, reduce the need for fertilization, and sustain agricultural production practices (Peoples et al., 2019). Therefore, sustainable increases in legume production relate to overall efficiency in the field of agricultural production and ecosystem health.

Leguminous crops, like lentils, chickpeas, beans, and peas, maintain the nitrogen balance in agroecosystems and are a cheap source of protein, hence improving food security (Stagnari et al., 2017). Therefore, the cultivation of legumes through sustainable means is becoming very important for improving food security, especially in developing countries. Recent studies have shown that the use of digital agriculture methods has tremendously increased in the production of legumes (Bohra et al., 2020). El-Sappagh et al. (2021) have proved that using drone-based imaging, supported with AI-enhanced data analytics, helps in early diagnosis of disease symptoms in chickpea cultivation, which reduces crop losses by 15%.

Digital agricultural practices increase the productivity of legume crops while simultaneously reducing environmental impacts. For instance, using sensor- and drone-based technologies may optimize fertilizer and pesticide applications, lowering the adverse environmental impacts caused by agricultural practices (Basso et al., 2018). Additionally, water resources can be managed in an efficient way, which becomes a great advantage when considering legume production. The function of smart irrigation systems in conserving water resources is to regulate water use according to soil moisture and plant needs (Mote et al., 2021).

Research on digital agriculture and leguminous crop production reveals that each domain has great benefits and may increase agricultural output when combined (Tripathi et al., 2022). The application of precision agriculture techniques in the production of legumes is indispensable for the realization of both increased productivity and improvement in environmental sustainability. For instance, in the study by Pandey et al. (2023), up to 30% yield increases in chickpea and lentil production are reported using sensors and data analytics. Such applications not only increase the economic gains of farmers but also contribute much toward meeting sustainable agriculture goals.

Digital agricultural practices are increasing the importance of legumes in farming systems while maximizing the environmental benefits brought about by the plants. More precisely, Hassani et al. (2022) found that using soil moisture sensors together with drone imaging enabled better disease identification and water-stress control in legume farming, increasing yield up to 35%. Also, by using digital agricultural technologies, the potential for nitrogen fixation by legumes could be observed and enhanced, thereby increasing soil fertility and decreasing reliance on synthetic fertilizers (Peoples et al., 2019).

In legume production, digital agriculture practices have transformed the traditional agricultural process into an efficient and sustainable production process. Most of the literature has noted that technologies do not only increase yields but also reduce environmental impacts in legume agriculture. The potential use of digital agriculture in legumes is therefore great and very promising for the future of agricultural production. Integration of digital technologies throughout the production chain is expected to lead to a substantial increase in productivity and sustainability, particularly for critical crops that are of strategic importance, such as legumes.

DATA COLLECTION TECHNOLOGIES

Gathering data technologies are critical to modernizing and digitizing agricultural operations. This process's technology has greatly improved the efficiency and sustainability of agricultural activities. Digital farming methods employ a variety of data collecting approaches to boost agricultural output. Sensors, remote sensing technology, and big data analytics enable agricultural decision-making that is more informed and data-driven. This section will give a thorough literature study on how these technologies are employed and the advantages they provide in agriculture.

Data and Data Collection Techniques

1. The application of data acquisition technologies plays a pivotal role in the modernization and digitalization of agricultural methodologies. The advancements in this technological domain have significantly enhanced the efficacy and sustainability of agricultural operations. Digital agricultural methodologies incorporate an array of data collection techniques aimed at augmenting agricultural productivity. The implementation of sensors, remote sensing technologies, and advanced data analytics facilitates a more informed and data-centric approach to agricultural decision-making. This section will present a comprehensive literature review regarding the application of these technologies and the benefits they confer within the agricultural sector.
2. **Sensors:** Sensors are one of the most used data collection tools in agriculture. Sensors assist farmers in making decisions by delivering real-time data at every level of agricultural activity (Kumar et al., 2021).
3. **Satellite and Drone Imaging:** Remote sensing technologies are used to monitor agricultural land and determine plant growth. Satellite and drone imagery provide large-scale monitoring of situations such as plant health and water stress (Zhang et al., 2019).
4. **IoT (Internet of Things) Devices**: IoT devices are used to gather agricultural data, transport it to cloud-based systems, and analyze it. IoT technology allows for the automation of agricultural operations and increased production (Mote et al., 2021).
5. **Meteorological Stations:** Meteorological stations are used to collect data on meteorological conditions that impact agricultural operations. These stations aid to agricultural activity planning by providing data such as temperature, humidity, and rainfall (Wolfert et al., 2017)..
6. **Handheld Devices and Mobile Applications:** Farmers utilize handheld gadgets and smartphone apps to capture agricultural data quickly in the field. This data may be immediately linked into agriculture systems that support decisions (Tripathi et al., 2022)..

Data collecting techniques enable agricultural operations to be managed more efficiently and sustainably. With these tools, farmers may boost production and save expenses by making educated decisions on topics such as crop growth, fertilizer and water demands, and prevention of diseases and pests (Devlin et al., 2020).).

Remote Sensing and Big Data

The methodologies associated with remote sensing technologies are of paramount significance in the field of agriculture, as they provide a foundational framework for the monitoring, evaluation, and enhancement of agricultural methodologies. These technologies facilitate the remote surveillance of agricultural environments through various instruments, such as satellites and drones, thus enabling the observation of extensive agricultural expanses (Zhang et al., 2019). This technological advancement yields substantial advantages for agronomic specialists across multiple dimensions, encompassing the analysis of vegetative health, evaluation of soil quality, management of hydric stress, and timely identification of plant diseases. A research endeavor conducted by Li et al. (2020) revealed that yield enhancement was realized through the surveillance of plant development utilizing remote sensing technologies, which facilitated optimization in the application of fertilizers.

In addition to augmenting the productivity of agricultural endeavors, remote sensing technologies play a crucial role in the optimization of resource utilization. For instance, the continuous surveillance of soil and vegetative conditions could be accomplished through the integration of these technologies, thereby ensuring the appropriate and timely application of water and nutrients (Basso et al., 2018). Such practices are likely to not only elevate financial returns but also contribute to the sustainability of ecological systems. The concept of big data emerges as a vital instrument in the enhancement of efficiency and sustainability within agricultural production. The exploration of huge datasets in agriculture requires the thorough examination of extensive collections of data sourced from multiple avenues, including sensors, remote sensing apparatus, and other data-collection instruments, with the objective of employing the insights garnered from these evaluations in the decision-making frameworks tied to agriculture (Wolfert et al., 2017). This capability to analyze substantial datasets provides the foresight requisite for informed decision-making in agricultural planning, thereby facilitating improvements in agricultural productivity (Devlin et al., 2020). Remote sensing technologies are instrumental in the acquisition of big data. Sensors embedded in devices such as satellites and drones are perpetually collecting data from the agricultural ecosystem and employing big data analytics for the assessment of this information (Tripathi et al., 2022). A 2020 investigation carried out by Devlin and others indicated that through the scrutiny of information acquired via remote sensing and big data analytics, the prime planting timeframe was identified in relation to existing climate conditions and soil factors, resulting in a yield increase of 25%. The integration of remote sensing technologies with big data analytics serves to enhance agricultural practices and empowers farmers to make more informed decisions. This synergy has fostered not only economic viability but also environmental responsibility in the domain of agricultural production (Wolfert et al., 2017)..

SENSORS AND THEIR USE IN AGRICULTURE

Sensors are fundamentally characterized as instruments that discern variables in the physical milieu and, through a process of transduction, convert these variables into quantifiable signals. In the realm of agriculture, sensors facilitate enhanced management of agricultural practices by enabling the monitoring of critical parameters such as soil moisture, temperature, pH levels, and nutrient composition (Kumar et al., 2021). This process generates pertinent data for the judicious application of water, fertilizers, and other essential inputs required by crops, thereby augmenting productivity while simultaneously ensuring the judicious utilization of resources (Jha et al., 2019). The incorporation of sensors in agricultural practices is of paramount significance concerning the applications of precision agriculture. Precision agriculture aims to administer agricultural inputs in optimal quantities, thereby promoting more efficient and sustainable production through the application of valuable data derived from sensors for this objective (Hassani et al., 2022). Sensors empower farmers to observe field conditions in real time, thus facilitating prompt interventions when necessary. Certain sensors, such as soil moisture sensors, ascertain the necessity for irrigation, consequently conserving water while also upholding favorable growth conditions for crops (Mote et al., 2021).

Sensor Types and Usage Areas

There are different types of sensors used in agriculture and each is used for different purposes:

1.Soil Moisture Sensors: These sensors detect the quantity of moisture in the soil and estimate watering requirements. This allows plants to be irrigated optimally while avoiding needless water stress (Mote et al., 2021).

2. Temperature Sensors: Plant growth and development are temperature dependent. Temperature sensors monitor ambient and soil temperatures, ensuring that plants develop at an appropriate temperature (Kumar et al., 2021)..

3. pH Sensors: The pH of the soil influences how plants take up nutrients. pH sensors detect soil acidity or alkalinity and enable for soil conditioner treatments as needed (Li et al., 2020).

4. Electrical Conductivity (EC) Sensors: These sensors assist farmers in optimizing fertilization decisions by detecting the concentration of nutrients in the soil (Hassani et al., 2022)..

5. Air Quality and Gas Sensors: These sensors measure the levels of carbon dioxide and other gases to offer information on plant photosynthesis and air quality (Jha et al., 2019)..

Sensors in agriculture boost production and product quality while also helping to preserve the environment. Sensors allow agricultural inputs (water, fertilizers, insecticides, etc.) to be administered at the optimal amount and timing, lowering costs while also reducing negative environmental consequences.

AGRICULTURAL MODELING AND USES

Approaches such as modeling and decision support give farmers tools to make better data-driven decisions in agricultural production. Agricultural modeling is one of the strategies used in agriculture to improve the efficiency and sustainability of production processes. These models combine climate data, soil properties, water and crop data to make predictions on how the agricultural production processes can be optimized (Jones et al., 2017). The use of Ag modeling helps optimize ag-related activities like cropping planning, irrigation managementf, fertilization and pest control. So, it helps farmers to take better decisions and handles agronomical processes in an enhanced way; as risk reduces. Models like DSSAT (Decision Support System for Agrotechnology Transfer) and APSIM (Agricultural Production Systems sIMulator) have gained widespread usage in (Jones et al., 2003). What it is: Agronomic modeling can also be applied for investigation of responses in crops to environmental stresses due to climate change. This is a crucial aspect of sustainability production planning with particular reference to the agricultural sector, which has been struggling to support rapid population expansion while simultaneously dealing with limited resources. Such as simulation of agricultural plant growth, moisture and nutrient cycling processes in the various production systems to improve agricultural productivity through APSIM model (Holzworth et al., 2014).

Legumes have unique features and production processes that can be studied during agricultural modeling. Legumes are essential crops that enhance soil fertility by increasing nitrogen content of the soils. We model these kinds of crops to better understand processes like nitrogen fixation, and water + nutrient use. In a study by Ahmed et al. Abstract (209 characters): The APSIM model is accurate for simulating the water and nutrition use of legumes with improvements in the productivity of legumes simulated due to high potential returns on investment. Abstract With the current scenario of climate change, gaining insights about how crops like legumes can adapt to environmental stress conditions, in particular with respect to drought response both at plant as well as soil-root systems levels are a must for cultivation of these crops more sustainably. DSSAT model has also employed to understand ligume growth processes and responses. In one such study, the DSSAT model was used to assess the water and nitrogen needs of legumes for a number of climate scenarios and determined rational planting time and fertilization strategies (Boote et al. 2013). This allows farmers to model resource usage for increased yielding while supporting environmental sustainability.

Studying leguminous crops in agricultural research is important for revealing how shifting climate conditions influence these species, along with crafting fitting adaptation strategies. By employing agricultural modeling methodologies, researchers can gain enhanced insights into the adaptive mechanisms of legumes in response to diverse climatic variables and the management of these adaptive processes. This knowledge enables legume cultivators to mitigate risks and secure sustainable agricultural practices. Moreover, such models are exceptionally beneficial for the design and administration of agricultural systems that exhibit increased resilience to the challenges posed by climate change (Lobell et al., 2008). The integration of agricultural modeling and investigations pertaining to legumes is crucial for fostering sustainable agricultural practices, optimizing the utilization of natural resources, and minimizing ecological repercussions. These inquiries capitalize on the nitrogen-fixing capabilities and soil-enhancing attributes of legumes to bolster soil health and promote crop yield.

Artificial Intelligence and Machine Learning

Artificial intelligence (AI) and machine learning (ML) are widely used technologies to increase yields and optimize farming systems in agriculture AI and ML analyze large amounts of data and extract meaningful information, and inform farmers allow for better decision making (by Kamilaris & Prenafeta - Boldú, 2018). For example, machine learning algorithms are used to rapidly detect and classify plant diseases, thereby reducing crop losses (Singh et al., 2018). By analyzing sensor data, machine learning can optimize the use of water and fertilizers, and contribute to more efficient use of resources (Sharma et al., 2020). Furthermore, AI can be used for tasks such as harvesting, irrigation and pest management in agricultural robotic applications (Aravind et al., 2021). These technologies can make agriculture more predictable and efficient. AI and ML technologies reduce uncertainty in agricultural production, reduce risks and provide farmers with flexibility to adapt to climate change and other external factors (Liakos et al., 2018). The application of this technology has great potential to increase seed production and environmental sustainability in agricultural production.

Decision Support Systems

The decision support system (DSS) enhances the ability of farmers to make rational decisions based on collected data in relation to agricultural production. The systems aid in the better management of agricultural processes through the integration of various sources such as sensors, remote sensing and big data (Choudhary et al.,2015). A CDS assists farmers to implement the suitable measures at the appropriate time and in the most cost-effective way. In agribusiness, however, an effective decision support system concentrates on production as well as resources management. For instance, if farmers are advised through CDS about the timing of irrigation and rates of fertilizer applications, they are likely to attain higher and quality yields (Jones et al., 2003). DSSAT (Decision Support System for Agrotechnology Transfer) is a type of CDS that allows the user to design the growth processes of various crops and gives information on fertilization, irrigation, and harvest planning for farmers. In such scenarios, these systems allow for less uncertainty in the agricultural processes enhancing better management decisions by the farmers.Support of decisions is also needed for climate change and for reaching goals of sustainable development of the environment. Such systems ensure that improved and precise decisions can be made on agricultural processes, which are variable with respect to climate change and the environment (Thorburn et al., 2011). Also the use of CDS allows farmers to respond quickly and appropriately to issues such as pest and diseases (Dutta et al., 2015).

Currently, given practicing digital agriculture, CDSs are gaining popularity in the agricultural sector. Moreover, these systems are beneficial for economical profitability and environmental reasons in addition to raising production efficiency in agriculture (Thorburn et al., 2011). For instance integrated decision support systems are a complete management that covers aspects such as soil, water, air and crops data. Such systems facilitate optimization of resource use and therefore reduce costs of production as well as minimizing the effect that agricultural activities have on the environment (Jones et al., 2017). With regard to risk management and crisis response in agriculture, it is also noteworthy to find out that CDSs have particular importance. For instance, CDSs bonded with early systems of warning against disasters such as storms enable farmers to protect crops as they anticipate possible impacts of such disasters. This makes the production in agricultural sustainable and plays a big role in food security (Thorburn et al., 2011)..

Yield Estimation and Applications

Yield forecasting in agriculture is a very useful management technique to ensure production planning in agriculture. Yield estimation is therefore the way in which a range of evidence is used to extrapolate the rate that a certain area or piece of land can yield. Such forecast implies the use of climate data, soil type, plant vigour, amount of irrigation among other environmental factors (Liakos et al., 2018). These data prove to be the most useful in minimizing risks in producing agricultural outputs or make better decisions with regards to these. When the effects of climate change are not very predictable, yield forecasting is a tool that improves farmers' outlook for the future.

While employing the methods for yield forecasting it is important to note that more organizations are employing artificial intelligence and machine learning in the process. These methods give better accuracy in yield forecasting and enable the farmers to control the agricultural procedures (Sharma et al., 2020). For instance, artificial neural networks, support vector machines (SVM), as well as decision trees have been accustomed in yield forecasts and are successful in their outcome. Singh et al. (2020) pointed out in their study the finding that machine learning algorithms achieve high accuracy in the prediction of corn yield.

Yield forecasting is also of great importance in increasing the development and practice of sustainable agriculture. The accuracy of these estimates minimizes the effects on the environment by eliminating the overuse of fertilizers and water (Kamilaris, & Prenafeta-Boldú, 2018). Especially, using fertilizer and water at the right time and right amount results in economic benefits and enables operations that are friendly to the environment. Advanced technologies like remote sensing coupled with big data analytics are among today's technologies that facilitate continuous monitoring of large areas of agricultural lands as well as better yield estimations (Tripathi et al., 2022).

The areas of the application with the Yield Estimation Technique are also broad. As for the agricultural insurance, the yield forecasts are applied to cover producers' losses. When the yield of the crop is properly estimated, the insurance firms can set better premiums to charge to the producers besides paying adequate compensation. In another case, in agricultural advisory services yield forecasting offer advice to growers particularly on planting period, fertilizer and watering rates. Thus, yield forecasts combined with smart agricultural technologies produce decision-making support in real-time to farmers and enhance the yield (Kamilaris & Prenafeta-Boldú, 2018).

Over and above yield determination, remote sensing technologies also have a useful role to play. Crop health condition and growth status of large agriculture fields are checked by satellite and drone imaging technologies and dependence of yield is calculated by the collected data (Zhang et al., 2019). Thus, it is possible to observe vast territories and emerge measures if necessary, as far as it is applicable. For instance, applying remote sensing data in plant growth, and then, feeding the acquired information for each analysis to AI algorithms yields more accurate results in yield estimation (Tripathi et al., 2022).

It has the important role in yield prediction and measuring effects of climatic shocks on the agricultural sector, designing ways of coping with the situations. Based on the loss of production, yield prediction models can be applied to assess the effects of climate change in agricultural production and different possible solutions presented to farmers to safeguard them against them. This keeps the sustainable production of agricultural crops and at the same time makes the production process more economically secure to the farmers (Boote et al., 2013).

Soil and Plant Nutrient Models

These models are aimed at improving soil community and nutrient conditions for agricultural production to increase the amount of soil fertility and to provide the plants with the right nutrients available through a modelizer (Jones et al., 2017). These models, which evaluate physical and chemical properties of the soil, assist with applying the amount and nutrients at the right time which plants need. To illustrate, DSSAT based models optimize fertilization strategies by simulating amounts of nutrients in the soils and how plants use them (Jones et al., 2003).

Soil and plant nutrient models play critical roles in addressing problems of resource scarcity and climate change. These models prevent misuse and overuse of the fertilizers, so it is possible to be environmentally sustainable and save money (Thorburn et al., 2011). Stöckle et al. (2014) developed the CropSyst model, a simulation model that optimizes agricultural production by running: plant growth, nutrient cycling and water management. Such modeling approaches are an important means of advancing the sustainability of agriculture and lowering the environmental impacts associated with agriculture. Farmers also get information on which fertilizers to use, when to use them and in what quantity through soil and nutrient models, thereby increasing productivity. This enables more data-based, agriculture-informed decisions (Boote et al., 2013). They also help lessen risks from agricultural production and also enhance product quality.

Water Management and Smart Irrigation

Unfortunately, water management is a critical issue in achieving efficient and sustainable agricultural production. Smart irrigation systems (Sharma et al., 2020) have the advantage of limited water resources and efficient water use in agricultural activities. An irrigation management where various sensors are used and data points collected to make use of the water in the most efficient and clocky manner, known as smart irrigation. This helps to always give plants the right amount of water they require and prevents unnecessary use of water resources.

Smart irrigation systems based on IoT have automatic irrigation schedules created by analyzing data from soil moisture sensors (Mote et al., 2021). Preventing waste of water contributes to the cost reduction and increase of productivity using these technologies. Water management with precision irrigation systems is one of the most effective tools in water management and highly supportive of agricultural sustainability, especially at times of water scarcity such as drought (Basso et al., 2018). Water management is also widely used in water management with remote sensing and drone technologies. These technologies allow for monitorying of water stress status in large areas and providing the required irrigation for them with the precision (Zhang et al., 2019).

Moreover, big data analytics can further optimize water management by helping improve understanding of plants’ water needs and the most efficient water use of water (Wolfert et al., 2017). Smart irrigation practice and water management combine to increase agro productivity as well as environmental sustainability. Use of these systems provides significant advantages for farmers in terms of energy and water saving. They show that smart irrigation increases productivity while at the same time minimizing environmental impacts in agricultural production (Tripathi et al., 2022).

Smart Agriculture Technologies

As part of the ongoing digitalization and automation in agriculture, smart agricultural technologies provide innovative solutions aimed at enhancing productivity throughout all stages of agricultural production. These technologies facilitate more efficient and effective management of agricultural processes by utilizing sensors, GPS-based systems, drones, robots, the Internet of Things (IoT), and artificial intelligence algorithms (Wolfert et al., 2017). By optimizing the use of water and fertilizers, these systems contribute to cost savings and environmental sustainability. Additionally, smart agricultural technologies empower farmers to make data-driven decisions in real-time, leading to increased crop yields.Recent studies highlight the benefits of smart agricultural technologies in farming. For instance, research by Li et al. (2020) found that IoT-based irrigation systems can reduce water usage by 30% while boosting plant productivity compared to conventional irrigation methods. Another study pointed out that artificial intelligence algorithms enable early detection of plant diseases, significantly minimizing crop losses (Singh et al., 2021). With smart agriculture applications, farmers can monitor the health of their crops across their fields and enhance yields by making timely interventions.

In the case of crops like legumes, smart agricultural technologies allow for precise management of water, fertilizers, and pesticides. For example, smart irrigation systems can quickly assess the water needs of plants, preventing unnecessary water waste (Sharma et al., 2020). Soil sensors provide valuable insights for fertilization by continuously monitoring soil conditions to meet the nutrient requirements of legumes (Tripathi et al., 2022). The implementation of smart agriculture technologies in legume farming promotes sustainable practices by ensuring more efficient water use, particularly during periods of drought and water scarcity.

PRECISION AGRICULTURE AND PRODUCTIVITY

Precision farming, which is the environmentally friendly approach for crime control, comes into force when agriculture uses less energy and resources that are produced across different agricultural stages. Precision agriculture applications are the most successful by providing perfect management of soil and plants by using technologies such as remote sensing, data analytics, GPS, drones, and sensors (Zhang et al., 2019). It enables accurate fertilization and chemical usage in areas (agricultural) where there is not enough accumulation, hence, preventing the loss of resources.

In legume crops, precision agriculture methods make it possible for plants to receive the right amount of water and fertilizers by constantly monitoring soil nutrient status and moisture content (Jones et al., 2017). Not only this but the techniques of precision agriculture are applicable in determining the plant growth process and very early detection of diseases. Additionally, the use of drones and multi-spectral cameras in agriculture can help health monitoring and even the early detection of diseases and pests (Zhang et al., 2019). Farmers who implement these practices would become better economically thereby supporting the earth. Precision farming is a management approach in farming that enables the farmer to manage resources that include water and fertilizers inflexibly or precisely in legume cultivation and to produce high-quality crops as well as reducing the cost (Boote et al., 2013).

Drone Applications

Drone applications represent a significant advancement in modern agriculture, playing a crucial role in various stages of farming. They enhance efficiency in numerous areas, including large-scale monitoring of farmland, assessing plant health, and optimizing irrigation and fertilization practices (Zhang et al., 2019). In particular, drone technology is highly beneficial for legume farming, as it simplifies the process of monitoring extensive agricultural fields and evaluating plant growth.

Drones assess plant health by capturing multispectral and thermal images of the field, which helps boost productivity in agricultural production. These images deliver detailed insights into the health of the plants, enabling more precise and efficient applications of fertilization, irrigation, and pest control (Basso et al., 2018). For instance, data collected from a drone can reveal nitrogen deficiencies in specific areas of a field, allowing farmers to target fertilization only where it's needed. This approach optimizes fertilizer usage and minimizes environmental impact (Mote et al., 2021). Moreover, using drones for spraying and fertilization reduces labor costs and enhances product quality by ensuring that pesticides are applied accurately to designated areas.

These technologies provide significant time and cost savings, particularly for farmers cultivating legumes over large expanses (Tripathi et al., 2022). The adoption of drones facilitates quick interventions and effective management in agriculture, leading to reduced crop losses and a notable increase in agricultural productivity.

Digital Agriculture Training

Digital agriculture training comprises activities that teach farmers how to properly employ digital agricultural technologies. These trainings teach farmers how to use current technology like sensors, drones, IoT-based devices, and data analytics into agricultural production operations. Digital agricultural training assists farmers in increasing output, lowering expenses, and ensuring environmental sustainability (Koutsouris 2018). Through digital agricultural training, legume growers, in particular, can optimize water and fertilizer consumption while also improving product quality.

Digital Platforms for Farmers

Farmers' digital platforms are online applications that promote access to agricultural information, data exchange, and agricultural process management. Weather predictions, crop disease warnings, marketing information, and agricultural advise are among the services offered by these platforms to farmers (Ferris et al., 2017). Platforms providing agricultural consulting services, for example, can assist legume producers in optimising their production processes by giving information on which fertilizer to apply and when. These digital platforms also enable farmers to share their skills and experiences.

Data Security Issues

With the increased use of digital technology in agriculture, data security concerns are becoming more acute. Data obtained from farmers' fields and production operations might raise questions regarding how the data will be maintained and disseminated (Wolfert et al., 2017). Data security entails preserving agricultural data ownership, preventing unwanted access, and safeguarding farmers' private information. As a result, implementing data security measures while using agricultural digital technology is critical. In particular, the confidentiality of data collected from legume farmers' fields is important to the acceptability and spread of these technologies.

Socio-economic Opportunities and Challenges

Digital agricultural technologies present both opportunities and challenges from a socio-economic standpoint. On the one hand, these technologies can help boost farmers' incomes and lower costs by enhancing agricultural productivity. On the other hand, there are significant hurdles in accessing and utilizing these technologies (Eastwood et al., 2019). Small-scale farmers may struggle to adopt digital agriculture due to high expenses and a lack of information. Nevertheless, these technologies hold substantial promises for legume producers, enabling them to increase productivity and use natural resources like water more efficiently. Consequently, it is essential to develop policies and training programs that promote access to digital agricultural technologies.

AGRICULTURAL TECHNOLOGIES OF THE FUTURE

Technology is going to bring a lot of new tools into farming, like artificial intelligence, machine learning, robots, genetic engineering, and biotechnology. Most of the improvements will focus on making farming more efficient, resource-use more efficient, and supporting a healthy environment (Rose & Chilvers, 2018). For instance, the farming robot reduces the labor costs due to its ability to automate weed control in legume farming. Moreover, machine learning tools can check how healthy plants are. This helps find diseases early and allows for quick action (Liakos et al., 2018). In the future, it is expected that these technologies will further expand and become even more applied in farming.

Sustainable Agriculture Strategies

Sustainable agricultural practices concentrate on optimizing the processes of production in agriculture to achieve goals that pertain to environmental, economic, and social sustainability. These practices include proper utilization of resources such as water, soil, and nutrients, along with the conservation of biodiversity and reduction in the environmental effects that arise due to agricultural activities (Pretty, 2008). Leguminous crops are quite important for sustainable agriculture since they enhance the nitrogen content in the soil. Adopting sustainable practices in legume production means great gains in productivity and soil health.

Legumes contribute much to sustainable agriculture by ability in increasing soil quality and supporting low-input agricultural practices. In the root nodules of legumes, Rhizobium bacteria help in the fixation of atmospheric nitrogen, thereby increasing the natural nitrogen content of the soil. This advantage is not only limited to the legumes themselves, but also spreads to many other plants (Peoples et al., 2009). The above features not only help in reducing the cost but also in controlling environmental pollution by decreasing reliance on chemical fertilizers. In addition, legume rotation with other crops enhances soil fertility, reduces erosion, and prevents disease prevalence (Stagnari et al., 2017). Legumes use water very efficiently, which makes them good for farming in places with not much water. Their deep roots help them take up water better, so they can produce a lot even when it's dry (Kerr et al., 2018). So, using legume farming in practice with careful irrigation methods and new technologies in farming makes the best use of water resources to help sustainable farming practices.

Such sustainable farming practices, for example, include using organic fertilizers, effective watering systems, crop rotation, and natural pest control measures. Incorporating legumes into crop rotation improves soil fertility and reduces the use of chemical fertilizers, thus saving the environment.

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CHAPTER 3

ARTIFICIAL INTELLIGENCE BASED NUTRIENT MANAGEMENT STRATEGIES IN LEGUME FARMING

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INTRODUCTION

Legumes have an important place in sustainable agricultural practices. Legumes reduce the need for chemical fertilizers by adding nitrogen to the soil through biological nitrogen fixation and contribute to ecosystem services. Legumes are among the preferred plants in sustainable agriculture because they improve soil structure, increase organic matter content and prevent erosion. In addition, their use in agricultural practices such as rotation helps to rest the soil and suppress harmful organisms (Rufaioğlu and Tunç, 2024). In addition, legumes are of great importance for global food security and sustainable agricultural practices. These plants increase the natural fertility of the soil by fixing nitrogen and contribute greatly to agricultural systems by meeting nitrogen needs (Mus et al., 2019). Although traditional nutrient management methods are effective to a certain extent in meeting the nutrient requirements of legumes, these methods may be insufficient in the face of the complex structure of agriculture and changing environmental conditions. Digitalization and artificial intelligence-based solutions offer new opportunities to make nutrient management processes in agriculture more efficient and sustainable (Basso & Antle, 2020).

Legumes have the ability to fix nitrogen from the atmosphere by establishing a symbiotic relationship with Rhizobium bacteria (Verzeaux et al., 2016). Thanks to this feature, they increase the fertility of the soil by providing significant amounts of nitrogen both to themselves and to the plants to be grown afterwards. However, legumes need to be properly supplemented for other nutrients, especially phosphorus, potassium and micronutrients. Phosphorus is particularly critical for legume root nodule development and nitrogen fixation (Khan et al., 2018). Conventional nutrient management methods are used to meet deficiencies of these nutrients but may not be sufficient, especially in large and diverse agricultural landscapes (Behera et al., 2021).

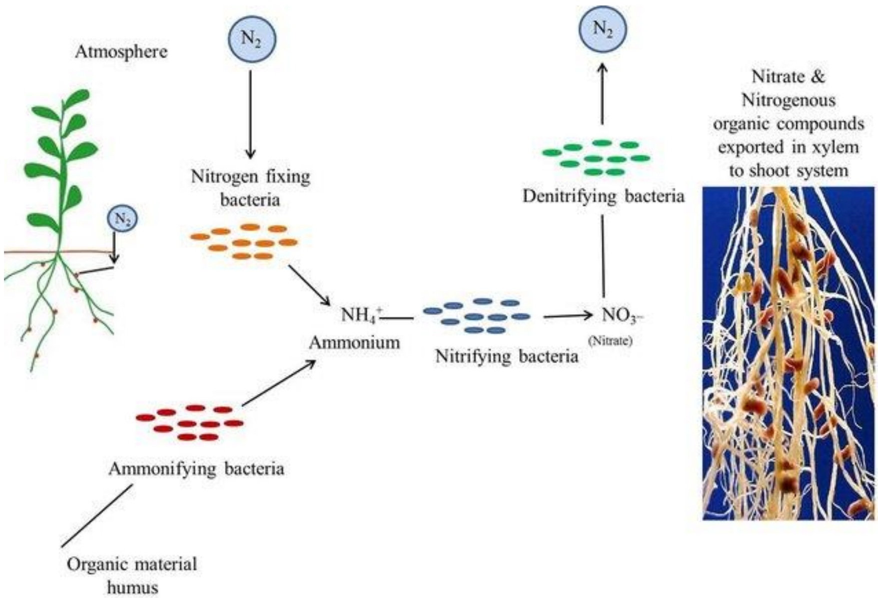

Figure.1. Atmospheric nitrogen fixation by microorganisms (Shah et al.,2017).

Artificial intelligence offers the potential to revolutionize agricultural nutrient management. This technology is of great benefit in analyzing agricultural data and developing optimal nutrient management strategies (Basso and Antle, 2020). By using machine learning and deep learning algorithms, data from soil, plant and environmental factors are analyzed to determine the most appropriate nutrient management strategies for agricultural production. AI-based nutrient management systems allow farmers to optimize nutrient applications in real time, which helps to meet the nutrient needs of plants at the right time and in the right amount (Sharma et al., 2020). For example, multiple data sources such as soil analysis, plant growth status and weather data from agricultural fields are processed instantly and nutrient management decisions are made based on these data (Jones et al., 2019). This process provides a precision in agriculture that cannot be achieved with traditional methods and makes it possible to meet the nutrient requirements of plants in the best possible way. AI-based nutrient management systems offer many advantages in legume agriculture. Economically, these systems can reduce costs for farmers by enabling more efficient use of nutrients. For example, avoiding unnecessary use of nutrients such as phosphorus and potassium can lead to a significant reduction in input costs (Mulla, 2013). On the environmental side, precise application of nutrients minimizes negative environmental impacts such as water pollution and soil degradation (Behera et al., 2021).

Furthermore, thanks to AI-enabled sensors and satellite imaging techniques, plant growth can be monitored remotely, allowing for more effective management of farmland (Jones et al., 2019). This technology increases agricultural productivity by enabling a management strategy based on the individual needs of plants, rather than a homogeneous application of nutrients over the entire agricultural area. In addition, the integration of AI and remote sensing technologies offers significant advantages in the management of agricultural activities such as plant health, harvest forecasting, irrigation and fertilization. AI-supported analyses contribute to more efficient and sustainable management of agricultural processes (Rufaioğlu and Kaplan, 2024).

AI-based nutrient management applications in legume agriculture play a critical role in the future of sustainable agriculture. With significant potential to ensure food security, these technologies also support environmental sustainability (Van Es & Woodard, 2017). For example, they contribute to the conservation of water resources by reducing unnecessary fertilizer use and improve soil health (Basso & Antle, 2020). The diffusion of AI technologies will contribute to increasing agricultural productivity and improving the economic situation of farmers, while minimizing environmental risks (Sharma et al., 2020).

This book chapter will provide a broad review of how artificial intelligence (AI)-based nutrient management strategies can be used in legume agriculture, the advantages of these technologies and their contribution to sustainable agriculture. AI technologies aim to increase crop productivity by more accurately determining and optimizing the nutrient needs of legumes. These approaches can support environmental sustainability while reducing input costs in agriculture (Van Es & Woodard, 2017).

1. LEGUMES AND NUTRIENT REQUIREMENTS

Legumes (Fabaceae) play an indispensable role for both human beings and nature due to their high nutritional value and ability to fix nitrogen. However, their agricultural value and role in nutrition have been emphasized in many studies (Duranti and Gius, 2011). These plants play an important role in human and animal nutrition as they are rich in protein. Apart from protein, legumes contain various vitamins (B group vitamins, folate, etc.) and minerals (iron, calcium, magnesium) (Arnoldi et al., 2015). These nutritional properties have made legumes an alternative to animal protein in poor societies and have therefore become a staple food in various parts of the world.

When talking about the agricultural importance of legumes, nitrogen fixation feature has an important place. Legumes, which establish a symbiotic relationship with Rhizobium bacteria, increase soil fertility by fixing free nitrogen in the atmosphere in plant roots and contribute to sustainable agriculture in this respect (Graham and Vance, 2003). Nitrogen fixation reduces the fertilizer requirement of legumes, thus reducing environmental impacts. This helps to reduce the use of chemical fertilizers and consequently nitrate pollution (Peoples et al., 2009).

The nutrient requirements of legumes depend on the nutrient content of the soil, climatic conditions and, in particular, the levels of nitrogen, phosphorus and potassium. Many studies have detailed the need of legumes for these nutrients for their optimum growth (Foyer et al., 2016). Legumes generally require high amounts of phosphorus because phosphorus is critical for nitrogen fixation and root development. However, potassium is important for maintaining plant water balance and disease resistance (Singh et al., 2014).

Legumes are an important source of protein, especially for people living in poor and arid regions of the world. For example, the protein-rich nature of lentils and chickpeas makes them a staple food in areas where animal proteins are difficult to obtain (Vaz Patto et al., 2015). These crops also have a low glycemic index, which offers an important advantage in the control of chronic diseases such as diabetes (Mitchell et al., 2009).

Recent studies have shown that legumes have a lower carbon footprint than other agricultural crops and therefore have the potential to mitigate climate change (Nemecek et al., 2014). The use of legumes in sustainable agricultural systems not only increases diversity and agricultural productivity, but also helps to keep the soil healthy.

The contributions of legumes to agricultural ecosystems are not limited to this. Legumes help improve soil structure by increasing the organic matter content of the soil. This offers a great advantage in terms of soil conservation, especially in areas with high erosion risk (Zahran, 2019). In addition, the roots of legumes increase the water-holding capacity of the soil, making it easier for plants to access water during drought periods. Due to these characteristics, legumes are an ideal option for sustainable agricultural practices, especially in regions where the impacts of climate change are felt (Miller and Jackson, 2017).

Another important aspect of legumes for environmental sustainability is their potential to increase biodiversity. Legume agriculture contributes to the conservation of biodiversity in agroecosystems by allowing the shelter and feeding of various insect species (Stagnari et al., 2017). At the same time, the flowers of these plants are a rich source of nectar for pollinators, which is of great importance for ecosystem health.

Today, the effective use of legumes in agricultural systems stands out with low input costs, sustainability and environmentally friendly agricultural strategies. The low carbon and water footprint of legumes makes them a priority in sustainable agricultural systems. With their high protein content, rich vitamin and mineral composition, legumes provide both nutritional security for future generations and offer an environmentally friendly alternative. In addition, recent research on the processing and utilization of legume products shows that these crops have the potential for further use in the food industry (Pellegrino et al., 2018).

Nitrogen Fixation and Soil Fertility

Legumes have the ability to convert nitrogen gas in the atmosphere into ammonia, the form available to plants. This process is accomplished through a symbiotic relationship with nitrogen-fixing bacteria such as Rhizobium living in root nodules (Mus et al., 2019). This symbiotic relationship reduces legumes' need for nitrogen fertilizers and promotes sustainability in agriculture (Verzeaux et al., 2016). This nitrogen in the soil also benefits other plants in subsequent cropping cycles, which is a great advantage, especially in organic farming practices (Khan et al., 2018).

This nitrogen fixing property of legumes contributes to increasing soil fertility and reducing the use of chemical fertilizers. This property of legumes provides an important advantage in agricultural production, especially since nitrogen fertilizers are costly and create environmental pollution (Behera et al., 2021). The process of nitrogen fixation also allows for increased biodiversity and support of microbial activities in the soil. This increases productivity by improving the physical and chemical properties of the soil (Basso & Antle, 2020).

Nitrogen fixation plays an important role in agroecosystems as a key component of the nitrogen cycle. This process not only reduces the need for nitrogen fertilizers, but also contributes to improving soil structure by increasing microbial activities and mycorrhizal associations in the soil (Mus et al., 2019). AI-supported agricultural management systems can help to manage the nitrogen fixation process more efficiently and thus meet the nitrogen needs of crops in a timely and appropriate manner (Sharma et al., 2020).

In addition, nitrogen fixation, which is an important way to increase soil fertility, also contributes to reducing the carbon footprint in sustainable agricultural practices. Nitrogen fixation prevents the overuse of chemical fertilizers, reducing production costs and preventing environmental pollution (Basso and Antle, 2020). Artificial intelligence and data analytics can increase efficiency in agricultural production by enabling this process to be implemented in a more efficient and optimized manner (Van Es and Woodard, 2017).

Importance of Phosphorus and Other Nutrients

Phosphorus is a critical nutrient for legume growth and root nodule formation. Phosphorus deficiency reduces the nitrogen fixation capacity of root nodules and negatively affects plant growth (Khan et al., 2018). Therefore, meeting the phosphorus needs of legumes is important for plant growth and productivity. Although phosphorus fertilization is commonly used in conventional farming methods, AI-based nutrient management systems can detect this need more precisely and thus ensure the optimal application of phosphorus (Jones et al., 2019).

In addition to phosphorus, micronutrients such as potassium, calcium, magnesium, iron and zinc are of great importance for legume cultivation. Potassium increases plant water balance and disease resistance, while magnesium is the main component of chlorophyll structure and is essential for photosynthesis (Behera et al., 2021). Calcium is essential for root development and cell wall stability (Sharma et al., 2020). Micronutrients such as iron and zinc play critical roles in plant metabolism and enzymatic activities (Van Es & Woodard, 2017).

AI-based systems can detect the deficiency of these nutrients in the early stages to optimize plant growth and prevent yield loss (Van Es & Woodard, 2017). For example, using satellite imaging and sensor technologies, the level of nutrients in the soil can be remotely monitored so that the nutrients plants need can be applied just in time (Jones et al., 2019). Such precision agriculture practices both support environmental sustainability and increase farmers' economic returns. Proper management of phosphorus not only improves plant health, but also reduces phosphate pollution in water resources. Phosphorus excess leads to eutrophication, especially in surface waters, reducing water quality (Behera et al., 2021). AI-supported nutrient management systems can prevent such environmental problems by ensuring that phosphorus is applied at the correct dosage and timing (Basso & Antle, 2020).

A balanced supply of nutrients in the soil is critical for the healthy development and high yields of legumes. Artificial intelligence and data analytics help farmers determine the levels of these elements in the soil and the needs of plants. Precision nutrient management ensures that nutrients in the soil are applied in a balanced manner and maximized utilization by the plant (Basso & Antle, 2020). The use of such technologies, especially in legume farming, ensures efficient use of resources and improves product quality.

2. ARTIFICIAL INTELLIGENCE BASED NUTRIENT MANAGEMENT

AI-based nutrient management has been increasingly used in agriculture and food production in recent years to increase efficiency, optimize process and achieve sustainability goals. AI-based approaches are used at various stages in agricultural production. For example, machine learning algorithms are used to predict the growth process of agricultural crops and identify pest control strategies (Patel et al., 2018). Deep learning techniques can be effectively used in plant health monitoring and early detection of diseases in plants (Singh et al., 2020).

These methods make important contributions to minimize crop losses by detecting disease symptoms through images of plants in the field and recommending appropriate treatment methods.

Artificial intelligence plays a major role in yield optimization. In precision agriculture applications, AI-based algorithms develop customized fertilization and irrigation strategies by analyzing soil moisture, nutrients, and plant growth data (Zhang et al., 2019). These efforts both increase the efficiency of resource use and minimize environmental impacts. In particular, algorithms such as deep learning and support vector machines (SVM) have been effective in increasing agricultural yields by providing solutions suitable for the climatic and physical conditions of the soil (Kumar and Yadav, 2021).

Moreover, the use of AI in agricultural technologies offers a more effective and efficient approach compared to traditional farming methods. Devices such as agricultural robots, unmanned aerial vehicles (drones) and smart sensors are integrated with AI algorithms and used in agricultural activities. For example, imaging studies with drones contribute significantly to the collection of agricultural data by monitoring plant health and growth status (Mohanty et al., 2022). This technology makes agricultural activities easier and faster when manual work is difficult in large agricultural areas.

In terms of sustainability, the use of AI-based systems offers significant benefits for reducing environmental impact in agricultural production. Precision fertilization and irrigation methods enable more efficient use of water and nutrient resources, while at the same time reducing environmental pollution (Jin et al., 2020). In addition, the use of AI increases the economic efficiency of agribusinesses and improves their ability to adapt to climate change. By using AI-based decision support systems in agricultural processes, both crop losses are reduced and sustainable agricultural practices are becoming widespread (Li and Chen, 2021). As a result, AI-based nutrient management has significant potential for increasing agricultural productivity, reducing environmental impacts, and achieving sustainability goals.

Using AI and Machine Learning Algorithms

Artificial intelligence (AI) and machine learning offer revolutionary innovations in agricultural production. AI-based systems automate data collection and analysis processes in agriculture, enabling more efficient and optimized management of agricultural processes (Sharma et al., 2020). In legume agriculture, it is of great importance to apply the right amount and time of nutrients that plants need during their growth periods. Machine learning algorithms are used to identify these needs and create the right strategies (Basso & Antle, 2020).These algorithms improve agricultural management by analyzing a wide range of data sources such as soil data, climatic conditions, plant growth and other environmental factors. Machine learning techniques such as support vector machines (SVM), decision trees and artificial neural networks provide accurate prediction of plant nutrient needs and help develop optimal fertilization strategies (Jones et al., 2019). Using these insights, AI continuously monitors the development process of plants and automates the application of needed nutrients.

Nowadays, artificial intelligence (AI) techniques are increasingly used to increase productivity and achieve sustainability goals in agriculture. AI methods such as machine learning (ML) and deep learning (DL) are widely used to analyze agricultural data to optimize production processes, reduce resource use, and minimize environmental impacts (Kamilaris & Prenafeta-Boldú, 2018). This study presents a post-2010 literature review examining the role of AI techniques on food production, yield optimization, agricultural technologies and sustainability.

The use of AI in agriculture has become particularly important in yield enhancement and resource management. For example, large data sets obtained using sensor data and satellite imaging play an important role in predicting traits such as plant size and disease detection (Liakos et al., 2018). ML algorithms support farmers' decision-making processes by optimizing agricultural parameters such as soil fertility, water use, and labor requirements (Shamshiri et al., 2018). These methods also contribute to less input use in agricultural processes by adapting to environmental conditions and thus increasing sustainability (Pantazi et al., 2016).Deep learning methods have been integrated into agricultural technologies, especially in image recognition and data processing. The DL-based models developed for the detection of plant diseases and pests can reduce the need for chemical control by providing early warnings to farmers, thus providing an environmentally friendly approach (Ferentinos, 2018). These methods are also used in various fields as part of precision agriculture practices, such as creating yield maps and supporting precision fertilization systems (Sishodia et al., 2020).

AI-based agricultural technologies also enable the analysis of compressed farm data. As Shamshiri et al. (2018) note, these technologies help optimize plant growth by improving water and nutrient use efficiency. In sustainability practices such as circular agriculture and carbon footprint reduction, AI contributes to minimizing environmental impacts by modeling different crop cycles (Kamilaris and Prenafeta-Boldú, 2018). The use of AI in agriculture also contributes to economic sustainability. Thanks to data-driven decision support systems, farmers can manage their marketing strategies more effectively and anticipate disruptions in the entire production chain (Jha et al., 2019). This is especially important for rapid adaptation to changing production conditions due to climate change (Wolfert et al., 2017).

Studies on the use of AI and ML in agriculture show that these techniques have significant potential to support sustainable agricultural practices. In particular, AI plays an important role in managing agricultural activities more effectively, conserving natural resources and reducing environmental impact.

Optimal Nutrient Management Strategies

Optimal nutrient management refers to the timely and accurate supply of nutrients that plants need during the growth process. AI-based nutrient management strategies enable more precise and efficient nutrient application in agriculture than traditional methods (Van Es & Woodard, 2017). Artificial intelligence integrated with precision agriculture techniques can determine the timing and amount of nutrient application, enabling plants to grow with maximum efficiency (Sharma et al., 2020).

For example, by monitoring soil and plant condition in real time with satellite data and sensors, the nutrients needed by plants can be precisely determined. This data is processed by machine learning algorithms and optimal nutrient application strategies are created (Jones et al., 2019). In this way, plants are not exposed to unnecessary nutrient applications and environmental impacts are minimized. These strategies contribute to more effective management of key nutrients, especially nitrogen, phosphorus and potassium (Behera et al., 2021). Furthermore, AI-based nutrient management strategies enable plants to become more resilient to stressors. For example, in situations such as drought or nutrient deficiency, instant adjustments can be made to the plant's needs. This not only improves plant health, but also increases agricultural productivity and crop quality (Basso and Antle, 2020). As part of the digital transformation in agriculture, AI plays an important role in nutrient management and contributes to the spread of sustainable agricultural practices (Van Es and Woodard, 2017).

Optimal nutrient management aims to make the most efficient use of nutrients to support plant growth and increase productivity. Artificial intelligence (AI) and machine learning (ML) techniques play a critical role in optimal nutrient management strategies. These techniques are used to predict nutrient requirements of crops, monitor soil and plant condition, and optimize nutrient applications (Shamshiri et al., 2018). In precision agriculture applications, AI algorithms enable farmers to apply the right amount of fertilizer at the right time by continuously monitoring soil fertility and plant growth (Pantazi et al., 2016). This approach both minimizes nutrient loss and reduces environmental impacts.

Models developed using AI and ML techniques allow the precise application of various nutrients to achieve plant nutrient balance. For example, ML algorithms are used to optimize the availability of macronutrients such as nitrogen, phosphorus and potassium in soil and plants (Liakos et al., 2018). In this way, the amount of nutrients needed by plants can be precisely determined and nutrient deficiencies can be eliminated at an early stage. Deep learning methods allow early detection of plant nutrient deficiencies with image processing techniques (Ferentinos, 2018). This early detection helps farmers to intervene in time and prevent yield loss.

Optimal nutrient management strategies are also important for environmental sustainability. In conventional fertilization practices, over-applied nutrients can damage groundwater and ecosystems. However, AI and ML-based approaches avoid these impacts by ensuring that nutrients are applied at the right time and in the right amount (Jha et al., 2019). From an economic perspective, optimal nutrient management strategies can increase farmers' income by reducing costs. Avoiding unnecessary fertilizer use reduces input costs while protecting plant health and increasing productivity. Especially in agricultural systems where the impacts of climate change are felt, precise nutrient management increases production continuity and resilience of agricultural systems (Wolfert et al., 2017).

Optimal nutrient management through the use of AI and ML techniques not only increases productivity and plant health, but also makes a significant contribution to environmental and economic sustainability. These approaches will help agricultural production systems become more resilient and efficient in the future.

3. ADVANTAGES OF ARTIFICIAL INTELLIGENCE-POWERED NUTRIENT MANAGEMENT SYSTEMS

Artificial intelligence (AI)-enabled nutrient management systems have the potential to revolutionize agriculture. By supporting precision agriculture, these systems offer farmers the opportunity to more effectively manage crop nutrient levels and optimize resource use. In this paper, we will examine the advantages of AI-assisted nutrient management systems, their economic and environmental benefits, their impact on productivity and their place in precision agriculture in the light of post-2010 academic studies. We will also provide an assessment of the advantages and challenges of these technologies.

One of the main advantages of AI-enabled nutrient management systems is their potential to increase agricultural productivity. By precisely managing plant nutrient levels, these technologies help to provide conditions that are more favorable to plant requirements. Their high-precision data collection and analysis capabilities give farmers the opportunity to determine the nutrient requirements of plants in a time-sensitive manner (Jha et al., 2019). Furthermore, with these systems, other factors affecting plant growth, such as soil structure, moisture level and weather, can be monitored instantly and appropriate nutrient management decisions can be made. This contributes to plants growing in optimal conditions and increasing yields (Li et al., 2021). For example, soil moisture sensors and drone-based imaging techniques enable more accurate determination of plants' nutrient needs, which in turn increases productivity. Furthermore, remote sensing technologies can be used to continuously monitor plant health and development status, allowing for immediate intervention (Li et al., 2021).

Economic and Environmental Benefits

AI-enabled nutrient management systems are gaining attention for their economic benefits. These technologies reduce input costs through more efficient use of nutrients. A well-planned nutrient management system saves farmers money by minimizing unnecessary input use (Shamshiri et al., 2018). Optimal use of high-cost nutrients such as nitrogen, phosphorus and potassium offers great economic advantages to farmers. In addition, thanks to the data accumulated over time, farmers can better manage input costs and sustain yield increases.

Environmentally, these systems are also very beneficial. The loss of nutrients and pollutants emitted by conventional fertilization methods can be reduced by AI-supported systems. Precision nutrient management reduces environmental pollution by preventing excess nutrients such as nitrogen and phosphorus from entering the soil and groundwater (Zhang et al., 2020). This contributes to environmentally friendly farming practices, which is one of the main goals of sustainable agriculture. It also contributes to the fight against climate change by reducing carbon emissions. In particular, reducing greenhouse gas emissions is made possible through precision nutrient management (Zhang et al., 2020).

Productivity and Precision Agriculture

Precision agriculture refers to the sensitive monitoring and management of crops and environmental conditions. It is also a form of management used to respond to indoor and outdoor variability in crop cultivation. Precision agriculture allows farmers to accurately time and quantify agricultural activities such as planting, harvesting and irrigation, avoiding wastage of resources such as water, fertilizers and pesticides and reducing environmental impact. This method has the potential to provide economic and environmental savings, especially in small farms (Rufaioğlu et al., 2024). AI-supported nutrient management systems make precision agriculture practices more effective. These systems analyze data from sensors and remote sensing devices to advise farmers on specific nutrient applications (Balafoutis et al., 2017). In this process, soil and plant analyses, data processing algorithms and predictive modeling are used to apply the nutrients that plants need at the optimal time and in the optimal amount.

One of the most important elements of productivity increase is the application of nutrients appropriate to plant developmental stages and avoiding unnecessary input use. Through precise nutrient management, plants grow healthier and yield higher yields by being supported with more appropriate nutrients during growth periods (Paustian et al., 2019). For example, nutrient applications tailored to the phenological stage of the plant maximize nutrient efficacy and reduce plant stress. This contributes to plants becoming more resistant to diseases and increases overall productivity.

AI-supported nutrient management systems have their advantages but also some challenges. The cost of these systems can be a major barrier, especially for small-scale farmers with limited access to technology. Establishing the necessary infrastructure and implementing these systems can require high initial costs. At the same time, the knowledge and training required for the proper use of these technologies is also important. Some studies suggest that farmers need a comprehensive training process to effectively utilize these systems (Rose et al., 2018). Lack of training can lead to misuse of technologies and failure to achieve expected productivity gains. In addition, data privacy and security issues can also affect farmers' trust in these technologies.

In the process of integration of AI-supported systems, government support and incentive programs are also of great importance for farmers to adopt and effectively use these technologies. In this context, it is necessary to provide training to farmers and access to cost-effective technology through public and private sector collaborations.

AI-enabled nutrient management systems offer significant benefits, such as increased agricultural productivity, economic savings and reduced environmental impact. Integrated with precision agriculture, these systems offer farmers significant benefits in better monitoring plant growth and ensuring proper nutrient management. However, more work needs to be done on access to information and technology and cost-effective implementation solutions for widespread adoption of these systems. Facilitating small-scale farmers' access to these technologies is critical to achieving sustainable agriculture goals. In the future, government-supported incentive programs and education campaigns can help to ensure more widespread use of these technologies.

4. ARTIFICIAL INTELLIGENCE BASED APPLICATIONS AND FUTURE PERSPECTIVES

Artificial Intelligence (AI)-based technologies have been used in agricultural applications in recent years to increase productivity, reduce costs and achieve sustainability goals. Especially in the post-2010 literature, many studies have been conducted on the use of AI in agricultural production and these studies have shown the effects of AI-based modeling, prediction and automation processes on different areas of agriculture (Li et al., 2019; Jones, 2019). AI-based applications have attracted attention, especially in areas such as image processing and data analytics. For example, drone-based imaging systems have been used in combination with AI algorithms to monitor plant health and detect diseases early. By detecting diseases and pests at an early stage, these systems minimize the use of chemical pesticides and thus contribute to sustainable agricultural practices (Zhang et al., 2020). Similarly, AI-based automation systems have also been developed that continuously monitor soil and weather conditions and optimize irrigation and fertilization needs (Patil and Singh, 2021). Again, an AI-supported agricultural advisory platform was developed in India. This platform provided farmers with personalized fertilization and irrigation recommendations based on soil analysis results, resulting in increased productivity (Sharma and Verma, 2017). Farmers' feedback reveals that such applications make a difference, especially in small-scale agricultural enterprises.

In order for AI-based agricultural applications to become more widespread, data collection processes for local needs need to be improved. In addition, the development of training programs and financial support mechanisms to facilitate farmers' access to these technologies will contribute to the effective use of these technologies.

Contributions of AI Technologies to Sustainable Agriculture

Sustainable agriculture is an approach that aims to increase productivity while minimizing environmental impacts, and AI technologies play a critical role in achieving these goals. In the post-2010 academic literature, there are many studies on how AI is used especially in precision agriculture practices (Rodriguez and Arrieta, 2022; Smith and Brown, 2021). Precision agriculture ensures the appropriate use of agricultural inputs (fertilizer, water, etc.) by continuously monitoring the variables in a specific area. In this way, it is possible to protect water resources, reduce the use of chemicals and maintain soil fertility in a sustainable manner.

AI technologies work in integration with big data analytics to support sustainable agricultural practices. For example, one study showed that water consumption can be reduced by 25% by developing an AI-based irrigation optimization system in Australia (Williams and Green, 2020). This system analyzes parameters such as soil moisture, air temperature and plant growth stages to ensure that only the required amount of water is used. Such applications offer effective solutions to combat problems such as drought and water scarcity. To increase the impact of AI in sustainable agriculture, the adaptability of these technologies to local conditions needs to be increased. In this direction, developing open data platforms and providing farmers with access to this data will facilitate the spread of sustainable agriculture practices. In addition, creating incentive mechanisms supported by policies is also an important step.

Agricultural Digital Transformation and Future Potential

Agricultural digital transformation has gained momentum in recent years and AI technologies have played a central role in this transformation. Digital transformation enables farmers to manage their production processes more efficiently and sustainably (Fernandez and Garcia, 2023; Lee and Kim, 2022). Agricultural digital transformation is supported by smart sensors, IoT (Internet of Things) and AI-based analytics. These technologies enable farmers to monitor conditions in the field in real time and take action accordingly. For example, in a case study conducted in Germany, a system for early detection of plant diseases was developed with the integration of agricultural IoT and AI (Muller and Schmidt, 2021). This system detected disease symptoms on plant leaves with high accuracy, enabling early intervention and reducing yield loss by 30%. To fully realize the potential of agricultural digital transformation, standards on data security and data sharing need to be established. In addition, government-supported projects and appropriate financing models should be developed to facilitate small-scale farmers' access to these technologies. Training and capacity building are also critical for digital agriculture practices to become widespread.

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CHAPTER 4

TANNINS in SOME FORAGE PLANTS and THEIR EFFECTS on RUMINANTS

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INTRODUCTION

Tannins are phenolic compounds naturally found in the structure of plants and produced by plants to defend themselves against pathogenic microorganisms and viruses (Kuloglu, 2007; Unver et al., 2014; Boga et al., 2021). The functions of tannins differ depending on the tissue in which they are present. For instance, tannins in the bud shield the plant from freezing, while those in the leaf tissue protect the plant from being eaten by insects, birds, and herbivorous animals due to tannins' bitter taste. However, the tannins found in the seed preserve it by having a bactericidal effect and thus ensure the plant's survival and sustainability (Unver et al., 2014). For grazing ruminants, tannins are essential in two ways. One of these is the prevention of bloating. Pasture bloat occurs when a significant amount of fresh, high-protein feed, such as alfalfa, is rapidly digested. It subsequently causes a rapid increase in rumen protein content, leading to an elevation in the rate of microbial fermentation in the rumen and rapid accumulation of carbon dioxide and methane gases. Microbial slime, plant cell membranes, and proteins combine with fermentation gases to form stable foam swallowed as a liquid in the valve leading from the rumen to the esophagus, causing it to remain closed. The gradually accumulated and trapped gasses cause swelling in the rumen and thus hinder blood flow and breathing. Untreated bloat might lead to death by cardiac arrest or asphyxiation. Yet, tannin-containing feeds do not induce bloating since tannins bind excess plant proteins, precipitate them in the rumen fluid, and avoid the formation of the stable foam, which is typical of pasture bloat. Another effect of tannins is that they suppress internal parasites (especially against numerous species of nematodes). The impact of tannins on nematodes largely depends on their concentrations, chemical structures, and the type of nematode species. The effectiveness of tannins also varies depending on the developing stage of the nematode and the location in the gastrointestinal tract where the tannin is active (MacAdam et al., 2013).

Tannins are found in numerous and various plant species especially forage legumes, acacia, oak, carob, tea, pomegranate, and grape (Boga et al., 2021). Table 1 lists the tannin concentrations found in some forage plants. Tannins are divided into two groups: hydrolyzed tannins and condensed tannins. Hydrolyzed tannins consist of polyphenol nuclei with molecular weights ranging from 500 to 3,000 Daltons (Da). However, condensed tannins are polyphenolic compounds that are found abundantly in many plants and have proven effectiveness in minimizing methane emissions among ruminant animals and preventing pasture bloat (McMahon et al., 2000; Roldan et al., 2022). Condensed tannins are also secondary products of plants, primarily present in dicotyledonous plant cell walls or stored in vacuoles, stems, bark, leaves, flowers, or seeds. They are also water-soluble organic compounds. Condensed tannins are oligomeric or polymeric flavonoids consisting of flavone-3-ols, including catechin, epicatechin, gallocatechin, and epigallocatechin. Their molecular weights range from 1,000 to 20,000 Da. They are depolymerized only by strong oxidation and acid and are highly resistant to degradation by anaerobic enzymes (Tong et al., 2022). Hydrolyzed tannins directly affect methane-gas-synthesizing microorganisms and hydrogen-molecule-releasing bacteria (Ece and Avci, 2018). Condensed tannins constitute up to 20% of the dry matter in legume forage plants used as ruminant feed (Mueller-Harvey et al., 2019). Furthermore, they lower greenhouse gas emissions derived from animals by inhibiting some hydrogen-releasing protozoa in the rumen and methane-synthesizing organisms that directly use hydrogen (Ozturk and Gulumser, 2023). Desirably, the condensed tannins in forage plants should not exceed 3% (Kaymak Bayram et al., 2023).

Table 1. Tannin concentrations in some forage plants

Forage Plants	Tannin type	Plant part	Stage	Tannin contents (%)
Medicago sativa	TT	Whole plant	%10-20 flowering stage	0.59-0.95% toplam tanen (Vieira et al., 2001)
Medicago sativa	CT	Whole plant	Late bud stage	1.8 g kg^{-1} DM(Lagrange and Villalba, 2019)
Medicago species	TT	Seed		0.27-1.23% (Kokten et al., 2011)
Moringa Oleifera	TT	leaf	-	1.4% (Ibrahima ve Kirkpinar, 2019)
Lathyrus sativus L.	CT	Whole plant	Flowering stage	1.03-1.37% (Sezer, 2024)
Lathyrus sativus L.	TT	Seed	-	324.47-856.45 mg 100 g^{-1} (Yerra and Kilari, 2018)
Lotus corniculatus (var. japonicus)	CT	Flower Petal	-	15 g kg^{-1} fresh weight 8 g kg^{-1} fresh weight

		Petioles, stem, roots		< 5 g kg^{-1} fresh weight (Morris et al., 1993)
Lotus corniculatus	CT	Whole plant	Full flowering	4.7 - 8.7 % (Acuña et al., 2008)
Lotus corniculatus L.	TT	Leaf	Flowering	8.5-58.8 mg g^{-1} Dry Weight (Marshall et al., 2005)
Onobrychis sativa	CT	Whole plant	Flowering	2.07-4.70% (Ulger and Kaplan, 2016)
Onobrychis viciifolia	CT	Whole plant	50-75% flowering stage.	6.81-7.64 mg g^{-1} DM (Abebe et al., 2024)
Onobrychis viciifolia	CT	Whole plant	Regrowth	58.7 g kg^{-1} DM (Berard et al., 2011)
Lotus corniculatus	CT	Whole plant	Late bud stage	13.0 g kg^{-1} DM(Lagrange and Villalba, 2019)
Lotus corniculatus	CT	Whole plant	Begin of flowering	24.2 g kg^{-1} DM (Uzun ve Ocak, 2018)
Lotus corniculatus	CT	Whole plant	Regrowth Flowering/full bloom	9.4 g kg^{-1} DM 18.6 g kg^{-1} DM (Berard et al., 2011)
Lotus tenuis	CT	Whole plant	Begin of flowering	24.1 g kg^{-1} DM (Uzun ve Ocak, 2018)
Trifolium hybridum	CT	Whole plant	Flowering/full bloom	11.6 g kg^{-1} DM (Berard et al., 2011)
Trifolium repens	CT	Whole plant	Flowering/full bloom	6.9 g kg^{-1} DM (Berard et al., 2011)
Trifolium pratense	CT	Whole plant	Regrowth (after harvest) Flowering/full bloom	0.2 g kg^{-1} DM 8.1 g kg^{-1} DM (Berard et al., 2011)
Onobrichis vicifolia	CT	Whole plant	Late flowering stage	27.1 g kg^{-1} DM (Lagrange and Villalba, 2019)
Trifolium meneghinianum Clem.	CT	Whole plant	Budding Flowering Pod setting periods	1.06 % 1.32 % 1.93 % (Kaymak Bayram et al., 2023)

TT: total tannins, CT: condensed tannins, Regrowth: after harvest

1. FACTORS AFFECTING TANNIN CONTENT

Tannin content varies within and among plant species depending on genetics, habitat, and developmental stages of plants (Yerra and Klari, 2018; Molnar et al., 2024). Air temperature and soil fertility are the most significant environmental parameters affecting the condensed tannin concentration (Acuña et al., 2008). Lees et al. (1994) reported growing *Lotus uliginosus* clones at two different temperatures (20°C and 30°C) and accordingly found that plants grown at 30°C had higher condensed tannin contents than plants grown at 20°C. They also remarked that high-temperature stress might lead to more condensed tannin synthesis in leaves. Additionally, Miller and Ehlke (1995) documented a positive correlation between lignin concentration and condensed tannin content. Berard et al. (2011) found that condensed tannin amounts considerably varied depending on the plant's developmental stages. They reported that the condensed tannin concentrations during the vegetative and flowering stages were 0.1 g kg^{-1} DM and 4.1 g kg^{-1} DM in *Trifolium ambiguum*, 0.2 g kg^{-1} DM and 8.1 g kg^{-1} DM in *Trifolium 66retense*, 9.4 g kg^{-1} DM and 18.6 g kg^{-1} DM in *Lotus corniculatus*, 0.0 g kg^{-1} DM and 6.9 g kg^{-1} DM in *Trifolium repens*, and 0.0 g kg^{-1} DM and 11.6 g kg^{-1} DM in *Trifolium hybridum*, respectively. Contrary to other plants, the condensed tannin content in *Onobrychis viciifolia* reportedly decreased from 58.7 g kg^{-1} DM to 33.7 g kg^{-1} DM with ripening. Several studies indicated that the observed declines in condensed tannin concentrations in *Onobrychis viciifolia* might originate from an increase in the leaf-stalk/leaf ratio with ripening and a decrease in enzyme activities responsible for condensed tannin production with ripening (Lees 1993; Lees et al., 1995; Taylor and Quesenberry, 1996; Singh et al., 1997; Joseph et al., 1998). Finally, Gardhouse (2020) also reported that condensed tannin content decreased with ripening in sainfoin (trefoil) cultivars.

2. THE SIGNIFICANCE of TANNINS for RUMINANTS

Tannins are polyphenolic chemicals with varying molecular weights that plants can synthesize during secondary metabolism. They can bind to proteins and interfere with ruminal fermentations (Vasta et al., 2008; Besharati et al., 2022). Tannins (hydrolyzed and condensed tannins) are present at different concentrations in various animal feed sources. Condensed tannins are the most typical tannin types found in forage legumes, shrubs, and tree leaves (Min et al., 2003). Many of these plants are alternative feed sources as part of ruminant feeding strategies to replace part of the grain ratio in animal diets to minimize production costs and maximize the quality of animal products in ruminant nutrition (Vasta and Luciano, 2011). However, it is acknowledged that they potentially cause toxic and/or anti-nutritional effects on animals (Mueller-Harvey 2006). The anti-nutritional effects of tannins reside in their digestion-delaying effects when they interact with dietary proteins and polymers, such as cellulose, hemicellulose, and pectin (McSweeney et al., 2001). The ability of tannins to bind and generate such complex molecules depends on the structure of the polyphenols and the availability of the necessary macromolecules (Besharati et al., 2022). These insoluble chemical complexes formed by the binding of tannins to proteins display a characteristic that can inhibit animals' nitrogen uptake, lead to a decrease in feed palatability, and result in a perception of astringency orally (Mueller-Harvey et al., 2019; Zeller 2019).

Min and Solaiman (2018) reported that the positive results of tannins primarily depend on their effects on gut microbiome diversity and their capacity to generate fermentation end products (short-chain fatty acids) with various biological roles. Fonseca et al. (2023) documented that condensed tannins in ruminant diets are useful for rumen fermentation and rumen protein degradation per unit of dry matter. They also decrease enteric methane production and increase weight gain. However, tannins contribute to ruminant productivity and health (Ramírez-Restrepo et al., 2005; Hoste et al., 2006). As a result, tannins may either remain neutral or favorably or adversely affect animal nutrition depending on some factors, including their chemical structure, molecular weight, their concentration in the diet, plant origin and composition of the diet, animal species, and physiological status of the animal fed (Makkar 2003). Such contrary tannin effects may arise from different chemical compositions or types, the amount of the tannins, the animal species fed, and the diet to which tannins are mixed (Patra and Saxena, 2011). Therefore, the chemical structures of tannins vary greatly (Rodríguez et al., 2014). Besides their chemical structure, tannins may generate either positive or negative effects on animal performance and production quality-both factors are intrinsically linked to animal physiology-depending on their ratio in the diet (Waghorn 2008). Using proper ratios and mixing tannins into the diet will improve the intestinal microbial ecosystem and intestinal health in ruminants; accordingly, it will positively affect animal production (Besharati et al., 2022). Some other contributions of tannins are the increase of protein that cannot be degraded in the rumen, the availability of feed protein for production purposes after the rumen, the increment in microbial protein synthesis efficiency, and the prevention of bloating in ruminants. Several tannins seemingly possess potent antioxidant and anti-carcinogenic properties (Riedl et al., 2002). Some studies also report that using tannin-rich plants in animal diets enriches the fatty acid profile of meat and milk, increases the healthy fatty acid concentrations, and improves the oxidative stability of the products (Benchaar and Chouinard, 2009; Dschaak et al., 2011). Thus, there is growing interest each year in using tannin-rich plants and plant extracts in ruminant diets to improve the quality of animal products. However, using tannin-rich feeds in animal diets requires extreme caution due to their possible detrimental effects on animal performance and induction of metabolic disorders. Several factors, including temperature, light intensity, water, stress, soil nutrients, soil quality, topography, and even variations within a single plant over the year, could affect a plant’s tannin concentrations and bioactivity (Patra and Saxena, 2011). As a result, the subject-related literature indicates widely disparate and seemingly contradictory findings for tannins.

3. INTERACTIONS between TANNINS and RUMEN MICROORGANISMS

Ruminal metabolism adapts to the anti-nutritional effects of tannins in feeds by providing microbial degradation of these compounds. Accordingly, plant phenolics are subject to varying degrees of microbial transformation and degradation while ingested in the gastrointestinal tract of ruminants. Several species have been identified as ruminal microorganisms that can tolerate high concentrations of hydrolyzed and condensed tannins, including *S. gallolyticus*, *S. bovis*, and strains closely related to *S. gallolyticus*, in addition to *Clostridium sp*. and a gram-negative rod from the class *Proteobacteria* (McSweeney et al., 2001). Tannins can hinder ruminal nitrogen metabolism by reducing proteolytic bacteria (Herremans et al., 2020). They can also increase the amount of conjugated linoleic acid in meat and milk production by altering the ruminal bio-hydrogenation process through selective activity on ruminal bacteria; however, this effect is dose-dependent (Kamel et al., 2018). In the presence of tannins, a higher propionate molar ratio in the fermentation system and lower protozoal numbers produced by tannins result in a higher efficiency of microbial protein synthesis (Wang et al., 1996). Cipriano-Salazar et al. (2018) reported that animals potentially tolerated 2% tannin added to ruminant diets depending on the presence of microorganisms that tolerate or degrade tannin in rumen fluid; however, the increment in the ratio completely inhibited ruminal bacteria functions.

4. EFFECTS of TANNINS on PROTEIN PROTECTION

Protein protection is crucial for high-yielding ruminants whose protein requirements cannot be satisfied by microbial protein synthesis. Hence, adding condensed tannins (CT) in animal diets is a prominent process to reduce ruminal protein destruction, i.e., as protein preservatives. Tannins are a heterogeneous group of high molecular weight phenolic compounds. The presence of many phenolic groups is the primary reason for tannins' high affinity for proteins (Bunglavan and Dutta, 2013). The tannin-protein complex is pH-dependent and stable in the rumen, where the pH varies between 5.0 and 7.0. However, condensed tannins and proanthocyanidins are decomposed in the abomasum and anterior duodenum, where the pH is much lower (below pH 3.5) (Grazziotin et al., 2020). Complexification increases the protein availability in the feed for digestion by protecting them from microbial hydrolysis and deamination in the rumen, thus allowing the absorption of more amino acids in the small intestine (Min et al., 2003). Hence, it increases the efficiency of nitrogen utilization and milk protein content by retaining more nitrogen in the body (Aguerre et al., 2020; Grazziotin et al., 2020; Herremans et al., 2020). Bhatta et al. (2000) reported that adding 7.5% tamarind (*Tamarindus indica, Linn*) seed hulls to a concentrated diet (0.75% tannin content in the diet) increased milk production and development rate, which they attributed to the protection of dietary protein against degradation in the rumen. Yet, McSweeney et al. (2001) revealed that, in some cases, protecting rumen protein with tannins potentially reduces rumen ammonia concentrations below critical levels for efficient digestion of forage diets. Hence, under these conditions, rumen populations better adapted (tolerant) to tannin-containing diets may be more efficient in protein and carbohydrate digestion. Dschaak et al. (2011) found that cows fed a diet supplemented with condensed tannin extract had lower amounts of milk urea nitrogen and ruminal ammonia nitrogen without any decrease in milk protein yield. This data potentially suggests that supplementing with condensed tannin extract may lessen the amount of nitrogen lost by the rumen as ammonia since rumen bacteria are less likely to degrade crude protein. Therefore, as organic protein preservatives, tannins can be utilized at safe concentrations in livestock farming to support better production and health of ruminants (Bunglavan and Dutta, 2013).

5. EFFECTS of TANNINS on GRAZING BEHAVIOR

Voluntary feed intake and digestibility typically decline among ruminants grazing on tannin-rich vegetation, and body weight and wool growth ratios decrease accordingly (Min et al., 2003). Animals have also developed various mechanisms to mitigate the adverse effects of plants and increase intake. For instance, while eating plants, grazing animals behave selectively in pastures based on the perceptual integration of taste, odor, and sensation in chemosensory cells in the oral cavity. As a result, they prefer eating some plants yet avoid consuming others (Beauchamp and Mennella, 2009). Physical and chemical properties determine the palatability of the feed. The integration effects of toxins during digestion are another factor that affects palatability (Atwood et al. 2001). Saliva also plays a critical role in the perception of taste and texture sensations (Engelen et al., 2007). Saliva, rich in tannin-binding salivary proteins, is one of the primary adaptive mechanisms, especially in small ruminants. Thus, saliva is the first defensive mechanism developed by mammalian species against tannins (Mueller-Harvey, 2006; Shimada, 2006). Proline-rich proteins and histatin peptides are among these tannin-binding salivary proteins, which have a strong affinity for tannins (Shimada 2006). Animals feeding high tannin-containing diets may produce more tannin-binding salivary proteins to regulate their adverse effects. In essence, salivary tannin-binding proteins are an inducible system that adapts to the nutritional availability of tannins in the diet (Clauss et al., 2005; Costa et al., 2008), since prolonged consumption of tannin-containing diets results in salivary gland enlargement (Van Soest 1994). However, not all animals salivate proline-rich proteins in their saliva. Bueno et al. (2015) reported that small ruminants are less affected by the harmful effects of tannin-rich diets than big ruminants. For instance, goats display a high tolerance to tannins since tannin-binding salivary proteins hinder adverse tannin effects on ruminal digestibility and stimulate the growth of tannin-tolerant bacteria (Min and Solaiman, 2018; Schmitt et al., 2020). Sorensen et al. (2005) indicated that experienced animals grazing tannin-rich pastures expectedly ingest more tannins, lose less body mass, experience fewer toxicity symptoms, and maintain a more positive energy balance in their favored plant.

6. EFFECTS of TANNINS on ANIMAL PRODUCTS and PERFORMANCE

Tannin-like polyphenolic compounds in plants are considered the primary source of natural antioxidants. Antioxidants are compounds that can donate hydrogen (H^-) radicals to pair with other available free radicals to prevent the spread of reactions during oxidation. Hence, this process reportedly minimizes rancidity in meat and delays lipid oxidation without impairing sensory or nutritional properties, thus preserving the quality and shelf life of the meat products (Kumar et al., 2015). Studies also reported that tannins lessen the harmful effects induced by mutagens and display a protective effect against DNA damage, facilitate rumen fermentation by modulating plasma metabolites and antioxidant capacity, and alter the body's fatty acid profile by generating a beneficial change in the rumen bio-hydrogenation process (Unver et al., 2014; Gao et al., 2024). Tannins alter the fatty acid profile by shortening the ruminal bio-hydrogenation process of unsaturated fatty acids and increasing their flow to the duodenum. This alteration also ensues changes in the unsaturated fatty acid profile of the meat and milk, presumably due to changes in the composition of rumen microbial populations. Khiaosa-Ard et al. (2009) reported that tannin-added lamb diets elevated the amount of saturated fatty acids in lamb meat by reducing the bio-hydrogenation of polyunsaturated fatty acids in the rumen. Dogan and Gunal (2020) documented that a 75 g DM^{-1} tannin-added diet adversely affected the production of total volatile fatty acids, recommending that the tannin concentration in the diet should not exceed 50 g kg^{-1} DM. Boga et al. (2021) emphasized the criticality of knowing the range of positive effects of ruminant diets and recommended using tannins in animal ratios, indicating that a 1-4% DM or 20-45 g day^{-1} tannin-added diet could provide substantial advantages. Accordingly, it is reasonable to conclude that feeding ruminants with tannin-supplemented diets is a robust strategy to improve the health properties of meat and milk (Vasta et al., 2008). However, Kushwaha et al. (2012) reported that condensed tannin had no favorable effect on eves grazing *Lotus corniculatus* in early lactation but increased milk yield by 2 liters in mid- and late lactation. Wang et al. (1996) observed slightly lower voluntary feed intake and higher live weight gain, carcass weight gain, carcass dressing-out percentage, and wool growth in lambs grazing *Lotus corniculatus* compared to lambs grazing alfalfa (*Medicago sativa* L.). They reported that the primary outcome of CT in lambs grazing *Lotus corniculatus* was to increase fleece wool growth without affecting voluntary feed intake, thus increasing the productivity of fleece wool production. They also noted that CT did not affect the rumen fermentation of carbohydrate-heavy volatile fatty acids. However, Girard et al. (2016) found that lambs fed condensed tannin derived from *Lotus corniculatus* and *Onobrychis viciifolia* had lower carcass yield, and they related this lower yield to lower weight gain rate, lower slaughter weight, and lower carcass weight. Dos Santos et al. (2022) reported that using tannins up to 1% in dry matter intake in ruminant diets induced no adverse effect on animal performance; however, they suggested extreme caution for usages over 1% rates due to the possibility of detrimental effects on DM intake, performance, and carcass characteristics of growing lambs. Zulfiqar et al. (2024) found that dietary tannin supplementation had no substantial difference in growth performance and nutrient digestibility in lambs; however, it increased protein bypass value since it considerably reduced blood urea nitrogen levels. Studying the effects of tannins on reproduction, Banchero et al. (2012) reported that 1.5% condensed tannin-supplemented soybean cosette on days –8 to –4 before ovulation increased the ovulation rate among sheep grazing on pasture. However, they noted that using a 2.5% tannin rate decreased their dry matter consumption and energy intake accordingly, and no increase in ovulation rate was observed in response to the protection of proteins by tannins. As a result, they concluded that the primary factor affecting the ovulation rate in very short-term tannin-supplemented feeding was not only the protein but also where the protein was used in the digestive system.

7. EFFECTS of TANNINS on ANIMAL HEALTH

Parasites in the digestive system of grazing animals are one of the factors that cause substantial losses in ruminant animals. These parasites reduce feed intake and live weight, negatively affecting animals' growth, milk yield, fleece wool yield, and reproduction. Anthelmintic drugs are ideal for controlling parasites in the digestive system; however, consumers consider their residues disturbing in animal products (Parkins and Holmes, 1989). It is widely known that tannins potentially reduce the number of internal parasites in different ways (Amesa and Asfaw, 2018). Firstly, tannins form non-biodegradable complexes with proteins in the rumen, and these complexes dissociate at low pH in the abomasum, releasing more proteins for metabolism in the small intestine of ruminants. In other words, tannins indirectly bind to proteins in the rumen and prevent microbial degradation by ensuring an anti-parasitic effect; as a result, it elevates the resistance and durability of the animal against nematode parasitic infections. Secondly, tannins may cause a direct anthelmintic effect by hindering the larval development of parasites in the animal digestive system (Waghorn et al., 1994). Min et al. (2003) reported that tannins-containing diet consumption among parasite-infected lambs and sheep gained live weight, and the parasite eggs in fecal matter dropped by roughly 20-50%. Similarly, Atiba et al. (2021) observed higher feed consumption and live weight increase among parasitized sheep and goats fed with condensed tannin-containing diets due to higher protein and amino acid availability. They also indicated that condensed tannin-containing feeds produced meat with lighter colors and higher levels of antioxidant activity. Alonso-Díaz et al. (2010) reported that small ruminants retain saliva rich in tannin-binding salivary proteins; hence, they potentially ingest higher amounts of tannin-rich plants, which in turn have more tannin in their gastrointestinal systems acting as an anthelmintic against gastrointestinal nematodes. Thus, it is possible to state that the tannins consumed by animals grazing on tannin-rich pastures act as natural anthelmintics against gastrointestinal nematodes. Besides improving protein nutrition, condensed tannins can also modulate the activity of host immune cells through eosinophil cells. A higher quantity of eosinophil cells, a type of white blood cell made in the bone marrow that is involved in the body's immune response, is the most significant factor in the body's response to parasitic infection and is typically associated with the expression of host resistance to parasites (Alba-Hurtado and Muñoz-Guzmán, 2013). Several studies also reported that condensed tannin-containing feedings improve feed intake in parasitized small ruminants (Lisonbee et al., 2009; Moore et al., 2008; Sokerya et al., 2009; Amit et al., 2013; Merera et al., 2013). Accordingly, feeding small ruminants with condensed tannin-containing diets has been considered an alternative to anthelmintic drugs to control parasitic nematodes and improve their productivity. However, bloat, vastly observed in ruminants, is a disease caused by flatulence in the rumen and reticulum and impairs the functions of the gastrointestinal and respiratory systems (Wang et al., 2012). Rumen bloat occurs due to the high solubility of feed proteins and is very common in cattle fed with legumes, especially in the spring period (Amesa and Asfaw, 2018). It is widely known that grazing animals with tannin-containing legumes eliminates bloating due to their protein complex formation properties. The recommended safe CT concentration in forage legumes to avoid bloating is 1-5 mg CT g^{-1} DM (Li et al., 1996). Despite the high growth rates, bloating is a considerable deterrent factor among ruminant animals grazing in alfalfa (*Medicago sativa* L.) pastures. Accordingly, adding sainfoin (*Onobrychis viciifolia* Scop.), a legume retaining condensed tannins; in the feed vastly controls minimizing alfalfa pasture bloat (Sottie et al., 2014). In this context, Ali et al. (2017) reported that adding hydrolyzed tannin (40 g) to the concentrate feed mixture of dairy cows increased milk yield and quality. It also improved udder health by decreasing the number of somatic cells. Hashemi et al. (2024) also reported that dietary tannins substantially reduced the quantity of Escherichia coli in cattle feces without adversely affecting their fecal consistency scores. As a result, they concluded that using tannins as a protein source up to 4% in milk replacer feeding resulted in no adverse effect on the performance characteristics and health of the calves. Hassan et al. (2020) also documented that dietary tannins improved growth performance, digestibility, and rumen functions in lambs, lowered oxidative stress markers, and enhanced antioxidant defense mechanisms. They also noted that adding up to 6% tannins to sheep diets could cause no harmful effects on the general health of lambs.

8. EFFECTS of TANNINS on METHANE EMISSION

The oxidation of soil organic matter, the loss of stocked carbon, and the decomposition of dead plant material in pastures release CO_2. The vast majority of CH_4 produced during ruminal fermentation is emitted through belching and, to a lesser extent, through animal feces. N_2O is emitted through animal feces and urine excretion. CO_2 accounts for approximately half of global gas emissions and considerably affects climate change, followed by CH_4 (20%) and N_2O (6%) (Aboagye et al., 2019). Researchers have focused on discovering natural alternatives for environmentally friendly animal production since animal husbandry significantly impacts climate change (Patra and Saxena, 2009). Tannin-like components in ruminant diets enable animals to utilize nitrogen better, minimize nitrogen losses in excreted urine, and reduce intestinal and soil methane emissions. The antibacterial properties of condensed tannins make them particularly promising as natural feed additives to lower rumen methanogenesis (Patra and Saxena, 2009). More than 12% of dietary energy can be lost as methane and heat since over 50% of dietary protein in ruminants can be converted into ammonia in the rumen and excreted through urine (Callaway et al., 2003). Such low conversion efficiency of nitrogen into animal protein declines productivity through energy loss, and the emitted nitrogen leads to environmental pollution (Herremans et al., 2020). Tannins inhibit some hydrogen-producing protozoa and methane-producing organisms using hydrogen directly in the animal rumen. Thus, they lower greenhouse gas emissions and increase animal productivity (Acar et al., 2020; Ayan et al., 2020). In this regard, tannins have been recognized as potential methanogenic bacterial reducers because of their capacity to decrease rumen degradability by preventing methanogenic bacteria from forming hydrogen bonds (Broderick et al., 2017; Fagundes et al., 2020). In balanced protein-energy diets, tannins can reduce CH_4 generation and ruminal protein degradability, which may improve animal metabolism and benefit the environment (Brutti et al., 2023). Specifically, condensed tannins are considered plant polyphenols that can act on feed digestibility and have the potential to minimize ruminant enteric methane emissions (Battelli et al., 2024). Khiaosa-Ard et al. (2009) reported that CT extract inhibited methane generation by stimulating bacterial population growth and increasing competition between bacteria involved in bio-hydrogenation and others. Fonseca et al. (2023) documented that tannin-containing diets suppressed methanogenic archaeal communities in ruminants and positively affected cellulolytic populations, making them an effective agency in declining rumen methane production. Battelli et al. (2024) stated that CT reduced ruminant CH_4 emissions; however, this reduction was related to the shift from urine to fecal N excretion but not to the increase in N utilization efficiency of CT. The nitrogen excretion shift from urine to feces favorably impacts the environment since the N element in feces is highly stable and thus lessens the release of NH_3 and N_2O into the atmosphere (Mueller-Harvey et al., 2019; Hristov et al., 2022). However, numerous studies also revealed that many feed types may lower ruminant methane production. For instance, tannins in *Lotus corniculatus* (Woodward et al., 2001), *Hedysarum coronarium* (Woodward et al., 2002), *Lotus pedunculatus* (Waghorn et al., 2002), *Kobe lespedeza* (Animut et al., 2008), *Populus deltoides* (Patra et al., 2008), *Vaccinium vitis idaea* L. (Cieslak et al., 2012), and *Caragana korshinskii* (Niu et al., 2024) reduced methane release.

9. CONCLUSION

Tannins are plentiful in feeds and forage legumes, which ruminants abundantly consume. It is necessary to analyze feed consumption, the structure and molecular weight of the compound, and the physiology of the consuming animal species to acknowledge the healthy and detrimental effects of tannins on ruminants. In essence, the positive or negative impacts of the condensed tannins depend on the concentration, amount, type, chemical structure of the crude protein, and feed composition in the diet. Hence, analyzing feed tannin content and supplementing it is essential in determining the tannin content in animal diets. This ratio should be at a level that will not create a toxic effect on the animals and should not negatively affect microbial protein synthesis in the rumen. The proper tannin ratio facilitates microbial protein synthesis and endogenous nitrogen use in the rumen. It also plays a critical role in averting infections in herds by strengthening the immune system in ruminants. In conclusion, diets with optimum tannin contents potentially ensure the sustainability of ruminant production systems.

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CHAPTER 5

USES AND PROPERTIES OF SILKWORM (*Bombyx mori* L.) SILK

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INTRODUCTION

The holometabolous insect Bombyx mori L. (B. mori) is a member of the family Bombycidae and the order Lepidoptera. It produces a lot of sericin until the end of the fifth larval stage and forms silk thread that is used to make cocoons in addition to fibroin, which creates the perfect environment for the larvae to transform into adults (Kundu et al. 2008). As shown in Figure 1, the silkworm has a brief and quick life cycle with four stages (Habeanu et al. 2023):

1st stage: egg,

2nd stage: larva,

3rd stage: pupa (in cocoon),

4th stage: butterfly (adult)

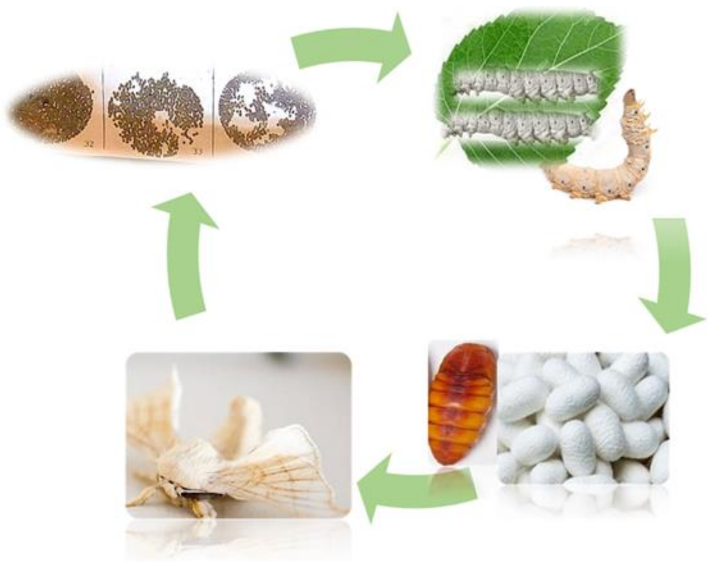

Figure 1. Silkworm (Bombyx mori L.) life cycle
Reference: Habeanu et al. (2023)

The greatest amount of silk protein (about 0.5 g per larva) is generated in the fifth larval stage, or final larval instar, even though it is produced throughout the larval stage (Ma et al. 2024). The extrusion of silk from the strands at the head and the tugging of the fiber with a distinctive figure-eight head movement are characteristics of this spinning stage. The silkworms create a silk cocoon at the end of the 5th instar by turning the substantial amount of silk from the silk gland into a continuous raw silk thread (Asakura and Williamson, 2023). The fiber threads can reach a length of over one kilometer after they are released from the silk cocoon.

Because of its simplicity of production, wide supply, and distinctive fabric qualities, B. mori silk has become more significant among the various types of silk (Huang et al. 2018). Furthermore, because of its biocompatibility, strong mechanical performance, ease of processing, tunable degradation, ample supply, and convenience of acquiring from the established sericulture business, silk derived from B. mori has been the most commonly used material for centuries (Rockwood et al. 2011). In the textile business, fibroin is transformed into raw silk and used to make different kinds of yarn and silk fabrics, while the cocoon is processed and sericin is mostly eliminated by a procedure known as degumming (Mondal et al. 2007). The mechanical characteristics of silkworm fibroin and its distinct interactions with tissue cells have drawn attention in recent years. According to Lawrence and Infanger (2024), fibroin offers a rich biopolymer platform that can be used to create biomaterials in a variety of forms, including water-containing medicines and three-dimensional structures. Fibrin has currently been studied as a biomedical material in a variety of fields, such as skin tissue, vascular grafts, nerve and ocular healing, drug release, ligaments, tendons, and bone and cartilage. The biomedical uses of silk fibroin are therefore very promising (Wenk et al. 2011; Kasoju and Bora 2012; Koh et al. 2015; Guo et al. 2020; Li and Sun 2022; Lu et al. 2024; Wang et al. 2024).

The fibroin filaments in the silk thread made by B. mori, a crucial part of raw silk and a substance employed of the cocoon, are encased and held together by sericin, which is naturally occurring polymer. Reusing and recovering silk that is abandoned by the textile industry generally has significant commercial and scientific value (Silva et al. 2022). Use in the food and cosmetic industries is made possible by the series's antioxidant capability and the very hydrophobic amino acids that make up its structure. However, its qualities including moisturizing power, wound healing, stimulating cell proliferation, radiation protection, anti-tumor, anti-microbial, anti-inflammatory, anti-coagulant, anti-bacterial, and anti-diabetic activities make it a useful biomaterial (Kunz et al. 2016; Khosropanah et al. 2022).

B. mori is one of the most economically significant insects, which is a model organism utilized in medicine in many impoverished nations, and a great representative of the lepidopteran species for many scientific investigations (Habeanu et al. 2023). The structure, secretion mechanism, and applications of the silk generated by the B. mori silkworm, which produces around 90% of the world's silk, have all been investigated in this paper.

1. STRUCTURE OF NATURAL SILKWORM SILK AND SILK GLAND

Silk has a crystalline structure and is a protein-based fiber. According to Kim et al. (2023), it is made up of two biopolymers: fibroin and sericin. Fibrin is the inner core protein made up of hydrophobic amino acids, glycine, and alanine repeat sequences (70–80%), whereas sericin, an antigenic glue-like protein, makes up the hydrophilic coating of the outside silk layer (20–30%) (Sobajo et al. 2008; Sun et al. 2019; Reddy et al. 2020). Waxy matter (range between 0.4 to 0.8%), carbohydrates (from 1.2 to 1.65%), inorganic matter (approximately 0.7%), and pigment (approximately 0.2%) are some of the other minor constituents of silk, which is generated by B. Mori (Gore et al. 2019). A glycoprotein P25 (approximately 25 kDa) is hydrophobically bonded to the H-L complex, which is made up of two type chains: the heavy chain (H-chain, approximately with a molecular weight of 390 kDa) and the light chain (L-chain, approximately molecular weight of 26 kDa), which are joined by disulfide bonds to create the H-L complex. Silk fibroin is created by combining the H-chain, and L-chain, and P25 in a 6:6:1 molar ratio (Inoue et al. 2000). Basic micelle elements are also formed as a result of this. Before it becomes fibers, a significant amount of fibroin can move through the silk gland lumen in a straight line because to the creation of micelle components. Light chains offer minimal mechanical support in silk fibers, while heavy chains create unique β-sheet structures that serve as the primary structural element and give the required mechanical strength (Koh et al. 2015). In all, glycine (45.9%), alanine (30.3%), serine (12.1%), tyrpthophan (5.3%), valine (1.8%), and 15 other amino acid types (4.7%) are present in the heavy chain of fibroin (Zhou et al. 2001; Huang et al. 2018; McGill et al. 2019). Aspartic acid (33.4%) and serine (16.7%) are the series' primary constituents (Aramwit et al. 2012; Tansil et al. 2012; Kunz et al. 2016; Cao and Zhang 2017). In another words, sericin is made up of amino acids with around 25% non-polar groups and roughly 75% polar side chains, whereas fibroin is made up of amino acids with roughly 76% mol of non-polar side chains and roughly 21% polar groups. Because of this compositional difference, sericin dissolves in water more readily than fibroin (Chopra and Gulrajani 1994). Silk has a density of 1.3–1.4 g cm-3 and a Young's modulus of 8.9–17.4 GPa. These values are comparable to those of human bone, which normally has a range of 1.8 to 2.0 g cm-3 and 3 to 20 GPa. Because of this, silk may be a better option for artificial bone materials than ceramic or metal implants (Lu et al., 2024).

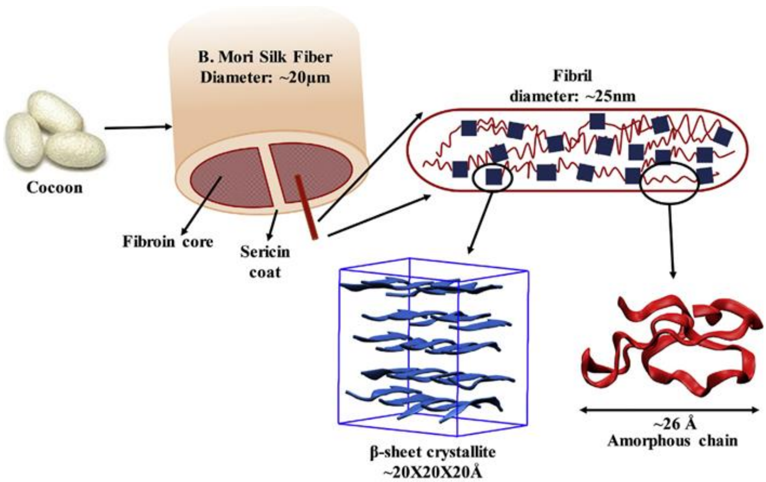

Figure 2. Structural components of B. mori silk fiber
Reference: Patel et al. (2020)

The silk gland produces and stores very large amounts of silk proteins. The silk gland of B. mori is a tubular epithelium that is separated into three portions with different pH values which is maintained with regulation of carbonic anhydrase enzyme (Domigan et al. 2015), as shown in Figure 3:

the posterior silk gland-PSG (pH between 7.2 and 8.2)

middle silk gland-MSG (pH between 7 and 7.2)

anterior silk gland-ASG (pH between 6.2 and 6.8)

The physical characteristics of silk fibers, such as their stickiness or viscosity, are influenced by varying pH levels (Pritchard et al. 2012; Herold and Scheibel 2017; Sehadova et al. 2021; Silva et al. 2022). Carbonic anhydrase is also produced by one of the four types of epithelial cells found in B. mori silk glands. The process that creates the intraluminal pH gradient that controls the aggregation of silk proteins and the subsequent production of fibers from soluble silk proteins requires carbonic anhydrase.

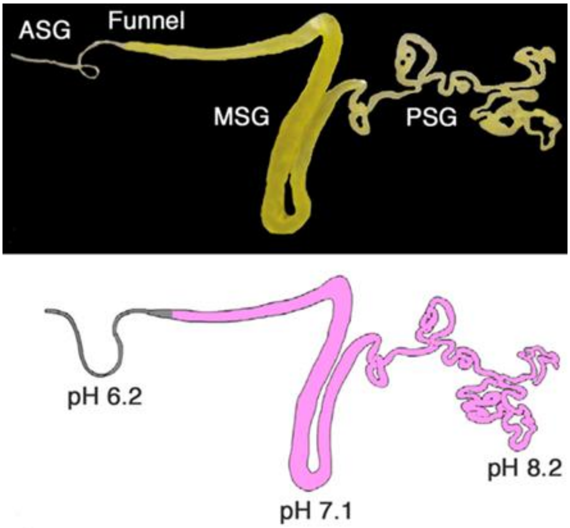

Figure 3. The silk glands' structure in a mature silkworm
Reference: Domigan et al. (2015)

Fibroin is produced in PSG. MSG cells produce three different forms of sericin: sericin 1, sericin 2, and sericin 3. Processing liquid silk is the responsibility of ASG, which does not manufacture silk. The primary component of silk is synthesized by the roughly 500 gland cells that make up the long PSG. About 300 secretory cells make up MSG, which is where silk proteins are kept until they are spun into a cocoon in its lumen. ASG is a narrow duct with around 250 cells that does not have a secretory role (Grzelak 1995). During the early phases of embryogenesis, these cells divide roughly ten times before going through an irreversible endoreplication process that encourages the formation of silk glands in the following phase without increasing the cell count (Ma et al., 2024).

Since silkworms typically spin their silks via a protein self-assembly process from highly concentrated protein gels or solutions into solid fibers, they have evolved biological fiber spinning systems over millions of years. There are five steps in the silk gland's production of silk fibers (Figure 4).

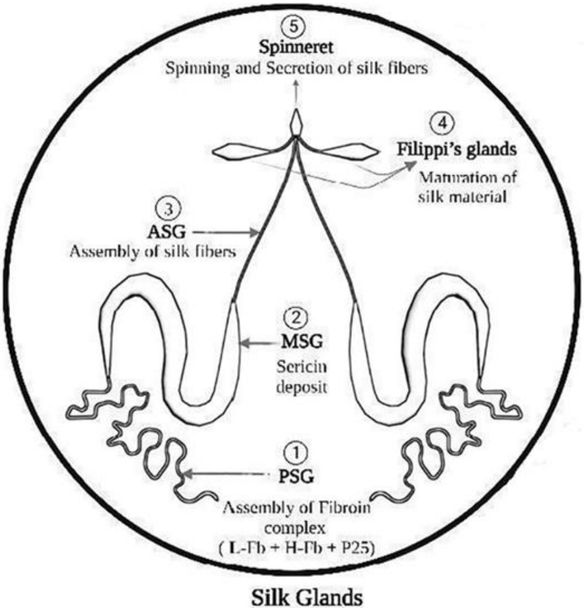

Figure 4. Natural production of silk
Reference: Bitar et al. (2024)

The H-Fb, L-Fb, and P25 subunits are first synthesized in PSG, followed by the formation of β-sheet structures and the eventual fibroin complex, which is held together by disulfide bonds. The fibroin complex then travels to the MSG, where sericin is released to coat the fibroin core's surface and create silk complexes. The pH and metal ion concentrations subsequently carry the complexes along the ASG and transform them into silk fibers. The Filippi's gland produces mature silk fiber, which is then extruded through the spinneret to spin a cocoon. (Bitar et al. 2024; Anderson et al. 2016). Furthermore, the orientation of the protein molecules in the silk thread is impacted by the precise and constant movement of B. mori's head during cocoon spinning. This causes the silk proteins to crystallize and come together, which increases their hydrophobicity and causes water to evaporate from the thread's surface (Liu and Zhang 2014).

Fibrin, the main component of silk fibers, is coated with sericin, an adhesive protein (Kapoor and Kundu, 2016; Katsuma et al. 2018; Ma et al. 2024). Because they aid in the production of cocoons, the adhesive layers produced by the globular-shaped sericin are also referred to as silk glue (Dai et al. 2019; Dinjaski and Kaplan 2016). While silk sericin protein is often soluble and can be eliminated through a thermochemical process called degumming, silk fibroin protein is resistant to water. In the silk business, sericin is extracted from fibroin to enhance the fibers' smoothness, brightness, lightness, and dyeability (Gupta et al. 2013). The most crucial step in guaranteeing biocompatibility is the elimination of fibroin fibers from the series (Lamboni et al. 2015). since an organism's employment of sericin and fibroin together tends to produce a pro-inflammatory response (DeBari and Abbott 2019). As a result, a silk fibroin solution consisting of three distinct proteins (H, L chain, and P25) is left over after the sericin coating is removed. It is believed that the presence of the heavy chain protein is what gives the biomaterials made from these solutions their primary characteristics (Bitar et al., 2024). However, depending on where it comes from, silk's composition, structure, and qualities can differ significantly. Silk fiber materials have more compact β-type protein structures. Both the touch and shine of these materials are softer (Fu et al. 2015; Saric and Scheibel 2019).

- **Sericin: Properties**

The alternate splicing of sericin genes results in the formation of the glycoprotein sericin. The synthesis of sericin is controlled by at least three genes, namely as Ser1, Ser2, and Ser3. According to Kunz et al. (2016), the Ser1 gene is roughly 23 kb in size and has nine exons; the Ser2 gene ranges in size from 28 to 2574 bp and has thirteen exons; and the Ser3 gene is roughly 3.5 bp in size and has three exons. According to Rajput and Singh (2015), the series' organic composition is carbon (46.5), oxygen (31%), nitrogen (16.5), and hydrogen (6%). It could be used in the food and cosmetic sector as a moisturizer, wound healer, cell proliferation stimulator, antimicrobial, antioxidant, anticancer, coagulant, and radiation protector due to its solubility, organic composition, and structural organization of the chemical groups in the series (Lamboni et al. 2015; Gilotra et al. 2018; Kumar and Abrahamse 2022).

Serine includes 18 amino acids, positively and negatively charged, aromatic, polar, and non-polar amino acids (Kunz et al. 2016). Furthermore, serine is water soluble due to its high concentration of hydrophilic amino acids, particularly critical amino acids. The size of the resultant serine molecules varies based on temperature, pH, and processing time when serine is hydrolyzed in acidic or alkaline solutions, dissolved in a polar solvent, or broken down by a protease. At 50–60°C or above, sericin dissolves in water on average. The series becomes less soluble at low temperatures, which causes a gel to develop (Dash et al. 2007). Therefore, when the temperature varies, the protein's structure changes as well. According to Kunz et al. (2016), sericin dissolves in the solution when heated and gels when cooled. While sericin peptides with high molecular weight (≥20 kDa) are primarily utilized as medical biomaterials, composite polymers, biodegradable biomaterials, hydrogels, functional biomembranes, functional fibers, and textiles. Sericin peptides with low molecular weight (≤20 kDa) or sericin hydrolysates are utilized in cosmetic products, such as skin and hair care, and health products, and pharmaceuticals (Zhang 2002). Around 50,000 tons of silk, which the textile industry considers trash and which is made from 1 million tons of fresh cocoons annually worldwide, are reportedly frequently disposed of in sewage systems, endangering the environment (Aramwit et al. 2012; Lamboni et al. 2015). In addition, it raises the oxygen demand for chemicals and biological processes and pollutes water. Therefore, the recovery and reuse of the thrown series contribute to both the evaluation of materials with high scientific and economic value and the minimizing of environmental difficulties (Kunz et al. 2016).

- **Fibroin: Properties**

Because of its exceptional mechanical strength, which comes from its structure, the silk fibroin fiber derived from B. mori has been utilized as a superior textile material for more than 5000 years (Asakura and Williamson 2023). Silk fibroin's strong tensile strength (300–740 MPa), high toughness (70–78 MJ.m-3), and big breaking strain (4–26%) are crucial for producing an exceptional textile material (Vollrath and Porter 2009; Koh et al. 2015; Guo et al. 2020). These days, textiles can be made from a variety of natural resources. Nonetheless, silk fibroin is unique among them due to its remarkable moisture absorption capabilities, soft-touch texture, exceptional mechanical qualities, ease of dyeing, excellent biocompatibility, and incredibly bright/beautiful look (Tansil et al. 2012). Silk obtained from B. mori cocoons has a tensile strength of approximately 0.5 gigapascals (GPa), a break elongation of 15%, and a fracture energy (toughness) of 6 × 10^4 J kg^-1 (Shao and Vollrath 2002). Silk fibroin H-chain is a highly organized biopolymer consisting of 11 hydrophilic regions and 12 hydrophobic regions. Hydrophobic regions contain amino acids in repeating sequences (hence called repeating regions), while hydrophilic regions contain amino acids in non-repeating sequences (hence called non-repeating regions) (Koh et al. 2015). Hydrophobic regions make up a large portion of silk proteins and primarily contain glycine, alanine, serine, and a lower content of tyrosine, valine, and threonine. Through hydrogen bonding and hydrophobic interactions, these hydrophobic regions in the structure of silk fibroin organize the formation of β-sheet crystallites, which give silk fibers their high strength, thermal stability, and insolubility (Foo et al. 2006). This results in the formation of highly organized crystalline regions in silk fibroin. The tensile strength of fibroin is based on these structures. Conversely, the hydrophilic sections of silk fibroin constitute a non-crystalline (semi-amorphous) region and are primarily composed of glutamic acid, aspartic acid, arginine, and lysine. Accordingly, fibroin is a continuous long molecular chain with a molecular weight of roughly 325,000 and is composed of roughly two-thirds crystalline phase and one-third amorphous phase (Cheng et al. 2014). The elasticity and robustness of fibroin are revealed by the combination of hydrophobic and hydrophilic regions (Zhang et al. 2009). As a result, fibroin fibers outperform even high-strength synthetic fibers like Kevlar and Aramid in terms of tensile strength, breaking elongation, and toughness (Koh et al. 2015). A polymer's mechanical characteristics and biodegradability are significantly influenced by its molecular weight. However, Jin and Kaplan (2003) reported that the interactions between β-sheet crystals, as well as the size and spacing of the crystals, play a critical role in silk processing and must be taken into account in this process. Basically, silk fibroin could form β-sheet crystals of various sizes and intervals, either intra-molecularly or inter-molecularly, parallel or antiparallel, along the axis of the silk fiber. The separation (splitting) of protein chains from the intramolecular β-sheet crystalline structures causes the silk fibers to elongate, while the separation from the intermolecular β-sheet crystalline structures weakens the bonds between the protein molecules in the silk fibers, resulting in a failure of pairing (Wu et al. 2009). When β-sheet crystals are arranged in a parallel manner, adjacent β-strands form long and non-linear hydrogen bonds, while anti-parallel adjacent β-strands form short and linear hydrogen bonds. These variations in hydrogen bonds lead to different arrangements of β-strands, thereby affecting the mechanical performance of silk fibers (Jin and Kaplan 2003). For example, it has been discovered that in antiparallel arranged β-sheet crystals, the hydrogen bond is stronger, and therefore, considering their fracture toughness and hardness, they are superior to their parallel counterparts. Additionally, it has been reported that when the β-sheet crystal size is limited to a few nanometers (2–4 nm), silk fibers exhibit greater mechanical strength, stiffness, and toughness compared to β-sheet crystals of larger sizes (Gore et al. 2019).

However, particularly in the past decade, silk fibroin has gained recognition as a superior biomaterial with a multitude of possible uses (Chen et al. 2020; Guo et al. 2020; Kong et al. 2020; Zuluaga-Vélez et al. 2021; Zhang et al. 2022; Kim et al. 2023; Lu et al. 2024). One limiting factor for clinical applications in materials intended for use as biomaterials is the biomaterial's immunogenicity or heterogeneity. Because when a heterologous antigen enters the body, B cells, dendritic cells, macrophages, and mast cells in immune system become activated and produce antibodies and various cytokines targeting the antigen epitopes on biomaterials with the aim of attacking and eliminating the "foreigners" through humoral and cellular immune responses. Thus, the most crucial factor is whether the materials to be employed as biomaterials are biocompatible (Zhang et al. 2009). Because of its amino acid sequence, silk fibroin presents potential for chemical changes that will provide biocompatibility. Potential reactive side groups utilized for these chemical alterations include the amines, phenols, alcohols, carboxyl groups, and thiols found in silk fibroin's structure. With their alteration, variations in silk fibroin's hydrophilicity and charge could also modify the degree of functionalization (Wenk et al. 2011). This way, it becomes easier to process silk fibroin in different forms such as sponge, fiber, hydrogel, etc. (Yang et al. 2007). Fibroin materials in different forms exhibit high biocompatibility by interacting positively with biological systems without causing adverse immunological reactions, supporting their adhesion, proliferation, growth, and functionality

(Hakimi et al. 2007). It has been reported that different forms of silk fibroin with good biocompatibility can significantly support the healing and regeneration of damaged nerves (Rajabi et al. 2018; Chen et al. 2020).

2. USES of SILK-BASED MATERIALS

It is well known that silk has been mainly and largely used for more than 5000 years in the textile sector and for surgical purposes. As mentioned below, silk has excellent properties including biodegradability, biocompatibility and unique physical, chemical and mechanical specialities that have provided a huge attraction for different intended use. Therefore, silkworm silk has been used recently in a variety of industries, mainly in textile sector, numerous scientific studies have been conducted to determine its potential uses (Chand et al. 2023). Along with its biocompatible and biodegradable qualities, silk also has the ability to retain moisture, adhere to the skin, and gel. These qualities make it a valuable biomedical material with a wide range of commercial practices in the pharmaceutical, cosmetic and food industries (Jastrzebska et al. 2015; Wang et al. 2015; Soumya et al. 2017; Fan et al. 2019).

Biomedical usage of silk

Silk is a biological substance because it contains hydrophobic amino acids and sericin, which has antioxidant properties. The antibacterial, anticoagulant, anticancer, and anti-inflammatory properties of silk are made possible by the antioxidant activity of sericin (Kunz et al. 2016). According to Chand et al. (2023), moisture also has a medicinal effect by promoting cell proliferation, wound healing, UV protection, and the creation of cosmetics like lotions and shampoos.

Silk is widely used in sutures, surgical fabrics and öeshes, tissue engineering, clinical experiments, and new biomedical applications such as films, electro-spun materials, scaffolds, hydrogels, and particles because of its biocompatibility and biodegradation qualities (Holland et al. 2019; Koh and Lee 2021; Saleh 2021).

Silk has biocompatible and biodegradable specialities because its sericin and proteinous nature make it vulnerable to the body's digestible proteolytic enzymes. Because of its propensity to retain moisture, gel, and adhere to skin, it may find extensive usage in the medical, pharmaceutical, and cosmetic industries (Padamwar and Pawar 2004). Scientific reports have clearly demonstrated that the sericin has an anti-tumor activity. Foods containing sericin could prevent constipation, treat bowel cancer, and promote the mineral absorption (Joseph and Justin Raj 2012; Kato et al. 2000).

Biomaterials derived from silk have beneficial impacts on fibroblast and keratinocyte development and proliferation (Zhang et al. 2009a). Therapeutic uses of silk sericin have been investigated, including antibacterial (Basal et al. 2010), wound-coagulant and wound-healing properties (Padol et al. 2011). According to Joseph and Justin Raj (2012) and Padamwar et al. (2005), silk sericin and silk fibroin can also be utilized in skin, nail and hair cosmetics as creams and ointments that increase skin elasticity and have anti-aging and anti-wrinkle properties. Nail cosmetics containing sericin with a range of 0.2 to 20% could potentially provide a preventive effect for nail brittleness, chapping and impart inherent gloss in nails (Yamada et al. 2001).

There are many kinds of different commercially produced silk-based materials in biomedical practices. Some of them are listed here according to usage aim (Babu and Suamte 2024):

Therapeutic apparel for individuals with skin conditions
Medialization of vocal folds and sufficiency of vocal folds
Perforation in the tympanic membrane
Repairing peripheral nerves
Hair care
Cream for moisturizing
Skin health and anti-aging care
Surgical adhesive dressing (sterile)
Topical antiseptic and ointment for wound healing
Transparent surgical incision port wound dressing
Transparent bandage for wounds with mild to moderate exudation
Hydrogel wound dressing
Antimicrobial and surface antiseptic/disinfectant spray for topical use
Antimicrobial and non-adherent gauze bandage
Antimicrobial adhesive wound dressing after surgery
Antimicrobial surgical mesh and surgical powder for treating wounds

Previou studies indicated that silk fabricated through non-weaving and electrospinning could be used in wound dressings, and as drug carriers (Altman et al. 2003; Li et al. 2015; Wharram et al. 2010; Farokhi et al. 2018). Silk fiber-based wound dressing material with unique antibacterial qualities containing silver nanoparticles have been developed (Xia et al. 2009). Additionally, the size of the wound, collagen, and epithelialization decreased when the wound dressing made up of two layers: a bioactive layer with glutaraldehyde cross-linked silk fibroin gelatin with a sericin sponge, and also silk woven fabric coated with wax, was applied (Wang et al. 2006; Kamalathevan et al. 2018; Chouhan et al. 2020).

Products made of silk could be utilized in many ways to improve the health of the skin. For instance, because of their antibacterial qualities, silk clothing has been developed as a textile-based treatment for atopic dermatitis. Silk's hygienic qualities minimize inflammation by protecting the skin from bacteria, viruses, and other contaminants (Hung et al. 2019; Macias et al. 2011). Additionally, the smooth and thin structure of silk filament threads makes them a comfortable material for the skin, minimizing skin irritation and scratching from friction (Criton and Gangadharan 2017). According to a prior study by Hung et al. (2019), wearing silk clothing significantly reduced the severity of dermatitis symptoms.

3. SILK FIBER as an INDUSTRIAL and ENGINEERING MATERIAL

As mentioned below, fibrin and sericin are the two main protein components of silk. While sericin is obtained as a waste product in the textile sector during the process of separating fibroin from sericin, fibroin is mostly used in textiles and industrial areas. Their low repeatability compromises the silk’s high tensile strength and stiffness values (Pérez-rigueiro et al. 1998; Soumya et al. 2017). Sericin is a valuable biomaterial that has been shown to be successful in tissue engineering, drug administration, culture media, and cryopreservation (Kunz et al. 2016).

In order to replace, improve, and preserve damaged or dysfunctional tissues, such as cartilage, bone, skin, 103lüoride organs, tissue engineering combines the concepts of biological sciences with engineering techniques (Caddeo et al. 2017). The final bio-substitute’s functionality depends on the biomaterial selection and the techniques employed. Silk is suitable for application in tissue engineering because of its strong mechanical qualities, low inflammatory response, and slow rate of degradation. Sericin must be totally eliminated before usage, nevertheless, as it may trigger an immunological reaction (Song 2011). Bombyx mori silk is the kind of silk that is frequently utilized in tissue engineering (Caddeo et al. 2017; Bandyopadhyay et al. 2019). Scaffolds in the form of skin grafts or artificial skin, artificial liver, bone grafts, cardiac tissue, artificial pancreas, and artificial intervertebral disc are examples of silk-based tissue engineering (Behrens et al. 2021).

Recently, polymeric methods for drug delivery have gained interest and importance (Kamalha et al. 2013). These systems enhance the physicochemical characteristics of medications by acting as reservoirs for their active ingredients (Tomeh et al. 2019). Additionally, polymeric drug delivery methods are effective in intracellular transport, selective targeting, and some are biocompatible, all of which contribute to better treatment outcomes and patient quality of life (Luo et al. 2019; Tomeh et al. 2019). Stabilizing the active component in medications, regulating the drug's release mechanism, being biocompatible and biodegradable, and reducing the negative consequences of tissue-specific targeting of extremely hazardous pharmaceuticals are all qualities of a good drug delivery system (Yin et al. 2018; Rezaei et al. 2020).

Silk fibroin is utilized in drug delivery systems because of its favorable mechanical qualities, mild aqueous processing conditions, biodegradability, biocompatibility, and capacity to improve the stability of small molecules and proteins that are the active ingredients in medications (Li et al. 2015; Choi et al. 2018). Nevertheless, a variety of methods can be used to treat silk fibroin solutions in order to create a variety of delivery systems, including films, hydrogels, scaffolds, microspheres, nanoparticles, and microcapsules (Seib 2018). Furthermore, silk fibroin contains amino and carboxyl groups that enable bio-functionalization with various biomolecules for precise medication administration (Vepari and Kaplan 2007). Hydrogels, microparticles, lyophilized sponges, films, nanofibers, and nanoparticles are examples of silk-based drug delivery methods.

In recent times, silk-based biosensors have increasingly gained interest by many researchers (Ru et al. 2022). The development of silk-based food sensors in the form of passive metamaterial antennas has allowed for detailed monitoring of food quality (Babu 2022) and biological analyses (Babu 2020). To enable close contact with the nano and microstructures that might probe and track changes in the surrounding environment, silk protein-based substrates have been created and applied to the surface of an apple. The sensor is edible and made entirely of biodegradable materials, suggesting potential applications in the food and medical industries (Tao et al. 2012).

Furthermore, silk fibroin hydrogels have been used in metal–insulator–metal (MIM) absorber-based surface Plasmon resonance (SPR) sensors. The resulting MIM structure is extremely sensitive to variations in the refractive index and thickness of the thin 20 nm silk fibroin hydrogel insulator layer sandwiched between two 200 nm gold films. Thus, the hydrogel characteristics of the silk spacer, which can hold water molecules up to 60% of its 105lüori, improve analytic sensitivity. The silk hydrogel's refractive index and swelling ratio have an impact on sensitivity. Silk plasmonic structures are appropriate for glucose sensor applications because the silk polymer chains may also function as fluidic channels that allow analytes to pass through a nano-sized layer in water (Lee et al. 2015).

A mixture of reduced graphene oxide (RGO)/glucose oxidase (Gox) and silk nanofibril was used to create a dependable glucose sensor. This sensor covered both diabetes patients (0–100 μM) and healthy individuals because it demonstrated detection even at very low limits (300 nM) and had a high sensitivity of 18.0 μA/Mm, which is within the sweat glucose range. According to Chen et al. (2022), tests on sweat samples revealed good reliability and correlation with data from a standard commercial glucometer.

In a different study, Li et al. (2021) employed spider dragline silk (SDS) to develop a novel humidity sensor that depends on the dragline silk's refractive shift mechanism in response to environmental humidity variations. In order to obtain an optical spectrum, the SDS was wrapped on a tapered single mode fiber, which allowed 105lüorid construction of a multimode interference structure. The multimode interference spectrum shifted as a result of changes in the environment's humidity, which also affected SDS's refractive index. According to the testing results, the suggested SDS-based sensor's average sensitivity was 0.532 nm/%RH over a range of 70% to 89% RH. The humidity sensing curve was roughly fitted using the linear approach, and the highest sensitivity was found at 0.789 nm/%RH over a range of 70%RH/- 89%RH (Li et al. 2021).

By carbonizing 105lüo silk georgette at a high temperature and then encasing it in the elastic polymer poly-dimethylsiloxane (PDMS), a wearable strain sensor was created. This has demonstrated encouraging potential for use in tracking a variety of human motion-based activities (Wang et al. 2017a). The idea behind silk-based wearable sensors is that silk fibroin can be thermally treated to become an electrically conductive graphite nano-carbon (Cho et al. 2015). Carbon membranes made from transparent and flexible silk nanofibers have also been created for multipurpose electronic skin that can 106lüorid physiological signals in humans (Wang et al. 2017b; Wang et al. 2017c). Silk and poly-vinylidene 106lüoride-co-trifluoroethylene have also been developed to create self-powered pressure sensor sheets for wearable technology (Jung et al. 2020). For application in epidermal electronics, calcium-modified silk fibroin has been created and demonstrated to have outstanding adhesive qualities in addition to superior stretchability, conductivity, and reusability. This enables a robust interaction between a biological surface and a sensor. Accordingly, calcium-modified silk fibroin exhibits potential for use as an adhesive for biomedical sensors based on the skin (Seo et al. 2018).

Another intriguing application for silk is coating optical fibers that are often non-biocompatible for biosensing inside the human body. Fluorophore 5,6-carboxynapthofluorescein (CNF) doping of silica exposed core fibers following a thin silk coating has been documented. Remote pH measurement along the fiber length is made possible by the fluorescent signals produced by the doped-silk layer when applied to mice. These signals are coupled into the core of the silica-exposed core fiber (Khalid et al. 2020).

4. CONCLUSION

Silk is a natural engineering material with unique properties. B. mori silk; due to its impressive mechanical properties, biocompatibility, and biodegradability, it has garnered significant interest in both biomedicine and tissue engineering fields. However, silk has cancer-preventive, antioxidant, antibacterial, anticoagulant, anti-inflammatory, anti-thrombotic, and anti-diabetic properties. Additionally, because they are renewable proteins with appealing flavors and high essential amino acid content, they are also gaining interest in the food industry. Considering the serious environmental pollution caused by the disposal of sericin and its beneficial properties as waste, interest in recycling this biomaterial, which could have strong and positive economic, social, and environmental impacts, is increasing day by day. However, since natural silk is a renewable and biodegradable material, it is generally assumed to be inherently sustainable. However, sustainability is entirely dependent on the continuity of silkworm farming. Silk farming typically involves the cultivation of mulberry trees, followed by the breeding of silkworm colonies and the production of silk. Therefore, it is of vital importance for sectors that will use silk as a raw material and develop sustainable products made from natural silk to be aware of the necessity of ensuring the sustainability and preservation of sericulture.

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CHAPTER 6

EFFECT OF VARIOUS ORGANIC BASED MATERIALS ON THE COMPRESSIVE RESISTANCE OF WOOD MATERIAL

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INTRODUCTION

Türkiye's forest area has been determined as 22.34 million hectares. This forest area is 28.5% of the country's total area. Scots pine wood is one of our primary forest tree species spreading over an area of 1,522,931 hectares. As a result of the changes made to the structure of Scots pine wood, it is made suitable for use in a wide variety of areas. Scots pine wood is mainly used in the fields of wood pulp, cellulose production, pole and molding board manufacturing, building construction, vehicle manufacturing, carpentry, furniture, particle board and coating industry, etc. (OGM, 2015).

It Wood, which has been used for various purposes since the beginning of human history, is one of the most important raw materials. With the rapid development of technology, the areas of use of wood have diversified and the amount used has also increased. This increase in the use of wood has caused it to be among the decreasing natural resources today (Kartal and Imamura, 2004). Since wood has a hygroscopic structure, it exchanges moisture with the surrounding air in order to adapt to the temperature and relative humidity of the air in the environment it is in. If this exchange occurs below the fiber saturation point, it changes in size and volume, and for this reason, it becomes vulnerable to biotic and abiotic factors. The most common protection method known is impregnation. The process of penetrating chemical substances with protective properties against various factors (rot, burning, dimensional work, etc.) in a way suitable for the place of use is known as impregnation. In impregnation, the success of the process depends on the degree of protection, the impregnation material and the properties of the wood, as well as the amount of net dry impregnation material attached to the wood (retention) and the depth of penetration of the impregnation material into the wood (Örs and Keskin, 2008).

The Wood material that is protected by impregnation against biological deterioration in the place of use, which has a high risk of decay, can sometimes be harmful to the environment and other living things. In recent years, the use of impregnation materials has been under pressure by some environmental organizations (Kartal and Kantay, 2006).

Generally used impregnation materials are divided into 3 groups as oily, organic solvent and water-soluble impregnation materials. Water-soluble impregnation materials are mostly preferred in the protection of wood. These are widely used in areas such as picnic tables, highway guardrails, roofing materials, packaging containers, wooden materials used in balconies and terraces, park garden arrangements and landscape timber (Aytaşkın, 2009).

Creosote is the most common oily impregnation material and is mostly used in the impregnation of railway sleepers. Organic-based impregnation materials are widely preferred in the impregnation of external doors, prefabricated structural elements and window frames (Temiz, 2004).

Within the scope of the research, the impregnation feature of the medicinal aromatic plant extract (*Black Cumin*) on larex wood and its effects on the change in compressive strength from mechanical properties were determined by correlating it with the application of water-based varnish.

1. MATERIAL AND METHOD

Within the scope of the study, larex wood (*Larix decidua Mill*.) wood was used. Sapwood samples cut in the radial direction were made according to TS 2471. Extract preparation was carried out from Black Cumin (*Nigella Sativa L*.) as a medicinal aromatic plant species.

1.1. Experimental Sample Preparation

While preparing the samples, the wood was prepared according to (TS 2470) from sapwood that does not show any irregularity in the fibrous structure, cracks, knots, tulle formation and discoloration, and was cut to 20x20x30 ±1 mm dimensions in accordance with TS 2595 principles for compressive strength tests.

1.2. Impregnation / Drying / Varnısh Process

The impregnation process was applied in accordance with the conditions in “ASTM–D 1413-76”. Experimental samples were prepared in 20x20x300 ±1mm and 20x20x30 ±1mm dimensions and were subjected to 30 minutes of vacuum and 30 minutes of diffusion process. In order for the impregnation material not to be affected by wood moisture, the experimental samples were made completely dry.

After the impregnation and diffusion process, the samples were kept in an air-dry environment for a while. Then, they were arranged so that they would not touch each other and placed in the oven and the temperature was fixed at 103±2°C. They were kept in the oven for 24 hours and made completely dry. At the end of the period, they were removed from the oven and completely dry measurements were made. Water-based system varnish application in the experimental phase was carried out in accordance with ASTM D-3023 standard.

1.3. Plant Extract Preparation

The black cumin plant, a medicinal aromatic plant species, was left to dry in the laboratory for 1-2 months until it reached a constant weight level. After drying for 1-2 months, it was passed through a blade blender (grinder) and turned into powder.

The extraction process was carried out in methanol by mixing in a shaker at room temperature for 24 hours. It was then filtered using ordinary filter paper and completed with the relevant solvents to certain volumes (5 L of methanol extract was prepared to be 1% concentration)" (Ceylan, 2020).

2. FINDINGS AND DISCUSSION

2.1. Extract (Solution) Feature

Solution properties are given in Table 1.

Table 1. Weight loss (%)

Plant extract (Black cumin)	**Solvent**	**Degree (ºC)**	**pH**		**Density (g/ml)**	
			Bİ	**Aİ**	**Bİ**	**Aİ**
1%	Methanol	22ºC	6.10	6.15	0.930	0.930

Bİ: Before impregnation **Aİ**: After impregnation

No change was found before and after impregnation of black cumin solution (1%).

2.2. % Retention

% retention change are given in Table 2.

Table 2. Retention (%)

Plant extract (Black cumin)	**Solvent**	**Degree (ºC)**	**Retention (%)**
1%	Methanol	22ºC	0.042

Black cumin plant extract adhered to larex wood and the reasons for the low level obtained may be due to wood type, anatomical structure of wood, concentration, plant type and impregnation method.

2.3. Compression Strength (N/mm^2)

Compressive strength change are given in Table 3.

Table 3. Compressive Strength Change (N/mm^2)

Plant Extract/Varnish/	Mean	HG
Control	62.56	C
Varnısh	69.67	A
1% Plant Extract	64.25	D
1% Plant Extract+Varnısh	67.86	B

HG: Homogeneity group

The highest value in the change of pressure resistance was determined in the varnısh (69.67 N/mm^2) and the lowest value in the control sample (62.56). Water-based varnish application and plant extract structure increased the pressure resistance value.

3. CONCLUSION

As a result, it is possible to increase the service life of wood material in the place of use and protect it against factors that degrade and cause destruction with impregnation. Today, many impregnation materials are used to protect wood material against biotic pests, abiotic factors and combustion. Boron compounds and a wide variety of chemicals are used in the wood protection industry. The most important desired features of human/environment friendly preservatives are that they are natural/organic. Medical aromatic plant extracts are also the most important of these. It can be said that it can be used easily in all kinds of environments. It can be used as a preservative with natural varnishes in all kinds of interior/exterior spaces.

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CHAPTER 7

PHYTOCHEMICALS AND POLYPHENOLS

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INTRODUCTION

Phytochemicals are secondary metabolites found in plants, distinct from primary metabolites, and play a crucial role in environmental adaptation, pathogen protection, and plant defense mechanisms (Al-Khayri et al., 2023; Kumar et al., 2023; Rasouli et al., 2017). These compounds are part of the plant's response to environmental stress factors and are recognized for their biological activities (D'Angelo, 2020; Yeshi, et al., 2022; Šamec, et al. 2021). Phytochemicals are classified into various chemical groups, such as polyphenols, terpenoids, alkaloids, and organosulfur compounds, each exhibiting specific functions in plants and diverse effects on human health (Fatima et al., 2021; Pham et al., 2020; Santhiravel et al., 2022; Upadhyay & Dixit, 2015). These compounds have garnered significant attention in both nutritional and medical research, particularly due to their antioxidant properties, contributions to cellular defense systems, and potential health benefits (Johnson, 2007; Muscolo et al., 2024).

Polyphenols represent the most prevalent and important group of phytochemicals, encompassing subclasses such as flavonoids, stilbenes, phenolic acids, and lignans (Alqarni et al., 2024; Rasouli et al., 2017). Among these, flavonoids are the most widely known and commonly found compounds, often associated with the color pigments in plants (D'Angelo, 2020; Roy et al., 2022; Shen et al., 2022). Additionally, terpenoids, such as carotenoids and limonoids, typically exhibit anti-inflammatory and immune-modulatory effects, regulating other metabolic functions in plants (Johnson, 2007; Kim et al., 2022; Teshome et al., 2023). Furthermore, organosulfur compounds, notably found in vegetables like broccoli and garlic, have garnered attention for their cancer-preventive properties (Adeeyo et al., 2021; D'Angelo, 2020). The biological effects of these compounds stem from their potent ability to modulate cellular signaling pathways (Javed et al., 2021; Upadhyay & Dixit, 2015).

Flavonoids, in particular, alleviate the effects of oxidative stress by inhibiting lipid peroxidation in cell membranes (Alsawaf et al., 2022; Rasouli et al., 2017). On the other hand, certain phytochemicals, such as organosulfur compounds, can reduce the effects of carcinogens that cause DNA damage by stimulating detoxification enzymes (Johnson, 2007; Ruhee et al., 2020). These mechanisms play a crucial role in understanding the health effects of phytochemicals (Cote et al., 2022; D'Angelo, 2020). In addition, phytochemicals have been reported to exhibit protective effects against various health issues, such as cancer, cardiovascular diseases, diabetes, and metabolic disorders, by regulating cellular signaling pathways and biological activities (Upadhyay & Dixit, 2015).

Epidemiological studies have shown that diets rich in phytochemicals, particularly from regular consumption of foods like vegetables, fruits, and tea, significantly reduce the risk of chronic diseases (D'Angelo, 2020). In addition to their antioxidant effects, polyphenols have shown promising results in cancer research due to their ability to halt cell proliferation or trigger apoptosis (Johnson, 2007). Furthermore, numerous studies have demonstrated the protective effects of phytochemicals against metabolic diseases, cardiovascular diseases, and diabetes (Rasouli et al., 2017).

In light of this information, phytochemicals are not only essential for plants but are also of critical importance to human health (Upadhyay & Dixit, 2015). These compounds, which hold great potential for future biomedical applications, are expected to play an essential role in the development of new treatment options and health strategies in the pharmaceutical field (D'Angelo, 2020).

1. POLYPHENOLS AND PHYTOCHEMICALS

1.1. Chemical Structure and Classification of Polyphenols

Polyphenols are organic compounds consisting of one or more phenolic rings attached to hydroxyl groups. Their chemical structures are crucial in determining their antioxidant capacity and biological activity levels. These structures play a significant role in reducing the effects of oxidative stress in the body and explain the protective health benefits of polyphenols (Rasouli et al., 2017; Manach et al., 2004). Polyphenols are typically divided into major subclasses, including flavonoids, phenolic acids, stilbenes, and lignans (Cao et al., 2017). These subclasses are key determinants of each compound's biological effects and activities in the body (Zhao et al., 2018).

Flavonoids: Flavonoids constitute the largest subgroup of polyphenols and are further divided into subclasses such as flavones, flavonols, flavanones, isoflavones, anthocyanidins, and flavan-3-ols (Çetinkaya et al., 2022; Upadhyay & Dixit, 2015). Flavonoids serve as color pigments in plants and are particularly known for their antioxidant, anti-inflammatory, antimicrobial, and cardioprotective properties (Scalbert et al., 2005; D'Angelo, 2020). Studies have shown that flavonoids have significant health effects, such as inhibiting the growth of cancer cells and preventing heart diseases (Li et al., 2016; Ullah et al., 2020).

Phenolic Acids: Phenolic acids are divided into two main groups: hydroxycinnamic and hydroxybenzoic acids, both possessing strong free radical scavenging properties (D'Angelo, 2020; Manach et al., 2004). These compounds play a vital role in the prevention of diseases such as cancer, cardiovascular diseases, and diabetes, in addition to their antioxidant properties (Cao et al., 2017; Ozdemir et al., 2023). Phenolic acids have also been shown to perform detoxification functions by preventing the accumulation of toxins in the body (Firuzi et al., 2017).

Stilbenes: The most studied compound in the stilbene class is resveratrol, which is recognized for its anti-inflammatory and anticancer properties. Resveratrol has shown promising results in pharmaceutical research, particularly due to its potential in slowing down the aging process (Johnson, 2007; Baur & Sinclair, 2006). Furthermore, resveratrol has been highlighted for its positive effects on cardiovascular health (Brown et al., 2024; Ghanim et al., 2010). Studies suggest that resveratrol may delay the aging process of cells and reduce the risk of heart, diabetic diseases and cancer (Baur & Sinclair, 2006; Ozdemir & Tuzcu, 2015).

Lignans: Lignans, especially those that interact with the gut microbiota, exhibit antioxidant and hormone-regulating effects (Rasouli et al., 2017). Lignans play a significant role in the prevention of hormone-related cancers, such as prostate cancer (Adlercreutz et al., 2007). Additionally, lignans have been shown to be effective in preventing diabetes and cardiovascular diseases (Madsen et al., 2014; van der Velde et al., 2016).

- **Polyphenols** (e.g., flavonoids, phenolic acids, tannins)
- **Terpenoids** (e.g., carotenoids, limonoids)
- **Alkaloids** (e.g., caffeine, morphine)

• **Sulfur-containing compounds** (e.g., glucosinolates, allyl sulfides)

Each of these classes has specific mechanisms of action that contribute to their health-promoting effects. For instance, terpenoids, known for their lipid solubility, play essential roles in cell membrane stability and immune modulation. Alkaloids exhibit various physiological effects and are often potent due to their interactions with neurotransmitters (Molyneux et al., 2007; Tilkat et al., 2024).

1.2. Biological Roles of Phytochemicals

Phytochemicals serve as part of the plant defense mechanisms, providing protection against environmental stress, UV radiation, and pathogens (Johnson, 2007; Shubayr 2023). These compounds enhance the survival abilities of plants while offering numerous health benefits for humans (Gohil & Patel, 2019). Phytochemicals confer health benefits through mechanisms such as antioxidant, anti-inflammatory, detoxification, and anticancer effects (D'Angelo, 2020).

Antioxidant Effects: Phytochemicals neutralize free radicals effectively, preventing lipid peroxidation in cell membranes (Rasouli et al., 2017; Manach et al., 2004). This reduces the harmful effects of oxidative stress and delays aging. Flavonoids and stilbenes, in particular, stand out with their antioxidant properties, playing an essential role in preventing cancer and heart diseases (Li et al., 2016; Gohil & Patel, 2019).

Anti-inflammatory Effects: The anti-inflammatory effects of phytochemicals arise from the suppression of inflammation markers in cells. Compounds such as flavonoids and terpenoids reduce inflammation by inhibiting the production of pro-inflammatory cytokines (D'Angelo, 2020; Gohil & Patel, 2019). Additionally, these compounds have been reported to modulate the immune system and regulate immune responses (Johnson, 2007; Li et al., 2016).

Detoxification and Anticancer Effects: Some phytochemicals promote detoxification enzymes, helping eliminate accumulated harmful substances in the body. Compounds such as organosulfur compounds and stilbenes reduce the effects of carcinogens and prevent the development of cancer (Firuzi et al., 2017; Gohil & Patel, 2019). Numerous studies have shown the anticancer effects of phytochemicals, particularly those abundant in fruits and vegetables, on cancer cells (Ayaz et al., 2022; Cao et al., 2017).

1.3. Bioavailability and Metabolism of Polyphenols

The bioavailability of polyphenols is limited by the absorption processes in the gastrointestinal system. For these compounds to be effectively utilized in the body, their metabolic conversion by the gut microbiota is crucial (Rasouli et al., 2017; Scalbert et al., 2005). Polyphenols are typically metabolized in the gut and liver, with their metabolites entering the bloodstream to exert biological effects in target tissues (Firuzi et al., 2017; Luca ert al., 2020; Manach et al., 2004).

Limitations of Bioavailability: Although polyphenols generally have low bioavailability, the gut microbiota can enhance their biological activity (D’Angelo, 2020). Microbial metabolism facilitates the conversion of polyphenols into active metabolites, thereby enhancing their biological effects. Therefore, the presence of a healthy gut microbiota is vital for the effectiveness of polyphenols and phytochemicals (Rasouli et al., 2017).

Metabolism and Effects: Once metabolized, polyphenols typically reach biological targets and affect molecular mechanisms within cells. In particular, phenolic acids and flavonoids exhibit antioxidant and anti-inflammatory effects, showing health benefits (Manach et al., 2004; Upadhyay & Dixit, 2015). Additionally, some polyphenols inhibit cell growth, preventing the proliferation of cancer cells (Johnson, 2007; Zhao et al., 2018).

2. EFFECTS OF POLYPHENOLS ON HEALTH

2.1 Antioxidant Mechanisms

Polyphenols prevent cellular damage by neutralizing reactive oxygen species (ROS). ROS induce oxidative stress in cells, leading to oxidative damage to DNA, lipids, and proteins. Polyphenols effectively neutralize these free radicals, reducing oxidative damage and helping cells remain healthy (Cao et al., 2017; Upadhyay & Dixit, 2015). Additionally, polyphenols enhance the activity of endogenous antioxidant enzymes, strengthening the body's defense mechanisms. Antioxidant enzymes such as glutathione peroxidase, superoxide dismutase, and catalase are activated by polyphenols, contributing to the prevention of oxidative damage (Erten et al., 2024; Scalbert et al., 2005). It has been shown that compounds like flavonoids increase the activity of these enzymes, thereby preventing cellular damage (Manach et al., 2004; Rasouli et al., 2017). These mechanisms play a significant role in preventing the development of diseases such as cardiovascular diseases and cancer. Maintaining low oxidative stress improves overall health and delays the aging process (Rasouli et al., 2017; Yang et al., 2024).

2.2 Anti-inflammatory Properties

Polyphenols inhibit enzymes that play a key role in the inflammatory process, thereby reducing inflammation. Inhibition of enzymes such as cyclooxygenase-2 (COX-2) and nuclear factor kappa B (NF-κB) constitutes the primary mechanism behind the anti-inflammatory effects of polyphenols (D'Angelo, 2020; Johnson, 2007; Orhan et al., 2022). These compounds, particularly flavonoids and stilbenes, reduce the production of inflammation markers and regulate the immune system (Baur & Sinclair, 2006; Li et al., 2016). It has been demonstrated that compounds such as quercetin and resveratrol suppress the production of inflammatory cytokines, indicating their crucial role in preventing various diseases through their anti-inflammatory effects (D'Angelo, 2020; Liu et al., 2023). Quercetin, in particular, is emerging as a potential agent in the treatment of inflammation-related diseases such as asthma, arthritis, and cardiovascular diseases (Gohil & Patel, 2019). These mechanisms demonstrate that polyphenols play a protective role not only against oxidative stress but also against inflammation (Wu et al., 2021).

2.3 Prevention of Cardiovascular Diseases

Polyphenols inhibit enzymes that play a key role in the inflammatory process, thereby reducing inflammation. Inhibition of enzymes such as cyclooxygenase-2 (COX-2) and nuclear factor kappa B (NF-κB) constitutes the primary mechanism behind the anti-inflammatory effects of polyphenols (D'Angelo, 2020; Johnson, 2007). These compounds, particularly flavonoids and stilbenes, reduce the production of inflammation markers and regulate the immune system (Baur & Sinclair, 2006; Li et al., 2016). It has been demonstrated that compounds such as quercetin and resveratrol suppress the production of inflammatory cytokines, indicating their crucial role in preventing various diseases through their anti-inflammatory effects (D'Angelo, 2020; Liu et al., 2023). Quercetin, in particular, is emerging as a potential agent in the treatment of inflammation-related diseases such as asthma, arthritis, and cardiovascular diseases (Gohil & Patel, 2019). These mechanisms demonstrate that polyphenols play a protective role not only against oxidative stress but also against inflammation (Wu et al., 2021).

2.4. Management of Diabetes and Metabolic Syndrome

Polyphenols play a crucial role in the management of diabetes and metabolic syndrome. These compounds have been shown to increase insulin sensitivity and regulate glucose metabolism, helping balance blood sugar levels (D'Angelo, 2020; Gohil & Patel, 2019). Specifically, epigallocatechin gallate (EGCG) enhances the expression of glucose transporter-4 (GLUT-4), promoting glucose uptake in cells and supporting cellular energy balance (Johnson, 2007). This mechanism contributes to the improvement of insulin resistance and normalizes blood sugar levels.

Moreover, polyphenols may aid in the treatment of metabolic syndrome by increasing the oxidation of free fatty acids. Polyphenols enhance insulin effectiveness, providing significant support in the management of diabetes. In individuals with metabolic syndrome, polyphenols have been shown to have beneficial effects on body weight, blood sugar levels, and lipid profiles (Firuzi et al., 2017). These effects highlight the important role of polyphenols in the management of diabetes and metabolic syndrome (Gasmi et al., 2022; Li et al., 2016).

3. CANCER AND POLYPHENOLS

3.1. Cancer Prevention: Epidemiological Data

There is strong evidence that diet plays a crucial role in cancer prevention. Numerous epidemiological studies have shown that diets rich in polyphenols reduce the risk of various types of cancer. Individuals with high fruit and vegetable consumption are found to have a lower risk of developing cancers, especially breast, colon, lung, and stomach cancers (Johnson, 2007; Rasouli et al., 2017). According to the World Cancer Research Fund, plant-based diets can reduce the overall risk of cancer by up to 30% (Rasouli et al., 2017). Studies emphasize that a diet enriched with polyphenols, particularly compounds with anticancer properties, is a significant factor in cancer prevention (Li et al., 2016). Moreover, polyphenols derived from fruits and vegetables have been shown to enhance the ability of cells to repair DNA damage and inhibit the proliferation of cancer cells (Cao et al., 2017).

3.2. Cellular and Molecular Mechanisms

Polyphenols target multiple stages of the cancer development process. These compounds exhibit various biological mechanisms to prevent the growth and spread of cancer cells (Briguglio et al., 2020).

3.2.1. Suppression of Tumor Cell Proliferation

Polyphenols can halt the uncontrolled proliferation of tumor cells by targeting cell cycle regulatory proteins. For example, resveratrol suppresses the expression of cyclin D1 and cyclin E proteins, blocking the G1-S transition and preventing tumor cell division (Upadhyay & Dixit, 2015; Li et al., 2016). Other polyphenols, such as flavonoids, can also affect other stages of the cell cycle to inhibit the growth of cancer cells (Briguglio et al., 2020; Manach et al., 2004).

3.2.2. Induction of Apoptosis

Polyphenols induce programmed cell death (apoptosis) to eliminate cancer cells. Epigallocatechin gallate (EGCG) increases the expression of Bax proteins while suppressing anti-apoptotic proteins such as Bcl-2, thereby promoting apoptosis in cancer cells (D'Angelo, 2020; Johnson, 2007). This mechanism prevents cancer cell survival and tumor growth. Additionally, polyphenols repair DNA damage by correcting genetic alterations in cancer cells (Baur & Sinclair, 2006). The increased apoptosis process represents a promising approach in cancer treatment, and polyphenols can effectively modulate these processes (Cháirez-Ramírez et al., 2021; Gohil & Patel, 2019).

3.2.3. Inhibition of Angiogenesis and Metastasis

Angiogenesis (formation of new blood vessels) and metastasis are crucial processes in cancer progression that are inhibited by polyphenols. EGCG suppresses the expression of vascular endothelial growth factor (VEGF), preventing the formation of blood vessels within tumors (Rasouli et al., 2017). This effect of EGCG reduces the metastatic potential of cancer and prevents the spread of tumors in the body (Li et al., 2016). Additionally, polyphenols can alter the tumor microenvironment where cancer cells interact, thus preventing the metastatic process (Baur & Sinclair, 2006). Inhibition of angiogenesis is considered a potential strategy in cancer therapy (Liu et al., 2023).

3.3. Polyphenol-Based Therapies: Resveratrol, EGCG, and More

Polyphenols show promise as complementary or preventive agents in cancer treatment. The various effects these compounds exert on cancer cells make them valuable in supporting cancer therapy (Dehelean et al., 2021; Sauter et al., 2020).

3.3.1. Resveratrol

Resveratrol activates the p53 gene, enhancing tumor-suppressing mechanisms. P53 is a key tumor suppressor gene that regulates the cell cycle and repairs DNA damage. Resveratrol also helps protect healthy cells by reducing oxidative stress (Johnson, 2007; Baur & Sinclair, 2006). This mechanism prevents the proliferation of cancer cells and prevents them from developing resistance to treatment. Additionally, resveratrol affects intracellular signaling pathways to slow cancer cell growth and inhibit metastasis (Behroozaghdam et al., 2022; Upadhyay & Dixit, 2015).

3.3.2. Epigallocatechin Gallate (EGCG)

EGCG, a polyphenol derived from green tea, has numerous beneficial effects in cancer treatment. EGCG reduces DNA damage in cancer cells and triggers apoptosis mechanisms (D'Angelo, 2020; Ozdemir, 2020). Additionally, EGCG's antioxidant properties neutralize free radicals in cells, thus inhibiting the growth of cancer cells (Li et al., 2016). Clinical studies have demonstrated that EGCG prevents the spread of metastatic cells and may assist in cancer treatment (Manach et al., 2004).

3.3.3. Curcumin

Curcumin, the active compound in turmeric, is recognized for its anti-inflammatory effects. This compound suppresses inflammation and modulates immune cells in the tumor microenvironment (Tuzcu et al., 2024; Upadhyay & Dixit, 2015; Johnson, 2007). Curcumin may also induce genetic and epigenetic changes that prevent the spread of cancer cells. Moreover, curcumin is being explored as a potential therapeutic agent in cancer treatment by enhancing immune cell activation within the tumor microenvironment (Li et al., 2016).

4. The Role of Polyphenols in the Food Industry

4.1. Use as Antioxidants

In the food industry, polyphenols are commonly used to slow down oxidation, thereby extending the shelf life of products. Oxidation leads to the deterioration of lipids, changes in color, loss of flavor, and a decrease in nutritional value in food products. In this context, polyphenols, as natural antioxidants, help preserve the freshness and quality of food, particularly by preventing the degradation of fats (Rasouli et al., 2017; Li et al., 2016). Flavonoids and other phenolic compounds increase the stability of food products due to their ability to neutralize free radicals (Manach et al., 2004). Polyphenols are frequently used in the food industry, especially in ready-made meals, beverages, and snacks, to maintain quality (Johnson, 2007). Another study has shown that green tea polyphenols extend the shelf life of food products by inhibiting microbial activity (Heimler et al., 2018).

4.2. Contribution to Extending the Shelf Life of Food

Polyphenols not only prevent oxidation but also inhibit microbial growth, thus preventing food spoilage. This property is especially significant in the meat, dairy, and fruit and vegetable processing industries. For instance, extracts from grape skins and seeds have been shown to inhibit both oxidation and microbial growth in meat products, significantly extending their shelf life (D'Angelo, 2020; Rahman et al., 2020). Additionally, tea polyphenols have been shown to prevent the growth of pathogenic microorganisms in meat and fish products, helping these items remain fresh for longer (Rasouli et al., 2017). These polyphenols also contribute to preserving the taste, color, and texture of food products, thus enhancing food safety (Zhao et al., 2015; Li et al., 2016).

4.3. Functional Foods and Health Supplements

Functional foods contain biologically active components that offer health benefits and are often enriched with polyphenols. Polyphenols impart antioxidant, anti-inflammatory, and immune-boosting properties to these foods (Johnson, 2007; Fernandes et al., 2020; Ozdemir, 2024). When combined with probiotics, polyphenols improve gut health and strengthen the immune system.

Studies have shown that polyphenol-enriched foods, supplemented with probiotics, enhance digestive health, regulate immune responses, and increase the body's resistance to diseases (D'Angelo, 2020; Gänzle, 2015). Furthermore, polyphenols may play a crucial role in the prevention of cardiovascular diseases, diabetes, and certain types of cancer (Manach et al., 2004; Lopes et al., 2020). These properties ensure the widespread use of polyphenols in the functional food and health supplement industries (Basu & Rhim, 2020).

4.4. Polyphenols and Food Processing

Food processing is an important factor that can affect the biological activity of polyphenols. Environmental factors such as heat, light, and oxygen can cause chemical changes in polyphenols, potentially limiting their benefits (Chen et al., 2017). For example, elevated temperatures can disrupt the structural integrity of flavonoids, leading to a reduction in their antioxidant capacity (Müller et al., 2021). However, some polyphenols, especially phenolic acids and flavonoids, are more resistant to high temperatures and can maintain their activity to some extent during food processing (Xu et al., 2020).

Furthermore, polyphenols' efficiency in food processing, such as in the extraction of fruit and vegetable essences, depends on the extraction methods used. Different solvents, such as water, alcohol, and organic solvents, can affect the polyphenol content and biological activities to varying degrees (Jahanbakhshi et al., 2019). Advanced techniques such as high-performance liquid chromatography (HPLC) are effective for maximizing polyphenol yield during extraction, offering more efficient processing possibilities in the food industry (Vivas et al., 2018).

Additionally, polyphenols in food processing can have direct health effects as functional foods. For example, in fermented foods, polyphenols may interact with microorganisms to exhibit probiotic properties (Bermúdez-Brito et al., 2012). This highlights the potential of food processing technologies to interact with and enhance polyphenols' effectiveness (Kasote et al., 2021).

4.5. Polyphenols and Food Safety

Polyphenols not only improve food quality and nutritional value but also enhance food safety. Food safety is a critical area for preventing potential hazards caused by microorganisms in food products. Polyphenols possess antimicrobial properties and can inhibit the growth of pathogenic bacteria

(Lopez et al., 2018; Ozdemir et al., 2022, 2023). For example, grape seed extracts have been shown to provide effective protection against pathogens such as Salmonella and Escherichia coli in meat products (González-Aguilar et al., 2018). Moreover, polyphenols can help prevent foodborne illnesses, thereby improving food safety.

The antimicrobial properties of polyphenols are primarily attributed to their ability to prevent microbial proliferation and inhibit toxin production. This characteristic makes polyphenols viable as natural preservatives in the food industry (Ozdemir et al., 2024; Nabavi et al., 2015). As a result, polyphenols not only improve food quality but also support the production of healthy and safe food (de Araújo et al., 2021).

5. Potential Health Applications of Polyphenols

5.1. Polyphenols and Potential Applications in Cancer Treatment

Polyphenols hold promising potential in cancer treatment. They can play a significant role at various stages, from early detection to therapy. Recent studies have increasingly focused on the clinical potential of polyphenols in cancer treatment. While cancer treatment traditionally relies on methods such as surgery, chemotherapy, and radiotherapy, polyphenols may offer alternative treatment options that target tumor cells with fewer invasive procedures and reduced side effects (Briguglio et al., 2020; Montané et al., 2020; Rogovskii et al., 2022).

5.2. Polyphenols and Inhibition of Cancer Cell Proliferation

Polyphenols inhibit the proliferation of cancer cells and suppress tumor growth. These effects occur by influencing cell cycle regulators, halting the uncontrolled division of cancer cells. Compounds such as resveratrol, EGCG, and curcumin have been shown to play a role in inhibiting proliferation in tumor cells (D'Angelo, 2020). These compounds prevent cancer cells from dividing by inhibiting regulators such as cyclin D1 and p21 in the G1 phase of the cell cycle (D'costa et al., 2023).

5.3. Polyphenols and Induction of Apoptosis

Apoptosis, the programmed cell death process, is a key target in cancer therapy as inducing this process can limit tumor growth. Polyphenols can trigger apoptosis through various mechanisms. For example, compounds such as EGCG and resveratrol reduce the expression of anti-apoptotic proteins like Bcl-2 and increase the levels of pro-apoptotic proteins like Bax. This effect promotes cell death and prevents the survival of cancer cells (Upadhyay & Dixit, 2015). Moreover, polyphenols can enhance apoptosis by activating tumor suppressor genes such as p53 (Chimento et al., 2023).

5.4. Polyphenols and Angiogenesis Inhibition

The progression of cancer is closely linked to angiogenesis, the formation of new blood vessels. Polyphenols can be effective at this critical stage of cancer. Compounds like EGCG inhibit vascular endothelial growth factor (VEGF), preventing tumor cells from forming new blood vessels (Rasouli et al., 2017). Additionally, compounds such as curcumin and quercetin have been shown to exert inhibitory effects on angiogenesis (Hasan et al., 2022).

5.5. Polyphenols and Inhibition of Metastasis

Polyphenols are also effective in the metastasis phase of cancer. Metastasis, the spread of cancer cells from the primary tumor to other parts of the body, is one of the most challenging aspects of cancer treatment. Polyphenols can inhibit the mobility of cancer cells and reduce the invasion of tumor cells into surrounding tissues by inhibiting matrix metalloproteinases (MMPs), thereby preventing metastasis (Johnson, 2007).

5.6. Polyphenols and Effects on the Immune System

Immune system modulation is another important strategy in cancer treatment. Polyphenols can enhance immune system activity, boosting the action of cancer-fighting cells. Resveratrol and EGCG promote the activation of T cells and help macrophages recognize and eliminate cancer cells (D'Angelo, 2020). Furthermore, polyphenols may regulate inflammation, preventing cancer cells from evading immune surveillance (Huang et al., 2022).

5.7. Polyphenols and Clinical Applications: Current Status and Future Perspectives

Polyphenols are being investigated as complementary treatments in clinical settings. Specifically, their use alongside chemotherapy and radiotherapy may offer additional therapeutic benefits. Recent clinical trials confirm the potential of polyphenols in cancer treatment, but further research is needed to fully establish their efficacy and safety (Rasouli et al., 2017; Sharma et al., 2022).

6. Polyphenols and Reaction Mechanisms

6.1. Polyphenols and Enzymes: Their Interactions

Polyphenols are compounds with numerous biological effects, interacting with various enzymes in the body. These interactions play a crucial role in the regulation of the biological activities of polyphenols. Enzymes like polyphenol oxidase (PPO) catalyze the oxidation of polyphenols, often leading to physical changes such as color alteration and degradation. This process is particularly important in controlling the oxidation of fruits and vegetables in the food industry (Rasouli et al., 2017). PPO accelerates the oxidation of polyphenols, causing browning and potentially affecting the quality of food products (Kaya et al., 2024a; Kaya et al., 2024b).

Additionally, polyphenols demonstrate beneficial health effects by inhibiting certain enzymes. For example, polyphenols affect numerous enzymatic mechanisms that play significant roles in cancer prevention. Flavonoids, by inhibiting enzymes like cyclooxygenase (COX) and lipoxygenase (LOX), can reduce inflammation and inhibit the proliferation of cancer cells (D'Angelo, 2020). Furthermore, polyphenols regulate various biological processes by influencing intracellular signaling pathways, thereby enhancing their antioxidant, anticancer, and anti-inflammatory properties (Upadhyay and Dixit, 2015).

6.2. Polyphenols and Metabolism

Polyphenols do not typically exist in the body in their free form. Upon ingestion, they undergo various biotransformations in the gastrointestinal system. Initially, polyphenols are absorbed in the stomach and small intestine, then metabolized in the liver. During this process, polyphenols are converted into conjugates (glucuronates, sulfates, and methyl groups), thereby increasing their bioavailability and converting them into more active metabolites (Rasouli et al., 2017).

The metabolism of polyphenols involves the role of various microorganisms that either activate them or modulate their biological effects.

The gut microbiota plays a significant role in the biotransformation of polyphenols. Polyphenols are converted by the bacteria in the intestines into smaller and more active metabolites. For instance, flavonoids such as quercetin and kaempferol are rapidly metabolized by the gut microbiota, and these metabolites may exhibit very different biological activities compared to the original compounds (D'Angelo, 2020).

Moreover, polyphenols can initiate numerous biochemical reactions in the body and participate in various metabolic pathways that improve health. For example, polyphenols enhance the activity of antioxidant enzymes (glutathione peroxidase and superoxide dismutase), combating cellular stress (Johnson, 2007). Additionally, polyphenols have been shown to increase insulin sensitivity, potentially aiding in the management of metabolic syndrome (Wang et al., 2022a).

6.3. Polyphenols and Bioavailability

Polyphenols exhibit varying effects depending on the absorption and bioavailability processes in the gastrointestinal system. Their bioavailability levels differ based on properties such as water solubility and molecular structure. For instance, polyphenols like flavonoids typically have low bioavailability in the intestine, though certain flavonoid metabolites may have higher bioavailability (D'Angelo, 2020). These differing bioavailability rates can alter the biological effects of polyphenols.

After absorption in the intestines, polyphenols are transported to the liver, where they undergo biotransformation. This metabolic process can influence the strength and duration of the biological effects of polyphenols. Additionally, polyphenols enter conjugation reactions in the liver, transforming into metabolites that enhance their bioavailability. Specifically, glucuronidation and sulfation are key reactions that increase the bioavailability of polyphenols (Upadhyay and Dixit, 2015).

Polyphenols can also be metabolized by interacting with the gut microbiota, producing active metabolites. For example, EGCG from green tea is metabolized by the microbiome, leading to significant changes in its biological effects (Johnson, 2007). The interactions of polyphenols with the gut flora can substantially modulate their health impacts (Catalkaya et al., 2020).

7. The Future Role and Importance of Polyphenols

7.1. Potential in Health and Pharmaceutical Industries

Polyphenols are increasingly being researched for their potential in health applications. Numerous studies have shown that polyphenols exhibit positive effects in the treatment of cardiovascular diseases, diabetes, cancer, and neurological disorders such as Alzheimer's and Parkinson's (Kim et al., 2020). With their free radical scavenging properties, polyphenols provide cellular protection and assist in the regulation of inflammation (Huang et al., 2019). In recent years, research on polyphenols derived from plant sources, particularly green tea and grape seeds, has demonstrated their potential for use in pharmaceutical formulations.

Polyphenols are gaining attention not only as natural therapeutic agents but also as potential treatment options in the pharmaceutical industry. For instance, compounds like resveratrol and quercetin, which inhibit the growth of cancer cells and prevent metastasis, show promise in cancer treatment (Rasouli et al., 2020). Furthermore, polyphenols may play a neuroprotective role in Alzheimer's disease by protecting brain cells (Chen et al., 2018).

7.2. Role in the Food Industry

Polyphenols are increasingly utilized in the food industry. They play an important role as natural antioxidants to extend the shelf life of food products and enhance their nutritional value (Patel et al., 2021). The antioxidant properties of polyphenols help prevent oxidation during food processing and preserve food quality. Additionally, polyphenols contribute aesthetic qualities such as taste, aroma, and color, making them attractive for food production.

Functional food production aims to design foods that promote health. Polyphenols, when combined with probiotics, can enhance immune function and improve gut health (Al-Solumani et al., 2020). Additionally, polyphenols function as food additives in the food industry, providing a wide range of applications. Various studies suggest that polyphenols can be used as substitutes for sugar, contributing to the production of low-calorie foods (Chang et al., 2021).

7.3. Agriculture and Sustainability

In agriculture, polyphenols may help reduce pesticide use and promote organic farming practices. Polyphenols strengthen plant defense mechanisms, providing natural protection against pests (Wang et al., 2018). This holds significant potential for environmental sustainability.

The use of polyphenols in agricultural production not only serves as an eco-friendly alternative but also plays a crucial role in improving plant health and increasing productivity. Research has shown that polyphenol-rich plants are more resistant to diseases and pests, and the quality of products derived from these plants is enhanced (Singh et al., 2020).

8. CONCLUSION

As one of the most important phytochemicals found in nature, polyphenols exhibit a broad range of positive effects on health. These compounds are gaining increasing importance in scientific literature due to their antioxidant properties, anti-inflammatory effects, roles in preventing cardiovascular diseases, and potential contributions to the treatment of chronic diseases such as cancer. Recent research highlights the need for further exploration into polyphenols, as a deeper understanding of their biological activities presents significant potential for health applications (Johnson, 2007; Patel et al., 2021; Upadhyay and Dixit, 2015).

Polyphenols not only offer health benefits but also hold a significant place in the food industry. They are used as natural antioxidants to extend the shelf life of food products, prevent oxidation, and improve food quality (Rasouli et al., 2017). Moreover, in functional food production and health supplements, polyphenols enhance nutritional value and strengthen the immune system (Johnson, 2007).

Furthermore, the use of polyphenols in agriculture offers important opportunities for environmental sustainability and reducing pesticide use. By strengthening plant defense mechanisms, polyphenols contribute to increased agricultural productivity while promoting eco-friendly practices (Wang et al., 2018; Wang et al., 2022b).

Research into polyphenols and other phytochemicals is expected to make significant contributions to the development of more effective and natural therapeutic methods, as well as improving applications in the pharmaceutical and food industries. Gaining further insight into the bioavailability, metabolism, and reaction mechanisms of these compounds will enable their broader use in health and food sectors.

In conclusion, polyphenols possess great potential in health, agriculture, and the food industry. However, to fully realize this potential, more clinical and epidemiological studies are required, and a better understanding of the biological effects of these compounds is essential. Future research will further solidify the role of polyphenols in these areas and increase their contributions to human health.

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CHAPTER 8

EVALUATION OF PHYTOPHTHORA ROOT AND CROWN ROT DISEASES ON ORNAMENTAL PLANTS IN TÜRKİYE

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INTRODUCTION

The fungi-like organism Phytophthora, appertain to the family Peronosporaceae and Oomycota phylum in the kingdom Stramenopila (Beakes, 2014; Thines and Choi, 2016). Phytophthora species are the most devastating group of plant pathogens on tree, ornamentals and crop plant species also in natural ecosystems. Phytophthora species are soil-borne pathogens and they lead to root and crown rot in different ornamental plants (Jung et al., 1996). In many studies conducted in Europe and other countries in the world, many Phytophthora species have been found to be the cause of root and crown rot in ornamental plants, forest trees in nurseries, greenhouse plants and natural forest areas (Goss et al., 2011; Hulvey et al., 2010; Moralejo et al., 2009; Schwingle et al., 2007; Themann et al., 2002).

Recently, there has been notably increase in Phytophthora species, but there is still much uncertainty over taxonomy of Phytophthora (Perez-Sierra and Jung, 2013; de Cock and Levesque, 2013). Taxonomy constantly changes with new species being described as molecular identification. Of the approximately 150 Phytophthora species identified in woody plants, 66% are reported to be responsible for root rot and more than 90% for crown rot (Kroon et al., 2012; Jung et al., 2011).

The taxonomic categorisation of Phytophthora species is based on morphological characters (e.g.,colony development, sporangia, oogonia, antheridia, homothallism) (Gallegly and Hong, 2008; Erwin and Ribeiro, 1996). Phytophthora species are primarily identified according to their morphology**.** In addition to morphological identication, molecular identification is also important for Phytophthora species. The species have been identified by molecular techniques, reaching a nearly 330 species divided into 12 clades of phylogenetic features (Scott et al., 2019; Matsiakh and Menkis, 2023). There are still many Phytophthora species that can not be taxonomically classified and identified to species level. Phytophthora taxonomy has turned into molecular techniques for multilocus phylogenies such as using an ITS region (internal transcribed spacer), coxI and coxII region (cytochrome oxidase genes)(Cooke et al., 2000; Tyler et al., 2006; Kroon et al., 2004; Blair et al., 2008).

Under suitable growth conditions, Phytophthora species are mostly isolated from the soil region of diseased plants and to be cause of serious economic loses in damaged areas (Perez-Sierra and Jung, 2013). Phytophthora species cause symptoms such as root and crown rot in many susceptible plants, as well as necrotic areas in root system, drying, wilting of leaves and death of whole plants, but also infect plants without causing symptoms (Ufer et al., 2008). Climatic conditions and plant development taking a very important role in the occurrence of Phytophthora infection. The development and sporulation of Phytophthora species are accelerated especially in high humidity conditions, hot weather, moist soils and airtight restricted plant growth areas (Donahoo and Lamour, 2008).

Phytophthora species induce several disease symptoms in forest trees, woody shrubs, and other ornamental plants all around the world (Jung et al., 2018; Tremblay et al., 2018). In different plant families, pathogens induce damping-off, root rot, aerial bleeding cankers on aerial and green parts of plants (Matsiakh et al., 2021). *P. nicotianae, P. cryptogea, P. ramorum, P. palmivora, and P. cinnamomi* infect various woody plants, but some species like *P. lateralis, P. quercina* and *P. × alni* infect limited number of hosts (Jung et al., 2018). Phytophthora species can be invader and they can appear as the most dangerous non-native pathogens (Santini et al., 2013; Wingfield et al., 2017; Jung et al., 2013). For example *P. acerina* (Ginetti et al., 2013), *P. pini* (Hong et al., 2011), *P. plurivora* (Jung and Burgess, 2009), *P. multivora* (Scott et al., 2009) and are considered pathogenic to a number of woody ornamental plants.

Phytophthora species are most particularly known as pathogens of cultivated plants, ornamental plants and especially forest trees. Phytophthora species are pathogenic wide range of healthy ornamental plants, forest tress and also widespread in soils. They can do devastating epidemics in the world (Hansen et al., 2015). Evaluations have indicated that more than 90% of trade plants in nearly 700 nurseries in countries of Europe countries is infected by Phytophthoras (Jung et al., 2016).

In this review, to aim sum up the learning on Phytophthora species related to ornamental plants in Türkiye; the host range of Phytophthora, symptoms of damage, pathways of introduction and control methods applied against the species. Through making use of this review, the researchers can be informed potential risks related to Phytophthora species on ornamental plants in Türkiye.

INVESTIGATION OF PHYTOPHTHORA DISEASES ON ORNAMENTAL PLANTS

It is known that Phytophthora diseases cause intense losses in ornamental plants in the world. The world literature on morphological and molecular identification of the causal Phytophthora species is quite well. Recently, Phytophthora species have important rising and the total number of species has exceeded more than 100 (Perez-Sierra and Jung, 2013; de Cock and Levesque, 2013). There are still many Phytophthora species that cannot be taxonomically classified and identified to species level. Many coniferous, deciduous and evergreen ornamental plant species are susceptible to Phytophthora species. Investigation on the epidemiology, pathogenesis of Phytophthora and ecology has focused on limited aggressive pathogens of cultivated plants and devastating pathogens in forests (Grunwald and Flier, 2005; Rizzo et al., 2005).

On global level, determining the risks level of Phytophthora species is highly complex. Through their skills, Phytophthora species induce many infections in different plants and producing hybrids that can be more virulent than their ancestors under certain conditions (Jung et al., 2013). Owing to their multicycling status and a powerful correlation on free water in the soil, Phytophthora species can optimize ornamental plants to biotic and abiotic factors. The presence of aggressive Phytophthora species (*Phytophthora nicotianae, P. cambivora, P. cryptogea, P. cactorum, P. plurivora, P. palmivora, P. cinnamomi, P. ramorum, P. gonapodyides, P. syringae, P. pseudosyringae,*) in ornamental plants means that they should be considered as a important threat to ornamental plants in urban, nursery and forest ecosystems.

The abundance of the Phytophthora species found out in forests, nurseries or greenhouses is superior than in nature, that is indicate the potential risks of pathogens with infected nursery plants (Jung et al., 2016; Blomquist, 2016; Redonto, 2018). Actually, nurseries are notable route of accessing invasive Phytophthora species in Europe (Jung et al., 2016; Santini et al., 2018). Infected plants in nursery often show not any symptoms, passing undetected by phytosanitary controls, treating like ‘pathogen reservoirs’ and undertaking the unwitting dispersion of Phytophthora species (Migliorini et al., 2015).

There are many studies from past to present about *P. lateralis* and *P. ramorum*, which are among the first pathogens to be studied *P. lateralis* was first reported in 1942, and after this year, the incidence of infection in

Chamaecyparis lawsoniana (Port Oxford Cedar) production areas has increased rapidly. *P. lateralis* was determined by Tucker and Milbradt in 1942. Phylogenetically, *P. lateralis* is the nearest related to *P. ramorum* (Yang et al., 2017; Brasier et al., 2012). Phytophthora lateralis is very aggressive to *C.lawsoniana* (Robin et al., 2015; Hansen et al., 2000). The symptoms are chlorosis, wilting, thinning, dieback and eventually death of plants. *P. lateralis* was isolated from necrotic leaves in Britain, this isolation brought to mind aerial infections (Robin et al., 2011; Green et al., 2013). Also, *P. lateralis* was isolated from leaves of *Thuja occidentalis* in Scottish nursery, it is originally imported in nursery from France (Schlenzig et al., 2011). *Phytophthora lateralis* has spread along the natural habitat of *C.lawsoniana* and it leads to destructive decline with high mortality levels (Jules et al., 2002; Jimerson et al., 2001).

P. ramorum is one of the most invasive Phytophthora species because of its ability to persist, reproduce and spread in ecosystem (Croucher et al., 2013). Infected ornamental plants, like as Viburnum, Rhododendron and Camellia, often conduce to long distance spread of *P.ramorum*. Apart from being a root and crown rot pathogen, *P. ramorum* is also known as a green part pathogen or aerial pathogen. Sudden Oak Death (SOD) is one of the most devastating epidemy of forests in the world caused by *P. ramorum*. Sudden Oak Disease quickly reached epidemic level in forests in California. A wide range of *Notholithocarpus densiflorus* and *Quercus* sp. trees infected by *P. ramorum* and plants demonstrated wilting and high mortality (Goheen et al., 2012). *P. ramorum* is airborne pathogen and it was first isolated from *Viburnum tinus* and *Rhododendron* sp. in Europe (Werres et al., 2001). Comprehensive researchs achieved in recent years, has provided much information about disease biology, aetiology, population structure and host range of *P. ramorum*. *P. ramorum's* host range has expanded constantly and it has exceeded to almost 150 host species ranging between herbaceous plants to woody shrubs and trees (Grunwald et al., 2012). Pathogen causes symptoms such as root and crown rot, stem rot, aerial cancer, branch and crown dieback, necrotic lesion, shoot blight and leaf lesions in woody ornamental plants (Grunwald et al., 2008). The disease caused by this pathogen was named 'Sudden Larch Death' (SLD) rapidly reached epidemic proportions on Larch trees (*Larix* spp.) (Brasier and Webber, 2010). *P. ramorum* infections have been found on woody plants such as *Castanea sativa*, *Fagus sylvatica*, *Betula pendula*, *Rhododendron ponticum*, *Nothofagus* spp. and on other conifers such as *Abies grandis, A. procera, P. menziesii, Tsuga heterophylla* and *Picea sitchensis (*Harris and Webber, 2016; Webber at al., 2010; Brasier and Webber, 2010).

Phytophthora ramorum and *P. lateralis* have taken their place in research as the most studied species. They are known as root and crown rot pathogens as well as green parts pathogen. Phytophthora species causing rots in root and crowns of ornamentals usually cause similar or the same symptoms in host plants. The number of studies on *Phytophthora cinnamomi*, a soil-borne pathogen, is quite high (Balci et al., 2010; Meadows and Jeffers, 2011). *Quercus sp*., *Chamaecyparis lawsoniana, Castanea sativa, , Abies* sp. (266 genera in 90 families; mostly woody trees) are infected by *P. cinnamomi* (Erwind and Ribeiro, 1996). Since the 1990s, *P. cinnamomi* and many other Phytophthora species have been responsible from oak declines in Europe. *P.cinnamomi* is very important species of forest trees, woody ornamentals, especially rhododendrons and other Ericaceae. With the climate change, *P. cinnamomi* has expanded its distribution area especially in Europe and North America and it has caused more damage (Matsiakh and Menkis, 2023). *P. cinnamomi* has been spreaded for more than one century and it has threatened some of the world’s richest plant communities (Hardham, 2005; Shearer et al., 2004).

When the studies in the world literature are examined in more detail, besides the identification of Phytophthora species, purposes such as revealing the diversity of the species, determining the host range and sensitivity come to the fore. In a study conducted in eastern Spain and the Balearic Islands in 2001-2006, a regional-scale result was reached for Phytophthora diseases (Moralejo et al., 2009). Surveys focused on the symptoms of chlorosis, sudden death, shoot death, drying and defoliation associated with root and crown rot infections. 125 isolates were isolated from 37 different host plants and 17 latent species were identified morphologically and molecularly based on rDNA-ITS region, mitochondrial and nuclear gene regions. *P.hedraiandra, P. ramorum, P. niederhaueserii, P.taxon 'Pgchlamydo'* and *P. kelmania* have been reported, which were not officially reported until 2001. Additionally, 37 new host-pathogen combinations were recorded for the first time. Another study was carried to reveal the Phytophthora diversity on forest trees and woody ornamental plants between 2006-2007 in the Czech Republic. In this study, more than 360 isolates were obtained from 20 plant taxa. 16 Phytophthora species have been reported, the most isolated species are *P. plurivora*, *P. cactorum* and *P. alni* (Cerny et al., 2011).

In a study conducsantinited in Italy to investigate the diversity of Phytophthora species in potted outdoor ornamental plants, DNA barcoding method was used, and diversity was determined by nested PCR using primers for the rDNA-ITS region of Phytophthora species. As a result of ITS sequencing, 15 different Phytophthora taxa were obtained. *P. citrophthora, P. nicotianae, P. taxon 'Pgchlamydo', P. cinnamomi, P. cambivora, P. lateralis, P. meadii, P. parvispora* and *P. niederhauserii* were detected species. For 3 phylotypes (*P. pseudosyringae, P. ilicis or P. nemorosa*; *P. cryptogea, P. erythroseptica, P. himalayensis* or *P.* sp. *'kelmania' and P. citricola* taxon E or III) ITS sequencing was not sufficient. In addition to these phylotypes, 3 new taxa were obtained as *P.cinnamomi-like, P. niederhauserii-like and P. meadii-like.* The analyzes emphasized that there are very complex Phytophthora taxa communities in ornamental plant nurseries in a restricted geographical area. The results have revealed the mainly mission of ornamental plant nurseries for the existence, spread and evolution of Phytophthora species (Prigigallo et al., 2015).

It is known that soil-borne pathogenic Phytophthoras are mostly lost in a certain area. Generally, investigations have been carried out nurseries, parks and forest areas or in a spesific region. In some years, plant losses have been noticed on a larger scale and the studies have been carried out in more than one country. In a study carried out within the scope of the European Union Project, symptoms of root and crown rot, drying, yellowing, defoliation and dieback were observed in plants in 2 large European nurseries. Root and soil samples were taken from a total of 17 symptomatic woody ornamental plant species. In addition, asymptomatic plants that did not show any symptoms were also sampled. Phytophthora species were identified by isolations and molecular identification methods. Phytophthora species were isolated from 87% of symptomatic plants and 70% of asymptomatic plants. The most frequently detected species was *P. cinnamomi* (Migliorini et al., 2015). An important study for the world literature was carried out in a very large area in Europe. As a result of study carried out in 732 nurseries and 2525 outdoor ornamental plant production areas; 49 (91.5%) of 670 nurseries were contaminated with

Phytophthora taxon. It was reported that 56 Phytophthora taxa were found in 1667 (66%) of the other 2525 cultivation areas. It was also emphasized that many of these species are exotic species for Europe. It has also been reported that this source of contamination poses a major risk to the European forest ecosystem (Jung et al., 2016).

Table 1. Most known Phytophthora species's hosts and disease symptoms

Species	Hosts	Disease
P.cinnamomi	*>1000 host species Especially in Castanea sativa, Quercus* sp., *Chamaecyparis lawsoniana, Abies* sp., *Rhododendron* sp.	Root and crown rot
P.plurivora (citricola)	Almost 100 host species Especially in *Azalea* sp., *Rhododendron* sp., *Quercus* sp.	Root and crown rot, cankers and blight
P.cryptogea	>150 host species Especially in *Gerbera jamesonii, Quercus* sp., *Castanea sativa, Abies* sp., *Chamaecparis* sp., *Cupressus* sp., *Juglans regia, Pinus* sp., *Rhododendron* sp.	Root and crown rot
P.quercina	*Quercus* sp.	Root rot, Oak decline

P.gonapodyides	*Chamaecyparis lawsoniana, Fagus slyvatica, Juglans regia, Quercus* sp., *Rhododendron* sp.	Root rot, cankers
P. pseudocryptogea	*Quercus* sp., *Fagus slyvatica, Alnus glutinosa*	Root and collar rot, cankers
P.cambivora	*Almost 30 host species Especially in Castanea sativa, Quercus* sp., *Fagus slyvatica., Rhododendron* sp., *Abies* sp., *Acer* sp., *Aesculus hippocastanum, Alnus glutinosa, Juglans regia,*	Root and collar rot, cankers
P.cactorum	*>200 host species Especially in Abies* sp., *Acer* sp., *Aesculus* sp.	Root and crown rot, cankers, blights and wilts
P.chlamydospora	*Fagus slyvatica, Juglans regia, Fraxinus excelsior, Quercus* sp., *Rhododendron* sp.	Root and crown rot
P.nicotianae (parasitica)	*>400 host species Especially in Buxus sp., Lavandula sp.,*	Root and crown rot, fruit rot, blights

	Rosmarinus sp. *Palm trees, Orchids*	
P.citrophthora	*>100 host species* *Especially in* *Aesculus* sp., *C.lawsoniana, Juglans regia, Rhododenron* sp., *Castanes sativa, Buxus* sp.	Root and crown rot, cankers and blights
P.syringae	*Almost 30 host species* *Especially in Castanea sativa, Cedrus* sp., *Aesculus* sp., *Fagus slyvatica, Rhododendron* sp.	Root and crown rot, cankers, wilts, fruit rot
P.ramorum	*Especially in* *Quercus* sp., *Abies* sp., *Aesculus hippocastanum,* *Alnus* sp., *Fagus slyvatica,* *Rhododendron* sp., *Larix kaempferi,* *Viburnum* sp., *Pieris* sp.	Stem cankers, shhot dieback, blights
P.lateralis	*Chamaecyparis lawsoniana, Thuja* sp., *Taxus brevifolia, Juniperus communis, Cupressus* sp.	Discoloration and death of foliage, root infection, tree decline

Although the number of studies on Phytophthora root and crown rot species is quite high in many countries of the world, studies on Phytophthora diseases in Türkiye are limited and insufficient. In the following section, the researches and studies carried out in Türkkiye will be analysed in detail.

PHYTOPHTHORA ROOT AND CROWN DISEASES DETECTED ON ORNAMENTAL PLANTS IN TÜRKİYE

When the studies on Phytophthora root and crown rot diseases in Türkiye are analysed, there is no comprehensive study on the determination of Phytophthora diseases in ornamental plant growing areas. Most of the studies have focused on especially forest trees. For this reason, it is not known whether there are diseases that will economically affect production in the ornamental plants group and which diseases are intense. Studies on ornamental plants are very limited. One of the reasons for this is that ornamental plants are not as important as cultivated plants produced for food. Another reason is that ornamental plants sampling is not as accessible and easy as cultivated plants.Especially in detecting soil-borne Phytopthora diseases, problems such as the size of the sampled plant, the permission taken from the area to be sampled, the inability to wait for the diseased plant or soil sample until sampling and therefore the inability to reach the plant sample limit the studies to be carried out. In addition, information on ornamental plant disease detection and management strategies of is very limited in Türkiye. Most of the studies have focused on identification and the control step has been incomplete. The known management strategy for Phytophthora diseases in ornamental plants is limited to cultural control. There are very few studies on the management of Phytophthora diseases in ornamental plants. Studies both in Türkiye and in other countries have focused on cultivated plants. In Türkiye, Phytophthora root and crown rot diseases in forest trees, ornamentals and nurseries recently have only recently started to be addressed. In this part of the review, Phytophthora species found in forest trees and ornamental plants, their distribution areas and precautions to be taken in control are presented. The contents of the studies on Phytophthora root and crown rot diseases of ornamental plants in Türkiye are described in detail below.

Phytophthora Root And Crown Rot Diseases On Forest Trees in Türkiye

Many Phytophthora species infect oak trees, but *P. quercina* and *P. citricola* are the most common and common distributed species, especially in Europe and Eurasia (Vettraino et al., 2002; Balci and Halmschlager, 2003). The first study on Phytophthora diseases in oaks in Türkiye was carried out Balcı and Halmschlager in 2003. Survey was carried out rhizosphere soils of healthy and diseased oak in different oak stands in Türkiye. Seven Phytophthora species were detected from oak species sampled: *Phytophthora* spp. 1 and *Phytophthora* spp. 2., *P. cryptogea, P. citricola, P. cinnamomi, P. quercina* and *P. gonapodyides.* The most constantly isolated species was *P. quercina.* The second most common species was *P. citricola* and it was divided into three subgroups: type A and B occurred only in the European part of Türkiye and type C occurred only in Anatolia. *P.cinnamomi* was found just one site and it has not played role in the oak decline in Türkiye.

Determination of the role of Phytophthora species in the drying of Oak (*Quercus* sp.), sweet chestnut (*Castanea sativa*) and Rhododendron (*Rhododendron* sp.), which are important woody taxa of the Black Sea Region Forest Ecosystem, within the scope of TÜBİTAK project 108O888, only Phytophthora forests in the Western Black Sea region were examined. 2 Phytophthora species from the Black Sea region Zonguldak Regional Directorate of Forestry; *P. plurivora* (*P. citricola*) and *P. quercina* were obtained (Maden et al., 2012).

Akıllı and other researchers frequently obtained *Phytophthora plurivora* and *P. quercina* from soil samples taken from the oak fields in Zonguldak, Çaycuma and Devrek districts. Researchers often isolated Pythium species together with Phytophthora species and found that one of them (*P. anandrum*) was as aggressive on oaks as Phytophthora species found in this region. These findings reveal the opinion that besides Phytophthora, Pythium species may also have a role in oak drying (Akıllı et al.,2013a).

Decay sypmtoms were occurred on oak trees (*Quercus robur*) in Emirgan Grove, İstanbul in 2015. Symptoms included crown dieback, bleeding cankers on the trunk and sparse canopies. Sypmtoms were generally above soil system, indicating Phytophthora infections. Firstly, Phytophthora species were not isolated, but two species were isolated by baiting and selective media techniques from soil samples. By morphological and molecular techniques *P. pseudocryptogea* and *P. plurivora* were isolated. This species species may have played major roles oak declines (Kurbetli et al., 2022).

In Marmara and Aegean regions of Türkiye, sweet chestnut (*Castanea sativa*) is an important tree species. In two regions are produced the large majority of edible nuts, especially using for marron glacé production. The first record of the presence of Phytophthora in chestnuts, an important tree species in Türkiye, dates back to 1951. In the study, laboratory studies on the isolation and diagnosis of the agent from diseased plants were carried out, although cultures similar to the mycelial growth of the agent were obtained several times, morphological features such as sporangium and zoospore used in the diagnosis of the disease agent could not be obtained. However, from the definition of disease symptoms, it is understood that Phytophthora root rot in chestnut has been present in Türkiye since ancient times.

During the control against ink disease in the Cumalıkızık village of Bursa province, it was stated that ink disease caused by *P. cambivora* in chestnuts reportedly dried out 19715 trees in the center of Bursa between 1925 and 1968. Although it was included in this record, no diagnostic study was carried out on *P. cambivora*, only a disease diagnosis based on symptoms and sources was expressed (Akdoğan, 1970). In addition, it is stated in a textbook that ink disease caused by *P. cambivora* in chestnuts, was found in Hopa, Borçka, Sürmene in the Eastern Black Sea region and also in Zonguldak Akçakoca, İstanbul-Belgrade forest, Bursa and İnegöl. However, it is not stated in this source to whom the findings belong (Çanakçıoğlu and Eliçin, 1998).

The first record of Phytophthora based on morphological and molecular characteristics in chestnuts in Türkiye was made by Çeliker and Onoğur in 2009. Researchers found that showing signs of ink disease in Marmara and Aegean regions; They took 11 soil samples from 8 regions: 3 from Balıkesir İvrindi, 1 from İzmir Beydağ, 2 from Kütahya Simav and 2 from Manisa Salihli. The researchers tried to identify Phytophthora species by trapping method using Azelae leaves from these soil samples and obtained 4 isolates that typically resemble Phytophthora sp. The researchers detected “K-2” Phytophthora morphological features in only one of these obtained isolates, and this isolate was sent to Sabine Werres in Germany and Kris van Poucke in Belgium for diagnosis. The first researcher (Sabine Werres) identified this isolate according to its morphological features. They identified it as *P. cactorum*, and the second investigator identified it as *P. cactorum* × P. *hedraiandra* based on its molecular characteristics (Çeliker and Onoğur, 2009).

Comprehensive Phytophthora root rot studies on chestnuts in Türkiye were first initiated in the Black Sea Region. In the study, soil samples were collected from 76 regions and by trapping method, 3 Phytophthora species were isolated from the chestnuts*; P. cambivora*, *P. plurivora* (*P. citricola*) and *P. cinnamomi*. Identification of these species was based on both the morphological and physiological characteristics of the agents and the ITS region of the agents using molecular methods (Akıllı et al., 2012a). In two different studies, Phytophthora species were identified by trapping method in a total of 110 soil samples, 49 from the Marmara Region and 61 from the Aegean Region. Phytophthora root rots did not show a uniform distribution in these regions. For example, while P. cinnamomi was found only around Istanbul, *P. cambivora* was more common in the Marmara and Aegean regions. The researchers found that there were symptoms of Phytophthora root rot in all parts of these regions, but they could not find this agent in all of the samples taken, and this situation continued during the periods when soil samples were taken. They emphasized that they attributed this to drought (Akıllı et al., 2012b; Katırcıoğlu et al., 2017).

In one of the recent studies, *C.sativa* forests in Marmara and Aegean regions, severe dieback symptoms were investigated. Soil samples were collected from symptomatic chestnut trees and Phytophthora spp. were isolated by soil baiting and selective media techniques. Species were identified by morphological characteristics and molecular techniques. *Phytophthora cambivora* was the most common species detected in symptomatic areas, followed by *P. cinnamomi*, *P. plurivora* and *P. cryptogea*. *Phytophthora cambivora* was detected in Marmara and Aegean regions, while *P. cinnamomi* was detected only in the coastal areas in Marmara region. *Phytophthora cryptogea*, was the first record on chestnut in Türkiye. These results recommend that *P. cinnamomi* and *P. cambivora* act a important role in Western Türkiye (Akıllı et al., 2019a).

Researchers observed sudden wilt and dieback associated with root rot in *Juglans regia* in Bingöl in 2015. Most of roots were definitely rotted and the inner bark of roots showed discoloration. Phytophthora species was permanently isolated from diseased plants. All morphological features were similar to *Phytophthora chlamydospora* (Hansen et al., 2017), previously known as *P. taxon Pgchlamydo*. *P. chlamydospora* has infected many woody ornamental plants, but this research is the first report of *P. chlamydospora* infection of walnut. *J.regia* has identified with P.chlamydospora for new host (Derviş et al., 2016).

Signs of die back were observed in ash trees (*Fraxinus* sp.) near the Sinop province of Türkiye and decay was observed in the roots of diseased plants. Soil samples taken from the roots of such trees were examined for Phytophthora and 4 out of 10 samples contained Phytophthora spp. and this species was later identified as P. lacustris (Akıllı et al., 2013b).

The pathogenicity and identification of Oomycota species leading to root rot were surveyed in forest tree nurseries in western Türkiye. Soil samples collected from the rhizosphere of diseased plants. Oomycota species were isolated by culturing on selective media. Baiting technique was used by young leaves of *Rhododendron simsii, R. ponticum and Quercus suber*. İsolates were identified by morphological methods and molecular techniques. *Pythium aphanidermatum, P.intermedium, P. ultimum, P. irregular, Phytophthora syringae, Phytophthora aff. cactorum, P. citricola sensu lato, P. crassamura and Phytopythium vexans* were common species among the isolates. *Phytophthora syringae* was detected in *Cebrus libani* in Antalya-Elmalı, Adapazarı-Hendek, İzmir-Torbalı, Isparta-Eğirdir and Denizli-Karahasanlı; *P. crassamura* was detected in *Castanea sativa* in Bursa; *P. cactorum* and *P. citricola* were detected in *Laurus nobilis* in İzmir-Torbalı; *P. citricola* was detected in *Buxus sempervirens* in Muğla-Gökova, Adapazarı-Hendek and İzmit-Sapanca. The importance of nursery infections in the introduction of potentially detrimental oomycete species into Turkish nurseries is debated (Lehtijarvi et al., 2017).

A study was conducted on the presence of Phytophthora species in *Alnus glutinosa* areas in Karacabey and Iğneada floodplain forests in Türkiye. Soil samples were obtained from the rhizosphere of diseased plants. Baiting techniques were used for Phytophthora isolation. Totally more than 300 Phytophthora isolates were acquired due to selective media. *Phytophthora plurivora* was the most isolated species (83%) according to morphological characteristics and the ITS sequencing. As well as *P. plurivora, P. gonapodyides* (9%), *P. chlamydospora* (3,8%), *P. lacustris* (2,5%) and *P. aff.*

cactorum (2%) were isolated from *A.glutinosa* forests. This study includes first report of *P. aff. cactorum* and *P. plurivora* obtained from the rhizosphere of Alnus species in Türkiye (Aday Kaya et al., 2018).

Phytophthora Root and Crown Rot Diseases on Other Ornamentals in Nurseries in Türkiye

In addition to forest trees, Phytophthora root and crown rot diseases were also examined in other ornamental plants in nurseries in Türkiye.

The research was carried out identify the fungi species which induce damping-off in some common sage (*Salvia officinalis*) plantation in Antalya and Izmir provinces of Türkiye. Diseased plants showed rot symptoms in root and crowns. Such sypmtoms were typical of Phytophthora species. *P. cryptogea*, new Phytophthora species, was isolated and identified by morphological and molecular characteristics of DNA sequencing. This research is the first report of *P. cryptogea* on *S.officinalis* in Türkiye (Çakır et al., 2017). Several Phytophthora species, such as *P. cryptogea*, are generally non-host specific and can affect a different plant groups.

Recently, dieback symptoms of boxwood (*Buxus sempervirens*) has been observed in many forests in Türkiye. In a study, boxwood diseases were researched in nurseries and forests in the Marmara and Black Sea regions of Türkiye. Nurseries and forests were surveyed and samples were collected from symptomatic plants tissues like soil, branch and leaves. 11 fungal genera were were identified based on morphological characteristics and sequencing. *P. plurivora* was detected in two nurseries while *Phytophthora nicotianae* was detected in one nursery and *P. occultans* in only a location in forests in the Black Sea region (Akıllı et al., 2019b).

The record of Phytophthora in horse chestnut (*Aesculus* sp.) in Türkiye dates back to 2002. In a park in Ankara, yellowing of the leaves, shrinkage of the leaves and necrosis with dark discharge on the trunk and main branches were observed in the horse chestnut, and *P. cactorum* was isolated from the tissues surrounding these necroses (Intini et al., 2002). In another study, a new Phytophthora species, *P. citrophthora*, was obtained from soil and root samples taken from the rhizosphere of horse chestnut trees in Ankara. The researchers identified this species according to both morphological and molecular characteristics (by determining the sequence of the ITS gene region) (Akıllı et al., 2012c).

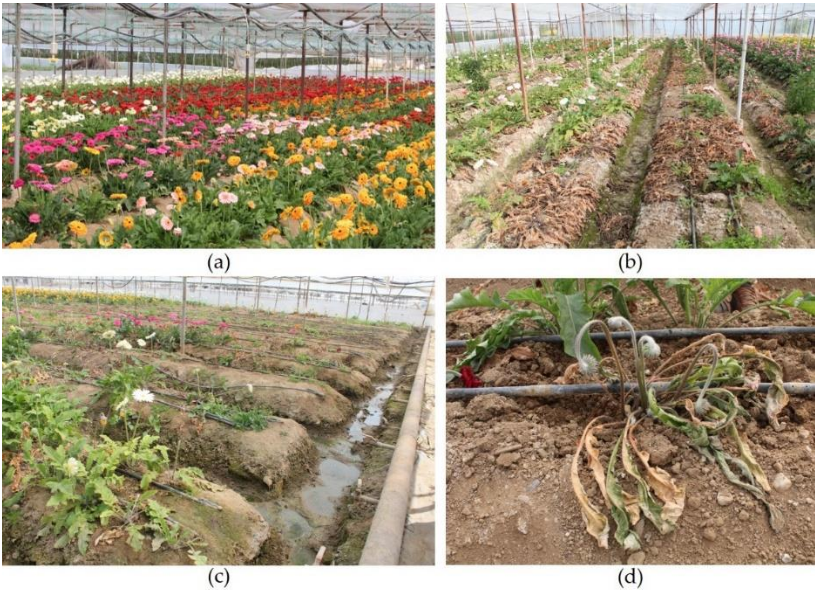

Figure 1. ***Phytophthora cryptogea*** **infected** ***Gerbera jamesonii*** **in Türkiye:** (a) Healthy *Gerbera jamesonii* in Izmir nurseries free of Phytophthora infection b) nursery with gerbera plants which have died due to Phytophthora cryptogea (c) increase in plant losses due to excess of irrigation water in Phytphthora root and crown diseases (d) infected Gerbera jamesonii with drying of leaves, dieback, wilting
Notes: All photos taken by Çiğdem Özkan Kahraman; retrieved from Çiğdem Özkan Kahraman's Master's thesis)

Root and crown rot pathogens are also seen in cut flowers in Türkiye. Dieback symptoms of gerbera were investigated in variety of greenhouses in Izmir province of Türkiye. Discoloration, yellowing, wilting, growth deficiency and decline sypmtoms were observed in greenhouses. The causal pathogen was identified as *Phytophthora cryptogea* based on morphological features and DNA sequencing of ITS region. This study is the first report of *P. cryptogea* on gerbera in Izmir (Kahraman and Yıldız, 2019). As a continuation of this study, pathogen management study was carried out. Management trial was performed in order to determine the in vivo efficacy of some fungicides and biofungicides. In this study, five fungicides were tested using by soildrenching."Azoxystrobin+difenoconazole","mandipropamid+difenoconaz ole", "propamocarb+fosetyl-Al", "mancozeb+metalaxyl-M", "Ametoctradin+dimethomorph" active substances were used. Similarly, the biofungicide active ingredient such as *Bacillus amyloliquefaciens* was applied by soil drenching. In this experiment, azoxystrobin+ difenoconazole showed the highest efficacy against *P. cryptogea*. The other fungicides and biofungicides were not effective. The aim of that management trial was to indicate the fungicides and biofungicides efficieny on preventing root and crown rot disease *P. cryptogea* in gerbera in greenhouses (Özkan Kahraman and Yıldız, 2019).

Table 2. Coincidence of Phytophthora species associated with ornamentals in Türkiye

Species	Region	Hosts	Source
Phytophthora spp.	Marmara and Aegean Region	*Castanea sativa*	Erdem, 1951
P.cambivora	Cumalıkızık, Bursa	*Castanea sativa*	Akdoğan, 1970
	Eastern Black Sea Region Zonguldak, İstanbul Bursa	*Castanea sativa*	Çanakçıoğlu and Eliçin, 1998
	Aegean Region	*Castanea sativa*	Katırcıoğlu et al., 2017
P. cactorum *P. cactorum×P.hedraiandra*	Marmara and Aegean Region (Balıkesir, İzmir, Kütahya, Manisa)	*Castanea sativa*	Çeliker and Onoğur, 2009

P. cambivora *P.cinnamomi* *P.plurivora (citricola)*	Black Sea Region	*Castanea sativa*	Akıllı et al., 2012a
P. cinnamomi *P.cambivora*	Marmara Region	*Castanea sativa*	Akıllı et al., 2012b
P.cinnamomi *P.plurivora(citricola)* *P.cryptogea* *P.cambivora*	Marmara and Aegean Region	*Castanea sativa*	Akıllı et al., 2019a
P.plurivora(citricola) *P. quercina*	Western Black Sea Region	*Castanea sativa, Quercus sp., Rhododendron sp.*	Maden et al., 2012
	Zonguldak	*Quercus sp.*	Akıllı et al., 2013a
P.plurivora(citricola) *P. pseudocryptogea*	İstanbul	*Quercus robur*	Kurbetli et al., 2022
P.cinnamomi *P.plurivora (citricola)* *P.cryptogea* *P.gonapodyides* *P.quercina* *P.sp 1* *P.sp 2*	51 oak stands in Türkiye	*Quercus sp.*	Balci and Halmschlager, 2003
P.lacustris	Sinop	*Fraxinus sp.*	Akıllı et al., 2013b
P.taxon Pgchlamydo *P.chlamydospora*	Bingöl	*Juglans regia*	Derviş et al., 2016
P. plurivora(citricola) *P.gonapodyides*	Bursa and İğneada	*Alnus glutinosa*	Aday Kaya et al., 2018

P.chlamydospora *P.lacustris* *P.aff.cactorum*	floodplain forests		
P.cactorum	Ankara	*Aesculus sp.*	Intini et al., 2002
P.citrophthora	Ankara	*Aesculus sp.*	Akıllı et al., 2012c
P.aff. cactorum *P.citricola sensu lata* *P.crassamura* *P.syringae*	Antalya, Adapazarı, İzmir, Isparta, Denizli, Bursa, Muğla, İzmit	*Cedrus libani-P.syringae* *Castanea sativa-P.crassamura* *Laurus nobilis-P.cactorum, P.citricola* *Buxus sempervirens-P.citricola*	Lehtijarvi et al., 2017
P.cryptogea	Antalya, İzmir	*Salvia officinalis*	Çakır et al., 2017
P.plurivora (citricola) *P.occultans* *P.nicotianae*	Marmara and Black Sea Region	*Buxus sempervirens*	Akıllı et al., 2019b
P.cryptogea	İzmir	*Gerbera jamesonii*	Kahraman and Yıldız, 2019

CONCLUSIONS

Some Phytophthora root and crown rot pathogens have still not been diagnosed in many countries in worlwide. Variety of root disorders of ornamental plants have been ascribed to other pathogens, and found whereby Phytophthora species just when suitable isolation techniques such as baiting and selective media were used. However, these specific techniques are still not widely used by many researchers today. Generally, they are unaware of the importance of these fungi like organisms that inducing severe infections, or of the peerless nature of their biology, soil ecology and pathology in relation to root systems development. It is expected that using special isolation techniques in diagnoses will result in increasing in the frequency of reports of determination of Phytophthora root and crown rots of ornamental plants in worlwide in the future.

While the world literature on Phytophthora species that cause root and crown rot is quite sufficient, studies in Türkiye are very limited and almost all of the studies have been done on forest trees and cut flowers. Most of the studies have focused on morphological and molecular identification and the control step has been missing. In addition to disease symptoms seen in other plants in nurseries and greenhouses other than forest trees, research should also be carried out on ornamental plants where problems are detected during the survey. Morphological diagnosis, which is the first step, and molecular diagnosis, which is the second step, has an important place. After diagnostic methods, basic research on control possibilities should be carried out. The results of the research will provide yield and quality increase in production areas where disease-related problems are experienced, as well as practical application, chemical control possibilities, and also environmentally friendly, biological origin preparations that do not harm the environment and human health. The increase in yield, quality and therefore income to be obtained from production will contribute to the Turkish economy by encouraging ornamental plant cultivation.

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CHAPTER 9

BIOACTIVE COMPOUND LYCOPENE IN TOMATO

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INTRODUCTION

Natural antioxidants play an important role in maintaining our health and preventing disaeses because of their therapeutic effect. Antioxidants (glutathione, arginine, selenium, zinc, vitamin E, vitamin C, vitamin A, lycopene, beta-carotene, etc.) are crucial effect for cleaning free radicals. If free radicals are not well controlled, they attact lipids sugars,proteins and DNA to induce oxidative damage to these molecules and eventually cause various diseases; cancer, aging, etc. In this part of the study, one of the most important antioxidant compounds lycopene will be evaluated in detail.

Lycopene is the most abundant antioxidant in human blood. Lycopene is the red carotenoid found predominantly in tomatoes and in a few other fruits and vegetables (Joseph et al., 2004).

Tomato Nutrition Glossary

Tomato is a very important nutrition in our diet. Tomato contains not only lycopene but also gallic acid, ferulic acid, quercetin, cafeic acid, chlorogenic acid, malic acid, vitamins (mainly vitamin A, vitamin E, and vitamin C), and various minerals (Ca, P, Fe, Na, K, etc.).

Gallic acid: Gallic acid (also known as gallate) is a benzoic acid that is thought to be one of the main phenolic acids. It is crucial for the creation of a category of tannins known as galatotanin-hydrolyzable tannins, which is made up of a unit of sugar and a variable number of phenol acid molecules (Fernandes and Salgado, 2016).

Malic acid: Malic acid, fumaric acid, itaconic acid, and succinic acid are examples of compounds that have a variety of potential uses as platform chemicals. Malic acid is an organic acid that is a crucial cell metabolism step and a member of the C_4 dicarboxylic acid group (Iyyappan et al., 2019).

Citric acid; Both plants and animals frequently metabolize citric acid, a tricarboxylic acid ($C_6H_8O_7 \cdot H_2O$), which is found in pineapple and citrus fruit juice.The molecular weight of pure citric acid is 210.14 g/mol, and it is colorless and easily soluble in water. In addition to being a multifunctional chemical for sequestering, buffering, wetting, cleaning, and dispersing, it is also biodegradable, environmentally friendly, cost-effective, and safe (Angumeenal and Venkappayya 2013).

Oxalic acid; With a molecular weight of 90 kg/kmol and the chemical formula $C_2H_2O_4$, oxalic acid is a naturally occurring dicarboxylic acid that is vital to many plant, animal, and microbiological species. Oxalic acid plays a crucial role in ion homeostasis, heavy metal detoxification, calcium control, and plant defense in plants (Amenaghawon et al., 2024).

Quercetin; The dietary flavonoid quercetin (3,5,7-trihydroxy-2-(3,4-dihydroxyphenyl)-4Hchromen-4-one) is found in fruit peels, leafy vegetables, strawberries, onions, cranberries, blueberries, black tea, lettuce, tomatoes, black chokeberries, capers, etc. (Dinç et al., 2023; Wang et al., 2016). Quercetin is typically found in plants attached to ethers, sugars, phenolic acids, and other substances. The rate at which quercetin derivatives are absorbed in the stomach and small intestine appears to vary depending on their shape (Wang et al., 2016). The amount of quercetin a person takes daily is approximately 16-25 mg (Dinç et al., 2023).

Naringenin; Mostly present in citrus fruits and some edible fruits like tomatoes and figs from the smyrna variety Ficus carica, naringenin is one of the most significant naturally occurring flavonoids. Naringenin, a flavonone in the flavonoid class, is produced by hydrolyzing naringin or narirutin, the glycone precursor. In addition to lowering protein carbonylation and lipid peroxidation biomarkers, naringenin promotes carbohydrate metabolism, boosts antioxidant defenses, scavenges reactive oxygen species, controls immune system activity, and has anti-inflammatory and anti-atherogenic properties (Salehi et al., 2019).

Cafeic acid; Caffeic acid (CA) is a metabolite of hydroxycinnamate and phenylpropanoid, widely synthesized by all plant species. This polyphenol can be found in a wide variety of foods, including propolis, coffee, tea, wine, blueberries, apples, cider, and honey. Potential antibacterial, antidiabetic, antioxidant, anti-inflammatory, antineoplastic, and cardioprotective properties have been described for CA and its main derivatives, such as caffeic acid phenethyl ester (CAPE) and caffeic acid 3,4-dihydroxy-phenethyl ester (CADPE). Caffeic acid phenethyl ester (CAPE) and caffeic acid 3,4-dihydroxy-phenethyl ester (CADPE), two of CA's main derivatives, have been shown to have potential antibacterial, antidiabetic, antioxidant, anti-inflammatory, antineoplastic, and cardioprotective properties (Ekeuku et al., 2021).

Ferulic acid; A phenolic molecule that is frequently present in plant tissues, ferulic acid (4-hydroxy-3-methoxycinnamic acid) is a bioactive ingredient in a variety of foods (Zhao and Moghadasian 2008). The dietary antioxidant ferulic acid (FA) is plentiful and may have protective effects against Alzheimer's disease, diabetes, heart disease, and cancer (Li et al., 2021).

Lycopene is an acyclic isomer of beta carotene (Lowe et al.,2018). Since lycopene does not have the beta-ionone ring structure, it cannot form vitamin A (Helmenstine, 2004). Lycopene, which has the molecular formula of $C_{40}H_{56}$ (Figure 1), was first studied by Willstatter and Escher (1910) who showed that lycopene is an isomer of carotenes. Karrer et al. (1930) published the chemical structure of lycopene. It was later isolated as a dark red crystalline pigment from Tamus communis L. Berries by Hartsen (1873). Millardet (1875) obtained a mixture containing lycopene from tomatoes and named it solanorubin. Schunck (1903) gave the name lycopene after showing that this pigment obtained from tomatoes had an absorption spectrum different from that of carotenes obtained from carrots (Nguyen and Schwartz, 1999).

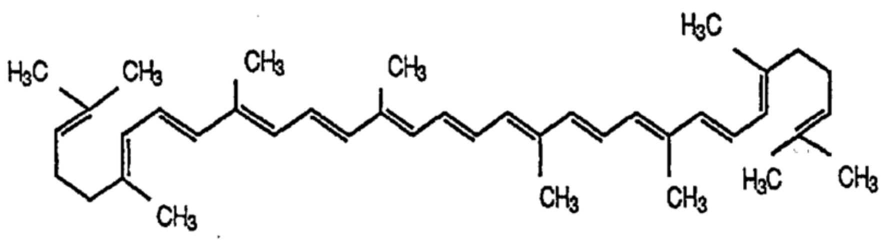

Figure 1. Chemical structure of lycopene

Lycopene is an aliphatic hydrocarbon with 11 conjugated carbon- carbon double bonds, making it soluble in fats and lipids and red in color.

While beta carotene and lutein are found in many different kinds of fruits and vegetables, only a few products contain important other carotenoids such as lycopene (Kumpulainen and Salonen, 1999). Foods containing lycopene are given in Table 1.

Lycopene is found predominantly in the chromoplast of plant tissues. Human bodies are unable to synthesized lycopene. The liver, adrenal glands, and prostate store the majority of the lycopene that is stored. Furthermore, it is present in other bodily areas (such as the skin and brain) in smaller amounts. The bioavailability of lycopene can be reduced by age and certain clinical conditions, including heart disease (Imran et al., 2020). In tomatoes, lycopene biosynthesis increases dramatically during the ripening process as chromoplasts undergo transformation to chromoplasts (Nguyen and Schwartz, 1999).

Table 1. Common food sources of lycopene

Food source	Type	Amount (mg/100 g wet weight)	Amount per serving	
			mg	Serving size
Apricots	Fresh	0.005	0.007	140 g
Apricots	Canned, drained	0.065	0.091	140 g
Apricots	Dried	0.86	0.34	40 g
Chilli	Processed	1.08 to 2.62	1.40 to 3.41	130 g
Grapefruit	Pink, fresh	3.36	4.70	140 g
Guava	Pink, fresh	5.40	7.56	140 g
Guava juice	Pink, processed	3.34	8.35	240 mL (250 g)
Ketchup	Processed	16.60	3.32	1 tbsp (20 g)
Papaya	Red, fresh	2.00 to 5.30	2.8 to 7.42	140 g
Pizza sauce	Canned	12.71	15.89	125 g
Pizza sauce	From pizza	32.89	9.867	125 g
Salsa	Processed	9.28	3.71	2 tbsp (40 g)
Spaghetti sauce	Processed	17.50	21.88	125 g
Tomatoes	Red, fresh	3.1 to 7.74	4.03 to 10.06	130 g
Tomatoes	Whole, peeled, processed	11.21	14.01	125 g
Tomato Juice	Processed	7.83	19.58	240 mL (250 g)
Tomato soup	Canned, condensed	3.99	9.77	245 g
Tomato paste	Canned	30.07	9.02	30 g
Watermelon	Red, fresh	4.10	11.48	280 g
Vegetable juice	Processed	7.28	17.47	240 mL (250 g)

(Singh and Goyal, 2008)

It has been demonstrated that lycopene cis-isomers are more bioavailable and bioactive than the naturally found all trans-isomers. Cis isomers of lycopene can be formed from the all trans forms of it by light, heat, and metabolic processes. Therefore, during the processing of foods, lycopene structure will be changed and as a result, increasing the proportion of cis-isomers. The stability, bioavailability, health effect, and distribution of lycopene isomers are different from each other (Honest et al., 2011). Lycopene's configuration enables it to inactivate free radicals. Because free radicals are electrochemically imbalanced molecules, they are highly aggressive, ready to react with cell components, and cause permanent damage. These toxic chemicals are formed naturally as by-products during oxidative cellular metabolism. As an antioxidant, lycopene has a singlet-oxygen-quenching ability twice as high as that of beta-carotene and ten times higher than that of alpha-tocopherol. Lycopene is fat-soluble, and absorption into tissues is improved when oil is added to the diet. (Helmenstine, 2004).

There are a lot of studies for lycopene some of them are given below;

In their study conducted in 2003, Kana et al. Total lycopene concentration and the concentrations of the cis- and trans-lycopene isomers were measured by HPLC in plasma samples taken 3-4 y apart from 144 mostly nonsmoking male participants in the Health Professionals Follow-up Study. Results suggest that measuring specific lycopene isomers in epidemiologic studies may not provide additional information beyond that provided by total lycopene concentration. Single plasma samples quantitating plasma lycopene are a valid predictor of long-term exposure for epidemiologic studies. (Kana et al., 2003).

In a study conducted in 2004, Different crystalline lycopene samples obtained from the fermentation process and recrystallized lycopene were analyzed. Structural properties (NMR, mass spectrometry, and powder X-ray diffraction) of lycopene were clarified with recent techniques. High-purity sample analysis by differential scanning calorimetry was used to study the thermal behavior of pure lycopene with traces of isomers. But also this was correlated with the HPLC method for determining lycopene purity and isomers in low proportion. (Estrella et al., 2004).

According to Yang et al., in recent years, the food industry and pharmaceutical industries have expressed a strong interest in the industrial synthesis of lycopene and beta-carotene from tomatoes for the creation of functional meals. First, a new neuro-fuzzy model was presented to model the supercritical CO2 extraction of lycopene and beta-carotene from tomato paste waste, taking into account many process factors. It can aid in the development of a quality assurance simulation and self-control system, as well as achieving optimal control in industrial production. A simulation analysis demonstrated the efficiency of the proposed model (Yang et al., 2004).

In the study by Hyman et al., product development for higher fruit lycopene content requires a rapid and efficient method for lycopene quantification. Among the available procedures, high-performance liquid chromatography (HPLC) may be accurate; however, it is time-consuming and requires the use of specialized personnel and highly hazardous solvents. Similarly, spectrophotometric procedures, although simpler than HPLC, require time-consuming extractions and may not be as reliable as they often overestimate fruit lycopene levels. Colorimetric assessment of fruit lycopene using chromaticity values has been presented as a faster method. The results showed that fruit lycopene content can be assessed simply and accurately in a wide range of tomato genotypes using chromaticity values obtained from fruit puree (Hyman et al. 2004).

Periago et al. used a simple mixture process design based on the comparison of both quadratic and special cubic models, including three mixture components (hexane/acetone/ethanol), to extract lycopene from raw tomatoes, tomato sauce, and tomato paste, and to test the hypothesis that lycopene extraction rates are a function of the solvent used during the extraction process. Conventional criteria (0.15 or less) were employed to assess the influencing effects in each model. Although hexane was the primary component utilized in lycopene extraction, it exhibited a favorable secondary synergistic interaction with ethanol (all sample types) and acetone (tomato paste samples), showing that a combination of all three components is required to enhance the extraction process. The partial special cubic model yielded three fixed points indicating the hexane, acetone, and ethanol concentrations required for optimal lycopene extraction in raw tomatoes, tomato sauce, and tomato paste (Periago et al., 2004).

The aim of the study by Chonn et al. was to examine the plasma concentration responses of total lycopene and its primary isomers to carotenoid dosing as tomato juice, tomato soup, or synthetic lycopene pills. The findings of this study indicate that the systemic availability of synthetic lycopene from the tablet formulation is similar to that of processed tomatoes (soup from tomato paste) and superior to tomato juice. There was no change in the elimination kinetics of natural and synthesized lycopene. The synthetic lycopene pill formulation used in this study may be useful for future clinical studies (Chohn et al., 2004).

Giuseppe et al. report a new method for extracting lycopene from tomatoes utilizing supercritical carbon dioxide and vegetable oil as a co-solvent. The co-solvent increases the yield of the lycopene extract and improves the pigment's stability. A comprehensive description of the extraction method is also provided. Experiments performed with and without co-solvent at pressures and temperatures ranging from 335 to 450 bar and 45 to 70 °C, respectively, showed that the amount of extractable lycopene depends on the experimental conditions. Furthermore, the maximum amount of extractable lycopene from dried tomatoes (6% moisture, average particle size about 1 mm) was 60% at 450 bar and 66 °C in the presence of co-solvent and using a flow rate of about 20 kg CO2/h. The extracts were analyzed by high-performance liquid chromatography and UV-vis spectra (Giuseppe et al., 2004).

CONCLUSION

Lycopene, a natural carotenoid, stands out as a molecule that has significant biological impacts on human health. It helps to prevent chronic diseases caused by oxidative stress by neutralizing free radicals, thanks to its powerful antioxidant qualities. Lycopene has been shown in studies to lessen the chance of acquiring a variety of health conditions, including cardiovascular disease, cancer, diabetes, and neurological illnesses. However, in vivo and in vitro research to understand the mechanisms of these effects has revealed that a wide range of complex processes are involved, including cellular gene expression regulation, inflammatory modulation, and cellular proliferation control. Lycopene's bioavailability and bioeffectiveness vary according to ingestion type, dietary matrix, processing methods, and individual metabolic variations. It is stressed that consuming lycopene from dietary sources such as tomatoes is more effective, although this effectiveness can be enhanced by using various formulations and nanotechnological transport systems.

As a result, lycopene is being studied as a potential therapeutic agent in modern medicine and nutritional science, as well as a key component in the development of functional foods. However, comprehensive randomized controlled studies and long-term human trials are required to further understand lycopene's biological effects and translate them into clinical applications. In this setting, multidisciplinary approaches to lycopene's effects on health will provide novel perspectives in both science and industry.

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