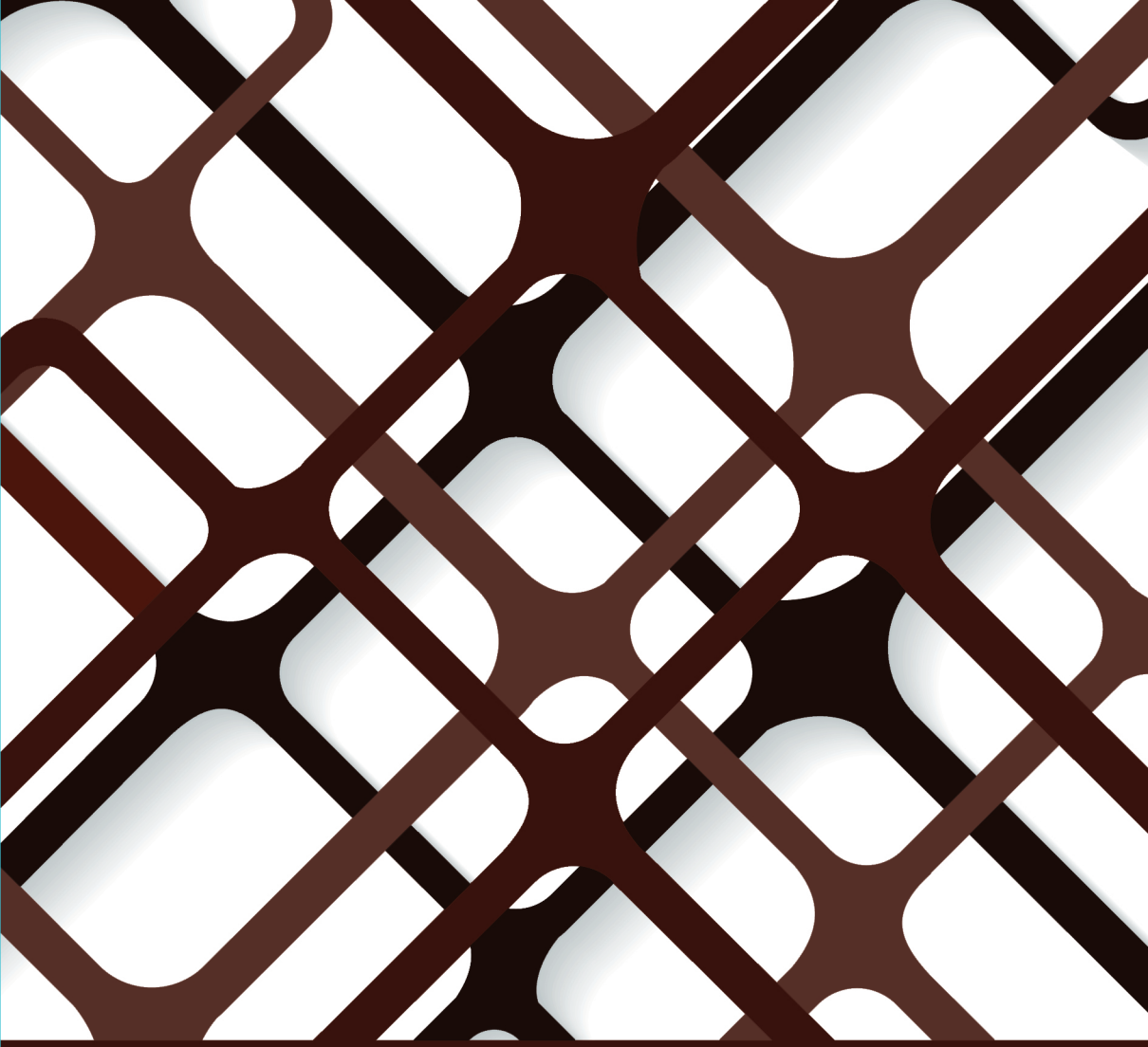

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SEPTEMBER/2021

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CONTENTS

Chapter 1

BOVINE BRUCELLOSIS: FROM TREATMENT TO PROTECTION (ERADICATION AND PRECAUTIONARY MEASURES)

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1. Etiology and characteristics

Brucellosis is a highly contagious zoonosis, which is observed throughout the world and affects domestic and wild mammals (Ducrotoy *et al.,* 2017; Chimana *et al.,* 2010). *Brucellae* are Gram-negative bacteria responsible for brucellosis. The genus *Brucella* belongs to the class *Alphaproteobacteria* under the phylum *Proteobacteria* (Głowacka *et al.,* 2018). Brucellosis affects bovine, caprine, ovine and porcine animals as well as camelids, and is also observed in humans (Pal *et al.,* 2017).

Table 1. Taxonomy of Brucella

Table 1. Taxonomy of *Brucella*	
Domain	Bacteria
Phylum	Proteobacteria
Class	Alphaproteobacteria
Family	Brucellaceae
Genus	Brucella
Species	*Brucella* spp.

The genus *Brucella* includes Gram-negative, facultative intracellular, non-capsulated and non-spore forming bacteria (Hassan *et al.,* 2020). While these bacteria survive freezing and thawing, they are killed by disinfectants effective against Gram-negative bacteria (Kiros *et al.,* 2016).

Brucellae are 0.5-0.7 μ in width and 0.6-1.5 μ in length. These bacteria are positive for catalase, oxidase and urease activity. *Brucella spp*. are non-motile, and excluding the chemotactic system, possess all the genes necessary for the assembly of a functional flagellum (Kiros *et al.,* 2016).

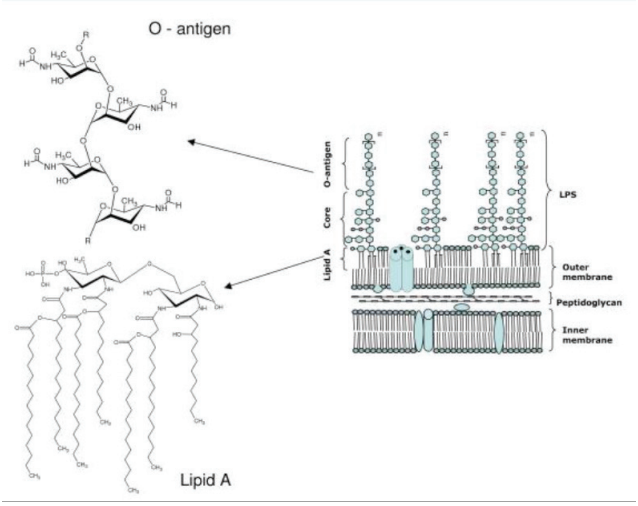
Although reported as being facultative intracellular pathogens in most references, based on their evolutionary relation to other *Alphaproteobacteria*, *Brucellae* have been re-designated as facultative extracellular intracellular pathogens (El-Sayed & Awad, 2018).

The ability of *Brucella* spp. to develop mechanisms to avoid an immune response by the host not only ensures their successful colonization and reproduction, but also avoids their extracellular killing. *Brucellae* contain lipopolysaccharides (LPS) in their outer membrane, and these are known to act as a major virulence factor (Cardoso *et al.,* 2006).

Different from intestinal bacteria such as *Escherichia coli*, which possess classical LPS, *Brucellae* are characterized by an untypical non-classical LPS (Lapaque *et al.,* 2005).

LPS, which is an essential virulence factor and the primary target of the mammalian immune system, has three domains, namely, the core oligosaccharide, lipid A, and the O-antigen (O-side chain) (Figure 1) (Cardoso *et al.,* 2006).

Figure 1. Lipopolysaccharide structure



In *Brucella* strains producing smooth colonies, smooth LPS (S-LPS) is composed of i) lipid A, which contains two types of amino glycose, fatty acid and β-hydroxymyristic acid, ii) a core comprised of mannose, glucose and quinovosamine, and iii) O-chains comprising 4-formamido-4,6-dideoxymannose. In *Brucella* strains producing rough colonies, the structure of R-LPS shows similarity to that of S-LPS, except for the O-chains, which are either absent or reduced (Głowacka *et al.,* 2018). Bacteria enter macrophages by means of the connection of the O-chains with lipid rafts on the macrophage surface.

Brucella strains characterized by R-LPS make no connection with these lipid rafts, but make fast connections with lysosomes (Głowacka *et al.,* 2018). *Brucella* strains characterized by S-LPS display an interaction of the O-chains with the tumor necrosis factor (TNF-α), and inhibit host cell apoptosis. As virulence factors are not released by dead cells, the host immune system is not activated and *Brucellae* are capable of avoiding the host immune response and surviving in their target host (Głowacka *et al.,* 2018).

Lipopolysaccharides not only render *Brucellae* very resistant to cationic antimicrobial peptides, but also prevent the access of C1q to the outer membrane and block complement-mediated killing, and thereby, stimulate extracellular survival (Neta *et al.,* 2010).

The long-chain acyl groups of lipid A, found in the LPS structure of *Brucellae*, reduce the host inflammatory response by interacting with the toll-like receptor TLR4, and this eventually enables the survival of the bacteria (Neta *et al.,* 2010). Compared to the classical LPS of *E. coli*, the non-classical LPS of *Brucella* strains is less toxic, less active, less pyrogenic, and a weaker inducer of the tumor necrosis factor (Głowacka *et al.,* 2018).

Specific survival mechanisms are activated when *Brucellae* invade the host cell, such that the natural defense mechanisms of the host are averted.

The genus *Brucella* represents a group of at least 10 coccobacilli species, which are named based on their preferred host organism or associated infection symptoms, including *B. melitensis, B. abortus, B. ovis, B. canis, B. suis, B microti, B. inopinata, B. neotome, B. pinnipedialis,* and *B. ceti* (Table 2) (Goodwin & Pascual, 2016; Higgins, 2015).

Table 2. The hosts and zoonotic potential of Brucella spp.

Species	Host(s)	Zoonotic Potential
Brucella abortus	Cattle	High
Brucella melitensis	Sheep and goats	High
Brucella ovis	Sheep	High
Brucella suis	Pigs, rabbits, reindeers, rodents	None
Brucella canis	Dogs	Moderate
Brucella neotomae	Desert wood rats	None
Brucella microti	Voles	Unknown
Brucella inopinata	Unknown	Moderate
Brucella pinnipedialis	Seals	Moderate
Brucella ceti	Whales, dolphins, porpoises	Moderate

Genetically, these species are highly associated and can be distinguished by high-resolution molecular typing tools (Haag *et al.,* 2010).

Recently, the genome sequences of *B. suis, B. melitensis* and *B. abortus* have been published. These *Brucella* species show close similarity in genome sequences, structure, and organization (Halling *et al.,* 2005).

Of the two open reading frames of the *Brucella* genome, bvrS encodes the BvrS protein (601 amino acids) and bvrR encodes the BvrR protein

(237 amino acids), and both proteins enhance bacterial intracellular survival (Głowacka *et al.,* 2018).

The *Brucella* BvrR/BvrS system prevents phagosome-lysosome fusion and intracellular replication, controls the expression of outer membrane proteins and forbids MHC II-peptide expression on the outer surface of the cell (Głowacka *et al.,* 2018; Goodwin & Pascual, 2016; Viadas *et al.,* 2010).

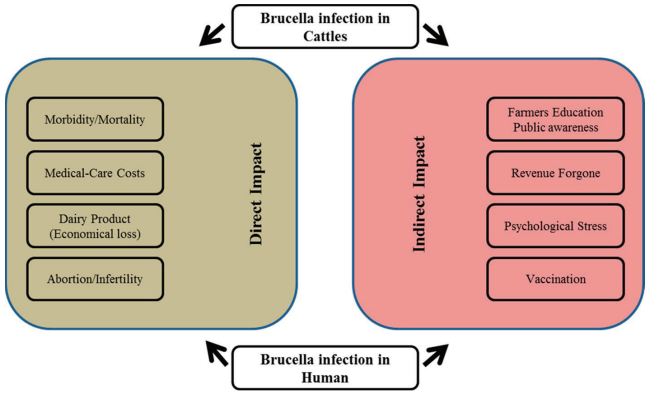
The BvrR/BvrS system regulates the expression of multiple genes and its dysfunction causes structural changes in lipopolysaccharides, rendering them more sensitive to cationic peptides. BvrR/bvrS mutants are incapable of activating GTPase (Cell Division Cycle 42) before entering the cell, so they remain extracellular and eventually do not infect the cell (Głowacka *et al.,* 2018; Goodwin & Pascual, 2016).

2. Impact of brucellosis on livestock

Brucellae cause both direct and indirect economic losses in the livestock sector. The direct effects of brucellosis include bovine abortion, reduced milk quantity and quality, decreased weight gain due to chronic infection, slower growth rate, premature death, culling of non-productive stock, and poor animal welfare (Franc *et al.,* 2018).

In endemic regions, brucellosis may significantly reduce herd productivity, and thereby, compromise both food security and the livelihood of farmers, who depend on the sale/trade of surplus meat, milk, and offspring of their animals. Depending on the animal species and organs involved, brucellosis may follow a course ranging from severe acute to chronic. Pregnant animals infected with brucellosis display visible swelling of the udder and navel region, and shed bacteria in the urine, milk, and vaginal discharge (Currò *et al.,* 2012).

Figure 2: *Impact of brucellosis on livestock and humans (Khan & Zahoor, 2018)*



Several high-income countries have successfully eradicated brucellosis through strict control strategies, involving prophylactic vaccination and the slaughter of infected animals (Franc *et al.,* 2018; Godfroid *et al.,* 2002).

Brucellae also cause losses related to disease management, including the costs of veterinary services, vaccination, diagnostics and farmer indemnification. Furthermore, trade restrictions applying to endemic areas (with *B. melitensis, B. abortus* and *B. suis* infection) and contaminated products lead to forgone revenue (OIE, 2018).

3. Global distribution of brucellosis

Brucellosis has a worldwide distribution, excluding countries, where the disease has been eradicated, including Japan, Australia, Canada, Cyprus, Denmark, Finland, the Netherlands, New Zealand, Norway, Sweden and the United Kingdom (Seleem *et al.,* 2010). North and east Africa, the Mediterranean European countries, the Near East, Mexico, India, Central Asia, and Central and South America are still not free from brucellosis (Kiros *et al.,* 2016).

Brucellosis has been known in Africa for a very long time with great reflection on public health and food security (Goodwin & Pascual, 2016). Bovine brucellosis was first reported in Zimbabwe in 1906, followed by Kenya in 1914 and the Orange Free State of South Africa in 1915 (Asmare *et al.,* 2010).

Through monitoring and eradication, various European Union countries have managed to successfully eradicate brucellosis. Despite ongoing eradication efforts, some countries (Spain and Portugal) are still endemic with brucellosis. Greece has one of the highest *Brucella* incidences worldwide (Goodwin & Pascual, 2016). The severe negative economic impact of brucellosis is associated with significant losses in animal production, reduced milk production, trade restrictions and increased public health costs related to diagnosis and treatment (Seleem *et al.,* 2010).

4. Diagnosis of brucellosis

The current methods used to diagnose human brucellosis are similar to those used for the diagnosis of the disease in livestock (Araj, 2010). As there are no pathognomonic signs of brucellosis in humans and livestock, diagnosis relies on laboratory testing. Diagnostic laboratory methods include milk and blood tests (indirect tests) and direct tests (conventional bacteriological tests and PCR-based assays). *Brucellae* are identified based

on their growth characteristics, and by serological, bacteriological and molecular methods. At present, the development of a conclusive method for the diagnosis of brucellosis seems an unattainable target (Getahun *et al.,* 2021).

Isolation of the bacterium by culture is a standard laboratory method for the definitive diagnosis of brucellosis. Milk, blood, vaginal discharge and parturition products are typically used as culture samples for the diagnosis of animal brucellosis. The polymerase chain reaction (PCR) is used for the detection of *Brucella* DNA in serum, whole-blood and fetal tissue samples from humans and animals (OIE, 2018). Blood is a source of DNA for the detection of *Brucella* infection. Also clinical specimens including serum, urine, synovial fluid and pus can be used for the diagnosis of brucellosis (Khan & Zahoor, 2018; Wang *et al.,* 2014; Queipo-Ortuño *et al.,* 2008).

PCR-based assays have a high specificity and reduced testing times. Serology is the most common laboratory method used for the diagnosis of brucellosis (Araj, 2010). The serum agglutination test (SAT), complement fixation test (CFT), ELISA, fluorescence polarization assay (FPA) and buffered *Brucella* antigen tests (Rose Bengal test (RBT) and the U.S. Card test) are the most commonly applied serological tests for the diagnosis of brucellosis in humans and livestock (Godfroid *et al*., 2010). The serum agglutination test is based on the reaction of a solution of *Brucella* whole-cell antigen with serum dilutions in tubes or microtiter plates. Large antigen-antibody complexes precipitate at the bottom of the tubes and plate wells, and are detected by dyeing. The major drawbacks of this test include the requirement of overnight incubation for the samples, low specificity, and the inability to diagnose chronic infections due to the detection of mainly IgM antibodies (Higgin, 2015).

The complement fixation test is an alternative available for the detection of IgG antibodies, but is generally used as a confirmatory assay (Khan & Zahoor, 2018). It is highly specific in comparison to the serum agglutination test, but requires the use of a large number of reagents. The buffered *Brucella* antigen test is performed using stained whole *Brucella* cells and involves encouraging agglutination by IgG antibodies over that by IgM antibodies, and has improved specificity as the antigen is used at an acidic pH. After the antigen mixture is combined with a serum sample on a plate, the resulting degree of agglutination is assessed over a period of several minutes (Higgin, 2015).

Buffered *Brucella* antigen tests offer the advantages of high sensitivity, easy application, and inexpensiveness (Higgin, 2015). The ELISA assays used for brucellosis diagnosis include the competitive (cELISA) and

indirect (iELISA) varieties. ELISA assays are highly specific and sensitive and are a perfect option for the diagnosis of chronic cases of brucellosis (Khan & Zahoor, 2018; Higgin, 2015).

The fluorescence polarization assay is a technology based on the measurement of molecule rotation. This test enables the diagnosis of infection, based on the fact that smaller molecules rotate faster in liquid media (Higgin, 2015). This test is performed by adding *Brucella*-positive serum to a fluorescently-conjugated *Brucella* antigen solution, such that the resulting large antigen-antibody complexes rotate slower than the unbound antigen. The alteration in the rotational speed of the fluorescent molecule is measured with polarized light (Higgin, 2015).

The fluorescence polarization assay is not only highly sensitive and specific in cattle, goats and humans, but also easy to perform, and can be applied on the field using handheld FPA instruments (Ramirez-Pfeiffer *et al*., 2006).

5. Prevention and control

It is required to adopt an effective approach for the eradication and prevention of bovine and human brucellosis. To date, success has been achieved in the control and eradication of brucellosis in some countries. For the eradication of animal brucellosis, the FAO has proposed preventing the spread of the disease among animals, culling infected animals, establishing and regularly monitoring brucellosis-free herds and regions, and implementing vaccination (Getahun *et al.,* 2021).

One of the most effective tools for the prevention of brucellosis in livestock is vaccination. Vaccination is highly relevant to the prevention of animal and human diseases (Yang et al., 2013). The prevalence of human brucellosis is directly related to the prevalence of bovine brucellosis, and currently no safe and effective vaccine is available for use in humans (Higgin, 2015).

The first step of vaccine development is a clear understanding of the natural host response to pathogens. As *Brucellae* are capable of infecting phagocytic and non-phagocytic cells and surviving long-term in them, antibodies do not provide full protection (Vitry *et al.,* 2014).

The host response induced by vaccination is strongly correlated with the formulation and administration of the vaccine. Several studies have been conducted on available vaccines with an aim to improve vaccine efficacy. The golden rules often recommended by experts are diagnosis, cure/eradication, and prevention. Effective vaccination, hygienic practices

and proper disposal of seropositive animals would reduce the prevalence of the disease in endemic regions (Li *et al.,* 2017; Nicoletti, 2010).

These three control methods are most effective when combined (Nicoletti, 2010). In view of the zoonotic character of brucellosis, farmers, field workers, and the local community in endemic regions need to be well informed (Khan & Zahoor *et al.,* 2018). Milk and other products should be pasteurized before consumption to prevent the spread of brucellosis. Furthermore, labware should be sterilized to prevent the infection of laboratory personnel (Roy *et al.,* 2011). Governmental programs generally include the culling of seropositive animals. Compensation payment for slaughtered animals is often absent and leads to livestock-holders not collaborating. Pre-movement tests implemented at local/international level are part of the disease control efforts (Nicoletti, 2010).

Vaccination is accepted as the most effective and readily applicable method of decreasing the occurrence of various diseases, including animal brucellosis. Live vaccines containing the *B. abortus* S19 and *B. melitensis* Rev 1 strains are reported to be most effective in cattle and sheep/goats, respectively. In some countries, strain RB51 has been altered with strain S19 (Nicoletti, 2010).

Not only is it relatively inexpensive to produce S19 and Rev 1, but these strains are also highly immunogenic. Although some vaccinated animals may not acquire full immunity, vaccination is reported to prevent the occurrence of clinical brucellosis and herd immunity exceeds 90% in cattle (Nicoletti, 2010). The effective control of brucellosis depends on various factors, including the spread of the disease, type of animal husbandry, vaccine availability and quality, and intersectoral collaboration (Nicoletti, 2010).

6. Treatment of brucellosis

Today, no brucellosis vaccines are available for humans, yet several vaccines are available for use in livestock (Głowacka *et al.,* 2018). Brucellosis rarely causes mortality and generally responds well to treatment (Głowacka *et al.,* 2018; Solís *et al*., 2015). Although the complex nature of the disease complicates treatment, long-term therapy with antimicrobials is considered useful (Khan & Zahoor *et al.,* 2018).

Brucellosis can be effectively treated only with antimicrobials that penetrate into macrophages and show activity in an acidic environment (Ranjbar, 2015). The use of a single antibiotic is not recommended for the treatment of brucellosis as it leads to the recurrence of the disease, but antibiotic combinations are reported to be more effective (Głowacka *et al.,* 2018; Moon *et al*., 2014; Pappas *et al*., 2006).

The combined use of two antibiotics is more effective than monotherapy against brucellosis (Głowacka *et al.,* 2018). A six-week treatment with oral doxycycline and rifampicin is recommended by the World Health Organization for acute brucellosis. While rifampicin monotherapy is recommended for treating pregnant women with brucellosis, the combined use of sulphamethoxazole and trimethoprim is recommended for the treatment of infected children (Khan & Zahoor *et al.,* 2018).

In clinical practice, various conventional antibiotics including tetracycline, aminoglycosides, trimethoprim sulfamethoxazole, quinolones, rifampicin, chloramphenicol, streptomycin, and doxycycline have found common use. While monotherapy with oxytetracycline, rifampin or doxycycline increases relapses (9-25%), extending the treatment period does not provide favorable results (Głowacka *et al.,* 2018).

Treatment should be aimed at preventing both the relapse of the disease and the development of secondary complications such as arthritis, spondylitis, and sacroilitis, and should also enable the quick relief of symptoms (Głowacka *et al.,* 2018). Treatment with doxycycline for six months, followed by the administration of streptomycin for three weeks has been reported to be very effective against human brucellosis (Yousefi-Nooraie *et al*., 2012). In conclusion, being a global public and animal health issue, brucellosis needs to be handled with utmost care. Vaccinating susceptible animals is the best way to reduce disease transmission and prevent economic losses. Effective surveillance and control strategies and the adoption of a standardized global approach are essential to brucellosis control.

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Chapter 2

TRANSPARENT WOOD: A NEW APPROACH FOR FUNCTIONAL AND STRUCTURAL APPLICATIONS

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INTRODUCTION

Wood has a unique structure as a structural material that grows naturally and has excellent mechanical properties (Eichhorn et al. 2001). Transparent wood is an invention that is first introduced in 1992 by Siegfried Fink, who transforms the wood into a transparent form in order to observe the structure of the wood. Although there has not been a sufficient amount of work on it since its inception, it has been reconsidered by the KTH Royal Swedish Institute of Technology (Li et al. 2016a) and University of Maryland working groups (Zhu et al. 2016b) between 2015 and 2016.

Cell walls of the wood are composed of ~3–5 nm diameter cellulose nano-elementary fibrils, lignin, pectin, and others (Xu et al. 2007). The strong hierarchical interaction among cellulose, hemicellulose and lignin gives the wood excellent mechanical properties. Recently, due to the nanostructure and excellent mechanical and optical properties of wood-derived cellulose nanofibers (CNF) and cellulose nanocrystals, it has received a great deal of attention in various fields of the electron, energy, and other applications (Chen et al. 2015). Although cellulose and hemicellulose are optically colorless, lignin is dark in color and has an extremely complex structure. In this case, wood can be made transparent with the help of polymers such as epoxy or PMMA resins (poly-methyl-methacryatel resins) by removing lignin by delignification and then infiltration of the polymer as a matrix instead of lignin. In general, it can be said that there are two steps of the process of transparent wood. As a first step, wood material becomes transparent after the color of the lignin removed. Then, as a second step, the sample lumens are vacuumed and filled with transparent polymers (PMMA, epoxy resin, etc.) with matching refractive indices. After the second stage, a transparent wood sample is obtained (Figure 1).

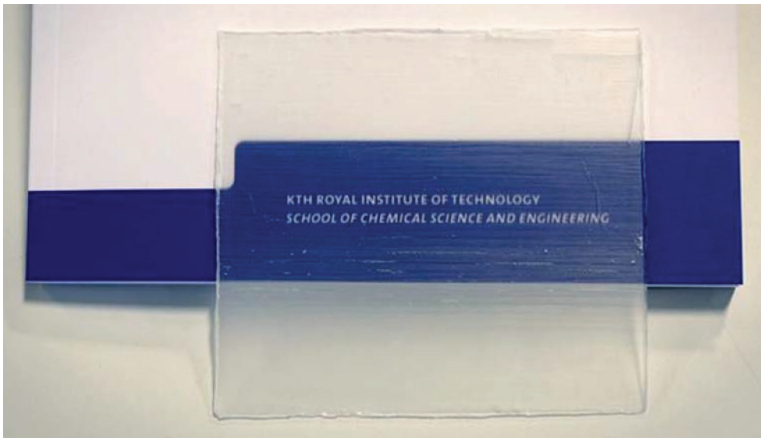


Figure 1. Transparent wood sample created at the KTH Royal Swedish Institute of Technology (Katunský et al. 2019).

Wu et al. (2020) produced transparent wood from six wood species (birch, Chinese fir, linden, New Zealand pine, okoumé, and black walnut) to investigate the colorimetric properties of transparent wood. The results show that the light transmittance was improved and the improvement in the highest mechanical performance of the transparent wood was about 40% when compared to the control group. It was also concluded that there was a good synergistic effect between wood and PMMA through scanning electron microscopy (SEM) and Fourier transform infrared spectroscopy (FTIR) analysis. Li et al. 2019 also mentioned that the mechanical strength of the transparent wood composite increased from 12.5 to 20.6MPa after infiltration of the epoxy resin. At the same time, the interfacial gap between the cell wall and the filled epoxy resin disappeared and the transmittance (wavelength 550 nm) increased from 80% to 87% since less light was absorbed by lignin.

TRANSPARENT WOOD FABRICATION

Different methods have been discussed in the transparency of wood. Transparent wood fabrication methods are based primarily on delignification followed by infiltration of a polymer with a refractive index matching that of wood (Li et al. 2016a). Delignification reduces the discrepancy between the light absorption of wood and the refractive index of the cell wall. Figure 2 shows a general illustration of how a wood block becomes a transparent structural material after polymer filling by the removal of lignin.

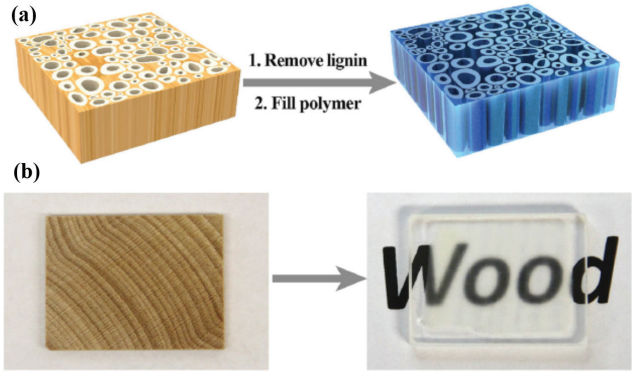


Figure 2. Illustration of how a wood block becomes a transparent wood: removing the lignin and filling with transparent polymers (a) and transparent wood after two steps (b) (Zhu et al. 2016b)

It has been observed in the literature that lignin can be removed by various solutions. These can be summarized in the followings: sodium hydroxide (NaOH) and sodium sulfite (Na_2S0_3), and subsequently in a hydrogen peroxide (H_2O_2) solution (Zhu et al. 2016); H_2O_2/HAc solutions

(Li et al. 2019); a peracetic acid solution (Fu et al. 2017); the combination of a sodium chloride ($NaClO_2$) solution (Gan et al. 2017), and a NaClO solution (Fink 1992).

Fink (1992), who first introduced the transparent wood fabrication, treated it with 5% aqueous sodium hypochlorite (NaClO) solution for 1-2 days to remove colored substances including lignin. Yano (2001) reported that lignin was removed from wood by sodium chloride ($NaClO_2$) treatment for 10 hours at 45 °C. Zhu et al. (2016) mentioned that lignin was removed by cooking in a NaOH (>98%) and Na_2SO_3 solution (>98%), followed by H_2O_2 (30%) to obtain a lignin content of less than 3%. Epoxy resin was used as a polymer for infiltration, whereas ethanol alcohol and deionized water were used as solvents. Li et al. (2019)developed a greener and more comprehensive H_2O_2 or H_2O_2/HAc steam-modified delignification approach, which eliminated the interfacial delamination gap between the cell wall of wood and the filled epoxy resin and removed more lignin. Thus, an increase in the number of pores has been observed, which would make the penetration of the epoxy resin more comfortable. As a result of this method, the amount of lignin decreased to 0.84%, whereas the amount of lignin was 1.9% as a result of delignification performed with solution-based methods.

Figure 3 shows the change in wood color from brown to white after delignification treatment. Wood is an opaque material due to its micro-scale porous structure, the different chemical components into its cell walls with different refractive indices. Light scattering occurs at all interfaces between the cell wall (refractive index about 1.53) and air (refractive index 1.0) (Fink 1992; Li et al. 2019). Differences in the refractive index of major chemical components such as cellulose (1.53), hemicellulose (1.53), and lignin (1.61) can cause light scattering (Fink 1992). In addition, due to the presence of light-absorbing components on the cell wall, strong light absorption from wood occurs. Previous studies have indicated that delignification is important because lignin accounts for 80-95% of light absorption in wood (Li et al. 2017). The light absorption of chemicals generally must be reduced or eliminated to make wood transparent. Light scattering at the air/cell wall interface and inside the cell wall should be minimized.

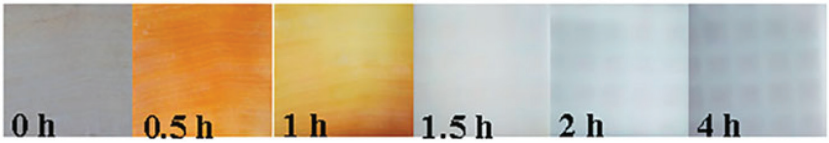


Figure 3. The color changes of basswood depending on the time (Li vd., 2019)

Different polymers show different viscosity, index of refraction, and shrinkage properties, affecting the preparation and properties of transparent

materials. Table 1 shows the polymers applied to make transparent wood in the literature and their refractive indices.

Tablo 1. Polymers and refractive indices applied to make wood transparent (Li et al. 2018)

Polymers	Refractive index
Diallyl phthalate and Polyvinylcarbazole	1.68
Polystyrene	1.59
Polyvinylpyrrolidone (PVP)	1.53
Dibutyl phthalate	1.52
Epoxy resin	approx. 1.50
Butyl methacrylate	1.50
PMMA	approx. 1.49
Isobornyl methacrylate	1.48-1.50

Previous studies show that the optical transmittance of wood samples decreases depending on the increase in thickness. While the highest optical transmittance value is 90% at 0.7mm thickness, it decreases significantly to around 40% at 3.7mm thickness (Karl'a 2019). The cutting direction of the wood blocks is also important in the transparency of the wood. Wood material cut in the radial direction has lumens perpendicular to the plane with the same depth as its thickness, whereas, in the longitudinal direction, the lumen depth is as long as the length of the wooden block. The microstructural difference leads to different mass transfer behaviors, where lignin can be removed much more easily from the radially cut sample due to the short depth lumen (Figure 4a). However, It would take much longer to remove lignin from wood cut in the longitudinal direction (Figure 4b).

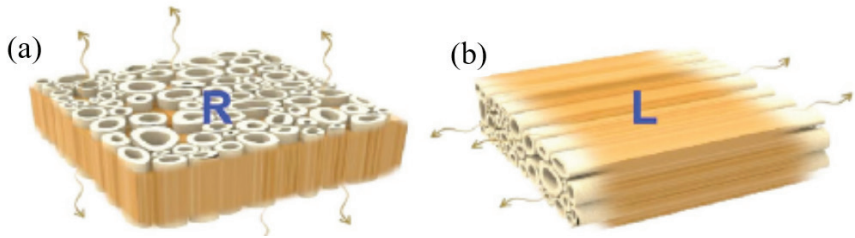


Figure 4. General configuration of two types of wood blocks: lumens in wood are perpendicular to the plane direction (a) and lumens in wood are along the plane direction (b) (Zhu et al. 2016b)

TRANSPARENT WOOD PROPERTIES

Table 2 summarizes how the optical and mechanical properties of transparent materials have changed when different woods and different polymers have been used. The mechanical properties are highly dependent on the wood species, density, ratios of the chemical components, cell structure morphology, annual ring structure, and the structural anisotropy of the wood (Li et al. 2018). The results in Table 2 show significant differences in the properties of transparent woods based on balsa, poplar, and beech impregnated with the same polymer (PMMA). Previous studies shows that in general the transparent wood has excellent mechanical properties. Yaddanapudi et al. (2017) investigated the fabrication and characterization of transparent wood for smart building applications. They mentioned that in general, the tensile strength and hardness of transparent wood were higher than delignified wood due to the enhanced interaction between the polymer and the cell walls of the wood. Zhu et al. (2016b) reported that the mechanical performance of transparent wood in the longitudinal cutting direction was twice that of the transparent wood in the radial cutting direction. However, higher optical transmittance and haze were obtained from the sample in the radial cutting direction.

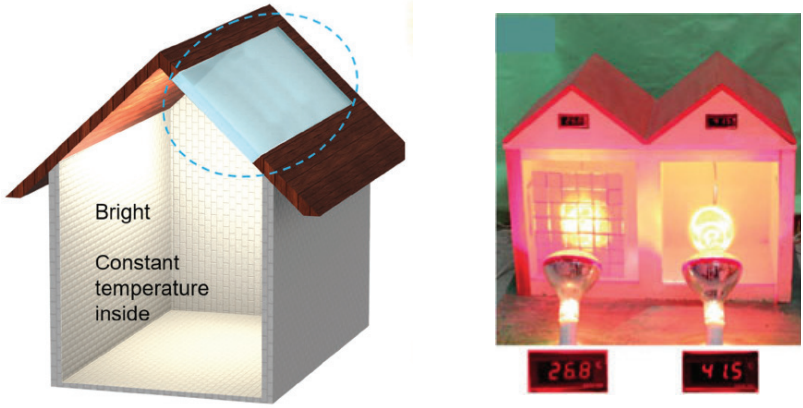
Transparent wood shows different optical properties with various thicknesses. The thinner sample has a higher optical transmittance (Katunský et al. 2019). In another word, optical transmittance decreases as wood thickness increases. Li et al. (2016a) found that a high optical transmittance value of 85% and haze of 71% were achieved when the transparent wood thickness was 1.2 mm. Yaddanapudi et al. (2017) reported that the maximum optical transmittance of 70% and the maximum haze of 49% were obtained for wood samples with a thickness of 0.1 mm and 0.7 mm, respectively. Li et al. (2016b) mentioned that the material has a high optical transmittance with an extremely high haze around 95% when compared to glass. They also mentioned that thermal conductivity significantly decreased as transparency increased. It means that the transparent wood could be a thermal insulation material for buildings.

Tablo 2. Summary of optical and mechanical properties of transparent wood in the literature

Reference	Wood species	Polymer	Wood cutting direction	Optical properties			Mechanical properties	
				Thickness (mm)	Transmittance (%)	Haze (%)	Elastic modulus (GPa)	Tensile strength (MPa)
Li et al. (2016a)	Balsa	PMMA	Longitudinal	0.7	90	~50	3.59	90
				3.7	40	~80		
Li et al. (2016b)	Basswood	Epoxy resin	Radial	5	90	95	—	—
Zhu et al. (2016a)	Basswood	PVP	Radial	1	90	80	—	11.7
Zhu et al. (2016b)	Basswood	Epoxy resin	Radial	2	90	~95	1.22	23.38
			Longitudinal	—	~80	~85	2.37	45.38
Gan et al. (2017)	Poplar	PMMA	Radial	0.5	86.1	—	2.66	45.92
Yaddanapudi et al. (2017)	Beech	PMMA	Radial	0.1	70	—	2.5	150
				0.3	30	18		
				0.6	15	40		
				0.7	10	49		
Yu et al. (2017)	Beech	PMMA	Longitudinal	5	86	90	2.67	60.1

APPLICATIONS

Transparent wood can be used in a variety of fields, from everyday use such as wooden furniture to advanced application fields such as structural materials for automobiles and optoelectronics (Fink 1992). Smart buildings or load-bearing structures with photonic capabilities can be included in the interesting application areas since transparent wood has low density, high optical transmittance and haze, good mechanical properties (Li et al. 2018). Building applications can be considered where a transparent wooden roof can provide more uniform and consistent lighting throughout the day. The roof of a house can be designed with a transparent roof in order to achieve a comfortable lighting condition and more constant ambient temperature as seen in Figure 5a. Li et al. (2018) mentioned that the transparent wooden windows have a lower temperature rise than glass windows. Therefore, it can be considered as a special window of energy saving (Figure 5b).



(a) **(b)**

Figure 5. An example of a house with a transparent roof for easy lighting and warmth (a) (Li et al. 2016b) and an example of a model house showing temperature changes after 10 minutes of exposure to simulated sunlight: transparent wood on the left and glass on the right (b) (Li et al. 2018)

Building panels made of transparent wood have lower thermal conductivity, better impact strength, and lower density compared to glass. Zhu et al. (2016a) also mentioned that when the transparent wood was used on top of the solar cells, the efficiency of the solar cell improved by 18.02%. Research on transparent wood is progressing rapidly although it has just begun. Transparent wood is becoming more environmentally friendly and easier to obtain a material with the developments in production technology. However, there are some criticisms about the chemicals used in lignin removal, transparency only at low thicknesses, and optical haze (Li et al. 2016a; Zhu et al. 2016b; Li et al. 2018). Therefore, it is important to carry out studies on the production of transparent wood with more advanced optical properties and higher thicknesses.

CONCLUSION

Today, with the increase in population, energy consumption in residential and commercial buildings is increasing around the world. Therefore, it should be aimed to reduce energy consumption in buildings by improving the thermal performance of the material. The lower thermal conductivity of transparent wood compared to glass increases energy efficiency and provides good thermal resistance. As a result, transparent wood has many advantages. The fact that this subject creates a new field of study and the limited publications on this subject could increase the interest in transparent wood in the near future. Making wood transparent can be tried, especially on species with low economic value, and it is predicted that the good results of the studies may lead to an increase in interest in these species and to become sought-after species in the industry.

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Chapter 3

THE CONCEPT OF GROWTH POTENTIAL IN TURFGRASS AND THE RELATIONSHIP BETWEEN TEMPERATURE-NITROGEN

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Introduction

As a result of the rapid increase in the world population, cities are developing and the need for new building stock is increasing to meet the growing demand. With intensive construction, this demand is met in an unplanned way, and irreversible mistakes are made in land use. Our cities are becoming a socially and culturally inadequate artificial environment for human life, far from natural areas, resulting in significant problems in various aspects. However, our cities need to be places used to meet the housing, industrial, commercial, cultural, artistic, and recreational needs of all residents living in them. Intensive construction has revealed the importance of urban green spaces, especially turf areas, that creates surface texture. Especially in recent years, thanks to advanced technologies in the construction industry, high and densely-populated buildings have emerged in cities and it has become important to create urban green areas that can meet the needs of the people living there (Altan, 1989). A variety of trees, shrubs, and ground cover crops are used to create urban green spaces, utilized in detached home gardens, large gardens on building complexes, and city parks. Among the plants used as ground covering plants in these green areas, some plants in the family Poaceae, also known as "turfgrass" are the most common ones (Orcun, 1979). In other words, turf areas are defined as artificially formed green surfaces, which develop rapidly by covering the soil surface, have a homogeneous look, and are kept short by constant mowing; and where plant communities belonging to the Gramineae (Poaceae) family are located (Beard, 1973; Avcioglu, 1997; Demiroglu Topcu and Ozkan, 2016a) (Figure 1).

Turf areas can absorb the sun's rays during the day and directly affect their environment by keeping the radiation they collect during the day at night hours (Beard, 1973). Furthermore, the loss of water by transpiration from the turfgrasses causes a decrease in ambient temperature of up to 5°C in summer. Therefore, a successfully formed 1 m^2 of turfgrass surface includes approximately 4.000 plants and functions as air conditioning in the environment where they are located due to their positive energy absorption properties. When the same surface is formed with concrete, the temperature difference can be more than approximately 20-25°C (Uzun, 1989; Avcioglu, 1997). Turf area, a natural oxygen producer, consume carbon dioxide in the atmosphere, as well as regularly transferring rain and snow water to groundwater. In addition, it has a positive effect on human psychology by enabling recreational activities thanks to the green spaces it creates. They reveal bush and tree masses with their soft texture and create contrasts in terms of color and construction (Karaguzel, 2007; Gurbuz, 2010).

To create a qualified and sustainable turf area attention should be paid to many issues such as the choice of plants to the purpose of use, the environment to grow, and the awareness of the acceptable level and appearance of sustainability (Harivandi et al., 2001). Because each genus and species of turfgrass have positive and negative properties as well as strengths and weaknesses. Under different ecological conditions, these properties should be well-known and researched (Beard, 1973; Avcioğlu, 1997). The origins, forms, properties, growing methods, ecological demands, techniques of pest and disease control, and ideal care procedures of these plants should be known in detail (Ucucu, 1993). Incorrect care procedures in turf areas, for example the application of fertilizer in an excessive amount and at the wrong time causes not only economic losses but also problems that cause environmental pollution.

Figure 1. *Some photos of turfgrass (original)*

The environment is defined as the whole of climate, soil, orographic and biological factors, and affects all living things in it. Turfgrass can form qualified and sustainable vegetation when they adapt to the conditions in full harmony with the environment in which they are grown (Danneberger and Code, 1993). In our country, which has a variety of different ecological conditions, there is a misconception that the same turfgrass genus and species can be applied to almost every region. Region-specific turfgrass

options should be considered in our regions with similar characteristics, taking into account the adaptation abilities and ecological demands of turfgrass according to scientific rules (Demiroglu Topcu and Ozkan, 2016a). At present, there are many genus, hundreds of species, subspecies, and varieties found in world markets and used in the different ecologies of different countries. Moreover, many new varieties are added to them every year. The selection of the most suitable genus, species or variety for establishing a good turf area is of great importance.

Types of Turfgrass

Turfgrass are classified as cool (C3) and warm (C4) season turfgrasses according to their physiological characteristics. Cool season turfgrasses grow successfully in warm or cold environments, while warm season turfgrasses grow successfully in tropical or subtropical environments (Bell, 2011; Christians et al., 2016). Figure 2 shows shoot growth models of cool and warm season turfgrasses according to the seasons (Ghali, 2010).

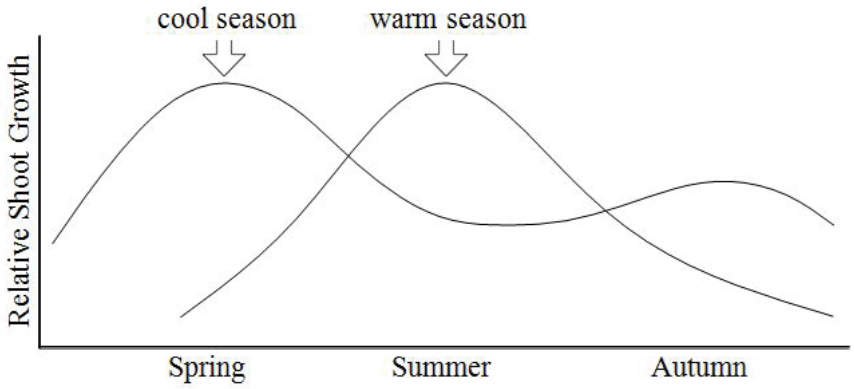

Figure 2. *Shoot growth patterns of cool and warm season turfgrasses (Christians et al., 2016)*

Many cool season turfgrasses are used in cool-wet, cool-sub-humid, and cool-semi-arid climates in worldwide and the transition climates located between them (Bonos and Huff, 2013). Warm season turfgrasses, on the other hand, need more heat than cool season turfgrass types, starting from the germination stage, especially during growth and development periods (Beard, 1973, Duble, 1996; Hanna et al., 2013). In our country, it is defined as turfgrasses that can be grown in climatic conditions where citrus and olive cultivation can be done practically (Acikgoz, 1994; Avcioglu, 1997). The most important difference of these plants from cool season turfgrasses is that they develop closer to the soil surface, have deeper root systems, resistant

structures to short mow, traffic and wear tolerances, and especially more resistance to temperature and drought. Although cool season turfgrasses are grown with seeds, the growing of many warm season turfgrasses mostly with vegetative parts (stolon, rhizome, etc.) stands out as another notable difference (Casler and Duncan, 2003).

Today, in hot and warm climates, many different types of turfgrasses are widely used on many areas, from home gardens to sports fields. Some warm season turfgrasses are becoming increasingly important because they can be grown in hot or semi-arid climatic conditions where irrigation is not available or can be irrigated in limited quantities (Hanna et al., 2013). There are also species with special values used in problematical areas that require land protection measures, such as airports and road slopes (Turgeon and Kaminski, 2019).

The Effect of Temperature on Turfgrass

Like all living organisms, temperature is an indispensable environmental factor in the vital functions of turfgrass such as the continuity of their metabolism. The temperatures that various plants in the plant kingdom need during different periods of growth and development differ from each other (Salisbury and Ross, 1992; Turkkan, 2008). The effects of temperature on turfgrass begin at the germination phase. Seeds of different genus and species need different degrees of temperatures to germinate and grow (Beard, 1973; Avcioglu, 1997). For example, the soil temperature for germination should be at least 5°C for cool season turfgrass and in the range of at least 12-15°C for warm season turfgrass. Similarly, the most suitable environment for germination of seeds of cool season turfgrasses occurs when the soil temperature rises up to 15-20°C. These values are in the range of 25-30°C for warm season turfgrasses. After germination stage and first shoots growth, it is enough that the air temperature is between 16-24°C for the growth and development of the aboveground parts of cool season turfgrasses to be optimal. However, this value should be in the range of 27-35°C for warm season turfgrasses. The best root growth achieve at temperatures between 10-18°C in cool season turfgrasses and 25-30°C in warm season turfgrasses (Duble, 1996; Bonos and Huff, 2013; Hanna et al., 2013).

Turfgrasses often show their ability to maximum grow and develop at high temperatures. However, the highest level of uniformity, density and attractive color characteristics of the vegetation in the turf areas are often achieved at temperatures lower than the specified optimum values. Because at these temperatures (10-15°C) and especially in cool season turfgrasses, although the growth rate of the plants decreases, the quality characteristics expected in a turf area increase due to emerge turf cover

with abundant leaves, dense texture and dark green color (Beard, 1973; Acikgoz, 1994; Avcioglu, 1997).

High temperatures, whose effect is seen especially in the summer season, cause great damage along with drought as well as disease and pest effects. This situation is more common in cool season turfgrasses than warm season turfgrasses (Beard, 1973). Therefore, the use of cool season turfgrasses in Aegean and Mediterranean regions which have warm climatic conditions, is limited. In these regions of Turkey, cool season turfgrasses such as *Agrostis*, *Poa*, *Lolium* and some *Festuca* species need to be used carefully and in limited amounts, as they are quickly damaged by high temperatures (Demiroglu et al., 2010; Kir et al., 2010; Demiroglu Topcu and Ozkan, 2016a).

High temperatures cause significant damage during the germination phase of the seeds. With the help of the dryer effect of the soil, the germination process extends and this situation often reduces the germination rate (Beard, 1973; Beard, 2002). The reactions of turfgrass to high temperatures during later periods of growth and development vary according to the environment in which they grow, the age of the plant, and the different tissues they have (McCarty, 2018). For example, in turf areas that are grown under shade conditions, are fertilized in quantities suitable for their needs or mowed high, damages due to excessive temperatures are less common (Dudeck and Peacock, 1992; Bell, 2011; Demiroglu Topcu and Ozkan, 2016b). In turfgrass plants, dormant growth points at the nodes of stolons and rhizomes, and dormant meristem tips on the root crown of mature grasses are defined as the most durable and productive tissues (Bell, 2011). Besides, the seeds of turfgrass can maintain their vitality for a long time at temperatures up to 40-45°C. At higher temperatures, they lose their germination ability in proportion to the exposure time to the high temperatures (Beard, 1973).

Damage to turf areas caused by high temperatures is observed mostly together with drought damage. This situation leads to a decrease in the number of shoots along with the slowing of the growth of turfgrass plants, shrinking and curling of the leaf blades, and darkening of their color to a blue-green color. Due to high temperature and drought stress, turfgrass plants become increasingly brown over time, and a bad appearance emerges because new leaves are not formed. In addition, the root development of turfgrass plants also slows down (Huang, 2003; Bell, 2011).

Different turfgrass genus and species vary widely in terms of resistance to high temperatures. Cool season turfgrasses stop growing at extreme temperatures seen in summer, entering the sleep period and protecting themselves from adverse conditions. Warm season turfgrasses

are usually not damaged by high temperatures when there is enough water in the environment in which they are grown, and this can even have a positive effect up to certain extreme temperature values (Beard, 1973; Avcioglu, 1997; Bonos and Huff, 2013; Hanna et al., 2013).

Biochemical reactions symbolizing the metabolic events in plants are actually closely related to the ambient temperature at which they are grown. In cases such as a decrease in ambient temperature or sudden cooling of the ambiance, these functions first slow down and then stop (Salisbury and Ross, 1992; Turkkan, 2008). In particular, growth and development in warm season turfgrasses decelerate at temperatures below 15°C and completely stop at temperatures below 10°C. Significant negative reactions occur at temperatures below 0°C in cool season turfgrasses (Beard, 1973; Duble, 1996; Avcioglu, 1997).

Cold tolerance is generally considered important for cool season turfgrasses. Because warm season turfgrasses such as *Cynodon dactylon*, *Zoysia japonica*, *Stenotaphrum secundatum*, etc. cannot withstand prolonged colds below 0°C seen in absolute continental climates. For these plants, resistance to low temperatures between 0-5°C in short-day conditions, which includes an insolation period of 7-8 hours, is considered important. They are protected by the winter dormancy system at lower temperature values (Beard, 1973; Avcioglu, 1997; Trenholm, 2000; Bell, 2011).

There are some factors that are effective in terms of the cold tolerance of turfgrass plants. For example, cold tolerance is closely related to the seasons. Spring and early autumn are the most risky periods, while endurance is maximized during periods of late autumn and winter dormancy when growth slows down. The maturity period of the plant is also effective on the tolerance to cold. Although plants old enough and with good development have high endurance, plants that are young and have not yet shown thorough rooting and tillering, and that have not formed enough leaves, are affected more quickly by low temperatures. Different parts of turfgrass plants also show different resistance to the cold. Older tissues are less damaged than young tissues, while leaves and roots are less resistant to cold damage than stems. The stolon and rhizome parts are known as the most durable plant organs. Moreover, the lowest level of temperature and the rate at which temperatures fall, directly affect the resistance to cold. Cold damage is also less common if the ambient temperature gradually decreases. The duration of exposure of plants to low temperatures, and the rate at which temperatures rise again, are other factors affecting cold tolerance. In particular, a fast increase in temperatures causes massive damage to plants. Since some turfgrasses have short stems, small-thick and dark green colored leaves, and exhibit a lateral growth, their resistance

to low temperatures is very good. In addition, the morphological structures of plants, including feathers, a wax layer, and a thick cuticle layer, also play an important role in cold tolerance. In turf areas, snow cover is also seen as an important factor that prevents cold damage. Due to this layer of protective cover, plants are minimally exposed to cold damage because the temperature in the environment does not fall below 0°C (Beard, 1973; Avcioglu, 1997; Trenholm, 2000; Bell, 2011).

The Concept of Growth Potential in Turfgrass

In order to be understand why the performance of turfgrass differs in every one of the regions and even yearly, it is necessary to have sufficient knowledge about the growth requirements of cool and warm season turfgrasses. It is possible to obtain sustainable turf areas only in light of this information (Dudeck and Peacock, 1992; Beard, 2002; Gelernter and Stowell, 2005; Woods, 2013). The turfgrass plants using the C3 photosynthetic pathway are called cool season turfgrass and show their growth and development most quickly at a temperature of 16 to 24°C (Beard, 1973; Duble, 1996; Bonos and Huff, 2013). The turfgrass plants using the C4 photosynthetic pathway, on the other hand, can also photosynthesize efficiently at high temperatures. For this reason, they are called warm season turfgrass and expected to their grow and develop in the fastest an average temperature range of 27 to 35°C (Beard, 1973; Duble, 1996; Hanna et al., 2013). In addition to temperature, the amount of nitrogen in the leaf, water status of the plant, and photosynthetically active radiation (PAR) affect turfgrass growth. These four factors "temperature, nitrogen, water and light" essentially directly control the growth and development characteristics of turfgrass plants (Beard, 1973; Avcioglu, 1997; Casler and Duncan, 2003; Woods, 2013; Christians et al., 2016). Although turfgrass growers can easily control the amount of nitrogen and water in the environment, they have little chance of intervention when it comes to temperature or light (Woods, 2013).

By estimating the growth potential of plants, the effect of temperature on turfgrass growth at any given time can be estimated. Knowing or predicting the impact of something uncontrollable provides great convenience to turfgrass growers in determining and implementing turf care practices. Today, turfgrass growers in charge of sports fields such as especially golf courses and football fields, often benefit from the concept of growth potential in turfgrass (Gelernter and Stowell, 2005; Woods, 2013).

Turfgrass growth potential is very useful in turf management. Based on optimum temperatures for healthy growth and development of turfgrass plants, it is possible to model their possible growth potential at any temperature. The development of a turfgrass growth model that

makes it easy to understand and explain the nature of the turf culture and maintenance is based on the principle of utilizing its interaction between weather and turf performance. Turfgrass growth potential takes a value between 0 and 1. A value of 0 means that growth is not possible, and a value of 1 shows that the temperature is most suitable for the growth of that plant. Additionally, these values can also be defined in percentages (%). On this scale, it can be expressed with values between 0-100% (Gelernter and Stowell, 2005; Woods, 2013). Determining the growth potential value in cool or warm season turfgrasses as 100% means that temperatures are ideal for these turfgrasses and growth and development are optimally realized (Figure 3). According to the growth potential model, when the growth potential is between 50% and 100%, it is accepted that the growth of turfgrass is good. However, when air temperatures are higher or lower than optimum values, the growth potential value declines below 50%. This situation means that turfgrass plants are beginning to be exposed to stress conditions. When the growth potential drops to 10% or less, it is accepted that growth is extremely limited and it stops completely at 0%. In Figure 3, it is seen that the growth potential of cool season turfgrass reach 100% when the air temperatures are 20°C. When the temperature is higher or lower than 20°C, the growth potential decreases. Warm season turfgrass exhibit a similar situation. The optimum growth potential reached at a temperature of 31°C decreases when the air temperature is above or below 31°C.

Growth potential is a simple way to predict growth. A more complex growth model requires the unavailable knowledge such as the maximum potential growth rate for a particular type of turfgrass, the effect of minimum temperatures, water content of plant, leaf nitrogen content, and photosynthetic radiation in the unit area in the growth. Temperature-based growth potential is simplified knowledge. However, it is easy and highly effective to use it in the creation and care applications of turf areas as a planning and management tool (Gelernter and Stowell, 2005; Woods, 2013).

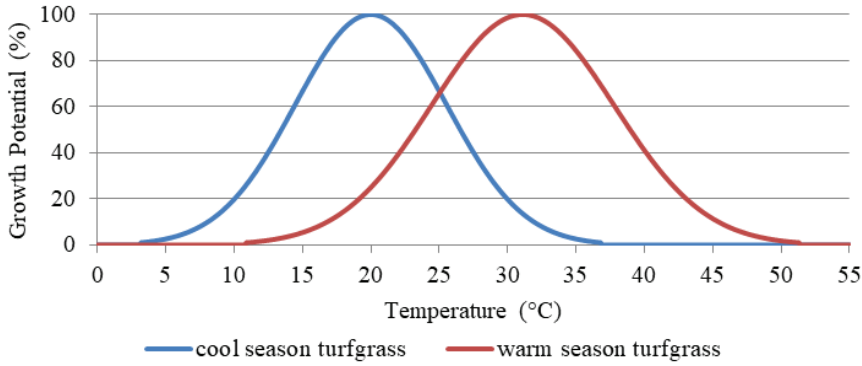

Figure 3. *Growth potential (%) of cool and warm season turfgrass at different air temperatures*

The Calculation of Growth Potential in Turfgrass

Turfgrass growers know that different turfgrass need to be grown in different climatic conditions, or that the growth rates of plants change as temperatures change throughout the year. The basis of turf management is directly related to the ability to control the growth rate of turfgrass. Therefore, determining the effect of temperature on growth is quite useful. This is possible with the concept of growth potential (Woods, 2013). Growth potential has been developed to describe the relationship between turfgrass growth and temperature (Gelernter and Stowell, 2005). In simplest terms, growth potential is a way of expressing the ability of turfgrass plants to grow at a certain temperature as a numerical value. The original formula created to calculate the growth potential in °F compares the actual temperature with the optimum temperature for growth and then converts it into a value between 0 and 1 (Figure 4).

$$GP = 100 \left[e^{\left[\frac{1}{2} \left[\frac{obsT - opT}{sd} \right]^2 \right]^1} \right]$$

GP = growth potential in turfgrass, on a scale of 0 to 1

obsT= observed temperature for a location, in °F

opT = optimum turf growth temperature, in °F

sd = standard deviation of the distribution (sd C3 turfgrass: 10 and sd C4 turfgrass: 12)

e = natural logarithm base 2.718282…

Figure 4. *The calculation of growth potential in turfgrass*

Table 1. *Growth potential (%) of cool and warm season turfgrass at different air temperatures*

Air Temp (°C)	Cool Season (%)	Warm Season (%)	Air Temp (°C)	Cool Season (%)	Warm Season (%)	Air Temp (°C)	Cool Season (%)	Warm Season (%)	Air Temp (°C)	Cool Season (%)	**Warm Season (%)**
0.0	0.0	0.0	**13.0**	45.2	2.5	**26.0**	55.8	74.5	**39.0**	0.0	49.7
0.5	0.0	0.0	**13.5**	50.4	3.1	**26.5**	50.4	78.7	**39.5**	0.0	45.3
1.0	0.0	0.0	**14.0**	55.8	3.7	**27.0**	45.2	82.7	**40.0**	0.0	41.1
1.5	0.0	0.0	**14.5**	61.3	4.5	**27.5**	40.2	86.4	**40.5**	0.0	37.1
2.0	0.0	0.0	**15.0**	66.7	5.4	**28.0**	35.5	89.7	**41.0**	0.0	33.3
2.5	0.0	0.0	**15.5**	72.0	6.4	**28.5**	31.0	92.6	**41.5**	0.0	29.7
3.0	0.0	0.0	**16.0**	77.2	7.7	**29.0**	26.9	95.1	**42.0**	0.0	26.3
3.5	1.2	0.0	**16.5**	82.0	9.1	**29.5**	23.2	97.1	**42.5**	0.0	23.2
4.0	1.6	0.0	**17.0**	86.4	10.6	**30.0**	19.8	98.6	**43.0**	0.0	20.4
4.5	2.0	0.0	**17.5**	90.4	12.4	**30.5**	16.8	99.6	**43.5**	0.0	17.8
5.0	2.6	0.0	**18.0**	93.7	14.5	**31.0**	14.1	100.0	**44.0**	0.0	15.4
5.5	3.3	0.0	**18.5**	96.4	16.7	**31.5**	11.7	99.8	**44.5**	0.0	13.3
6.0	4.2	0.0	**19.0**	98.4	19.2	**32.0**	9.7	99.1	**45.0**	0.0	11.4
6.5	5.2	0.0	**19.5**	99.6	21.9	**32.5**	8.0	97.9	**45.5**	0.0	9.7
7.0	6.5	0.0	**20.0**	100.0	24.9	**33.0**	6.5	96.1	**46.0**	0.0	8.3
7.5	8.0	0.0	**20.5**	99.6	28.2	**33.5**	5.2	93.8	**46.5**	0.0	7.0
8.0	9.7	0.0	**21.0**	98.4	31.7	**34.0**	4.2	91.0	**47.0**	0.0	5.8
8.5	11.7	0.0	**21.5**	96.4	35.4	**34.5**	3.3	87.9	**47.5**	0.0	4.9
9.0	14.1	0.0	**22.0**	93.7	39.3	**35.0**	2.6	84.4	**48.0**	0.0	4.0
9.5	16.8	0.0	**22.5**	90.4	43.4	**35.5**	2.0	80.5	**48.5**	0.0	3.3
10.0	19.8	0.0	**23.0**	86.4	47.7	**36.0**	1.6	76.4	**49.0**	0.0	2.7
10.5	23.2	0.0	**23.5**	82.0	52.1	**36.5**	1.2	72.1	**49.5**	0.0	2.2
11.0	26.9	1.1	**24.0**	77.2	56.6	**37.0**	0.0	67.7	**50.0**	0.0	1.8
11.5	31.0	1.3	**24.5**	72.0	61.2	**37.5**	0.0	63.2	**50.5**	0.0	1.5
12.0	35.5	1.6	**25.0**	66.7	65.7	**38.0**	0.0	58.6	**51.0**	0.0	1.2
12.5	40.2	2.0	**25.5**	61.3	70.2	**38.5**	0.0	54.1	**51.5**	0.0	0.0

To calculate the growth potential with the help of the formula given in Figure 4, turfgrass growers can used the monthly average temperature data of their location. In sports fields such as golf course, football pitch etc., the values of the instant growth potential of turfgrass can also be calculated by using the data obtained from the meteorological stations usually within their institutions. According to formula, the calculation of growth potential starts by determining the median of the optimum temperature range. Since the optimum growth and development temperature for cool season (C3) turfgrass is in the range of 16 to 24°C, its median is 20°C. For warm season (C4) turfgrass with the most appropriate growth and development temperature being between 27 and 35°C, this point is 31°C. As the temperature moves away from the optimum level, the potential of grass plants' growth speed decreases (Figure 3). Although the growth of cool season turfgrass decreases when the temperatures increases beyond

the optimum range, there is no such decrease in warm season turfgrass. Because photorespiration does not occur, and the "actual" growth of warm season turfgrass remains constant or increases further as the temperature rises above the optimum range. The average daily temperature remains mostly within the optimum range, even in the hottest locations where turf growing is carried out. Therefore, this is not very important for the practical use of growth potential. The growth potential data calculated for certain temperature values (°C) are given in Table 1.

The Nitrogen Fertilization in Turfgrass

In 1804, the most important foundations of plant nutrition were defined by the German chemist Justus von Liebig. Accordingly, it was determined that plants needed the nutrient elements C, O, H, N, S, P, K, Ca, Mg, and Si for their development. Plant nutrition made significant progress in parallel with developments in other basic and applied sciences in the 19th and 20th centuries, eventually arriving to its current level (Kahraman, 2012).

In recent years, the use of chemical fertilizers has increased rapidly in our country as in all countries around the world with the "The Green Revolution" (Kacar and Katkat, 2011). This situtation is also frequently seen in turf areas. So, an important reason why quality and sustainable turf areas cannot be obtained is intensive and excessive fertilization. Adequately meeting the requirements of turfgrass plants from the fertilizers used is closely related to the correct determination of the amount of fertilizer to be given along with other factors of soil, plant, and climate (Landschoot, 2003). In fact, the most fundamental condition of success in fertilization is to meet the nutritional needs of turfgrass plants throughout all seasons and to be able to make conscious and balanced fertilization taking into account the environment and human health while achieving this. With fertilization at its highest effectiveness, fertilizer costs and nutrient element losses in the soil can be significantly reduced, and high-quality turf areas can be obtained (Lawson and Skogley, 1996; Avcioglu, 1997).

In optimum environmental and temperature conditions, there is an increase in the shoot and root development of plants. Therefore, an increased root development of plants causes a higher water and nutrient intake from the soil. However, the decrease in permeability and transpiration of plant stem cells at low temperatures causes the intake of nutrient elements by the roots to decrease. Also, the movement of nutrients in the soil (diffusion and mass flow) and their transport to the root zone are slowed down at low-temperatures. In some cases, even if there are enough plant nutrient elements in the soil, plants cannot make sufficient use of these nutrient elements due to low temperature. On the other hand, the intake of nutrient elements by plant roots increases up until 40°C, and over this temperature,

the intake of nutrient elements rapidly decreases (Salisbury and Ross, 1992; Turkkan, 2008; Kahraman, 2012).

Plant nutrients requests, intakes and usage activities of different turfgrass species and varieties may vary. Newly developed varieties of turfgrasses in recent years are also known to benefit more from nutrients than older varieties. In addition to turfgrass species and varieties, many plant characteristics such as the development status of turfgrass plants, root length and thickness are also important factors in nutrient intake (Marschner, 1995; Duncan and Carrow, 1999).

The nitrogen element, which is necessary for all living things, is also the plant nutrient element that turfgrass plants need most (Beard, 1973). Although abundant in the atmosphere, it is in a limited amount in the soil and can be used by plants mostly after conversion to nitrate (NO_3^-) or ammonium (NH_4^+) through microorganisms or industrial processes (Kahraman, 2012). Therefore, nitrogen fertilizer should be applied regularly to create a high-quality turf area and ensure its sustainability (Landschoot, 2003; Bell, 2011).

Although nitrogen fertilization is required for sustainable turf areas, over-use of it causes contamination in under-ground and surface waters through leakage and flow (Van Noordwijk and Cadisch, 2002). Increased nitrate concentrations in drinking water poses risks, especially to babies, pregnant and breastfeeding mothers, and young children. The contamination of nutrients into the surface waters (eutrophication) causes algae to grow due to the mixing of nitrogen into the water, intensive growth of aquatic plants, depletion of oxygen, and the death of fish in the further stages (Fletcher, 1991; Olsthoorn and Fong, 1998). Ultimately, this can accelerate the deterioration of ponds, lakes, coastal bays, and estuaries (Landschoot, 2003).

The nitrogen element has an active and dynamic structure. Therefore, nitrogen fertilizers should be given in the appropriate periods according to the needs of the plant to prevent them from being washed from the soil or lost in gas form (Kacar and Katkat, 2011). The basic principle in nitrogen fertilization in turfgrass plants is that turfgrass plants need nitrogen almost the entire time they are grown due to their regular mowing, and therefore it is necessary to provide nitrogen to these plants continuously (Beard, 1973; Avcioglu, 1997). If the nitrogen needed by turfgrass plants is given to the soil at once or in large quantities, a significant loss of nitrogen in gas form or due to washing is inevitable (Bell, 2011). Furthermore, excessive nitrogen application at one time causes a salt effect. Therefore, some of the required amounts of nitrogen fertilizer in sowing or planting should be applied as a starter fertilizer, while the rest should be given by dividing it into at least a few parts according to the growth phases. Especially in

light textured soils, nitrogen loss occurs at much greater levels (Pessarakli, 2007; Sorochan, 2010).

In cases where plants cannot meet their nitrogen needs, a pale light green cover appearance usually occurs in turf areas. In cases of advanced deficiency, a homogeneous yellowing begins in the environment (Emmons and Rossi, 2015). Nitrogen deficiency adversely affects the vegetative development of the plant, especially by causing the weakening of shoots and accordingly shortens the period of vegetative development (Salisbury and Ross, 1992; Turkkan, 2008). It causes earing and premature aging of plants, which is one of the most undesirable situations in turf areas (Bell, 2011).

Excessive nitrogen fertilization causes plants to become a dark blue-green color (Beard, 2002). Excessive nitrogen use promotes vegetative development, which increases tillering in turf areas where Poaceae family are heavily used, causing the number of shoots in the unit area to increase above the desired level (Fry and Huang, 2004). Besides, nitrate, which is found in excessive quantities in plants, causes chlorosis and necrosis to be seen on the leaf edges, and the leaf edges curl downwards in the form of reverse bowls (Salisbury and Ross, 1992; Bell, 2011).

Estimation of Nitrogen Requirements of Turfgrass by The Concept of Growth Potential

As in all countries of the world, fertilizers containing nitrogen have the largest share among the chemical fertilizers used in our country and serious amounts of nitrogen are added to the soil every year. Depending on soil properties, fertilizer type, plant type, climatic conditions, etc., the annual amounts of nitrogen added to soil with chemical fertilizers vary (Kacar and Katkat, 2011; Kahraman, 2012). One of the applications that can benefit from the concept of growth potential is estimating when and how much nitrogen the grass plants can use (Woods, 2013). As is known, the growth potential takes a value between 0 and 1 (Gelernter and Stowell, 2005). Therefore, when the maximum amount of nitrogen that any turfgrass can use under optimum conditions in a day, a week or a month is known, by multiplying this value with the growth potential value in that time period, the amount of nitrogen needed can be determined (Woods, 2013). By determining the maximum amount of nitrogen that turfgrass can use over any period, the estimated use of nitrogen can be reduced as the growth potential decreases. Thus, it is thought that excessive nitrogen use can be prevented by taking advantage of the growth potential for sustainable turf areas.

The concept of growth potential is based on the optimum temperatures needed by cool (C3) and warm (C4) season turfgrass plants

for photosynthesis (Gelernter and Stowell, 2005). For maximum root growth and carbohydrate production, turfgrass plants must be fertilized with sufficient amounts of nitrogen corresponding to their ability to photosynthesize (Cook, 1966; Hull, 1992; Petrovic et al., 2005). The maximum amount of nitrogen that a turfgrass plant can use in optimal conditions varies depending on the region and the species or varieties of turfgrass grown (Beard, 2002; Pessarakli, 2007; Bell, 2011; Christians et al., 2016). Therefore, it is necessary to determine it by scientific studies specific to the turfgrass plants planned to be grown in the region (Avcioglu, 1997). By multiplying the data obtained with the growth potential values, the maximum nitrogen requirement should be determined and it is important to fertilize according to the need. After determining the amount of nitrogen that turfgrass plants can use, it is also useful to reduce the nitrogen to be given to the soil to some extent. Because, there is always the possibility of additional fertilization, but there is no return from the over-given nitrogen from the soil (Landschoot, 2003). Therefore, it is always more useful and recommended to use as short periods as possible in calculating the value of growth potential (Woods, 2013).

Special situations should be taken into account in the calculation of growth potential and nitrogen requirements in turf areas. For example, in turf areas such as football fields or golf courses where regular care practices are carried out, the value of growth potential also declines in cases where a plant growth regulator such as trinexapac-ethyl is used. Considering this situation, nitrogen fertilization should also be reduced by up to 20-25%. Additionally, it is known that the traffic effect on turf areas increases on long summer days (Watschke and Schmidt, 1992; Christians and Agnew, 2008). In such areas, it is useful to make a fair amount of increase in nitrogen fertilization to stimulate the growth of turfgrass plants.

It is extremely useful to use the growth potential to predict when turfgrass plants will use nitrogen the most. The growth activities of turfgrass plants decrease or stop completely at very low temperatures (Trenholm, 2000). In these cases, the need for nitrogen fertilization is reduced to minimum levels. Using growth potential to predict how much nitrogen turfgrass plants can use throughout the year due to temperature changes can help turfgrass growers optimize the carbohydrate production of plants (Woods, 2013).

Usability of The Growth Potential in Turfgrass

The concept of growth potential is simply an indicator of how turfgrass can grow, and the turfgrass grower can use this index in several ways. In other words, it is defined as using growth potential to determine how turfgrass growth is affected by temperature. The use of growth potential is

not a fixed criterion that should be done in a certain way. Therefore, growth potential should also not be considered as the only reality that shows how turfgrass grow (Woods, 2013). For example, instead of the optimum air temperature value of 31°C for warm season turfgrass in the equation given in Figure 4, different temperature values can be used by turfgrass growers for different warm season turfgrass species.

Growth potential provides turfgrass growers with opportunities such as calculating the relevant growth potential by looking at average monthly, weekly, or daily temperatures and making long-term care plans according to these temperatures. It also allows making short-term plans by calculating an actual growth potential according to the present situation rather than the average situation, and looking at the temperature values predicted for the next day or week by taking advantage of meteorological forecasts (Woods, 2013). As is known, high-temperature stress for cool season turfgrass is a source of concern for turfgrass growers (Pessarakli, 2007). Based on the adjustments made in the equation in Figure 4, it can be predicted how much stress turfgrass can be under during the hottest months of summer. In particular, it is very useful to examine the growth potential before planning core aerification and other maintenance applications. Interruptions in games due to applications such as maintenance should always be kept at a minimum time in terms of economic activities on turf areas such as football fields, golf courses, etc (Petersen, 1991; Stewart, 1994; Beard, 2002). As a result of planning and carrying out these maintenance activities in a period of high growth potential, turfgrass regeneration is ensured as soon as possible and game interruptions are minimized. Also, turfgrass growth potential should be determined by using area-specific weather data to calculate the nitrogen requirements in these areas in the best way. It should be remembered that nitrogen is not the only element that can be managed according to the growth potential. In many turf areas, the amount of nitrogen applied also affects the intake of other macronutrient elements (Lawson and Skogley, 1996). Therefore, the concept of growth potential can also be adapted for other nutrients.

Conclusion

In order to be understand why the performance of turfgrass differs in every one of the regions and even yearly, it is necessary to have sufficient knowledge about the growth requirements of cool and warm season turfgrass species. It is possible to obtain sustainable turf areas only in light of this information. It is known that optimum growth and development is achieved in the range of 20±4 °C for cool season turfgrass species and 31±4 °C for warm season turfgrass species. Turfgrass growers need to learn how the growth potential should be calculated and how this model can be used in a practical way to calculate nitrogen requirements

in turfgrass, in order to create sustainable turf areas. Moreover, the use of growth potential should not be perceived as a fixed criterion, which should be used in a certain way. It should simply be considered as an indicator of how turfgrass can grow, and it should not be overlooked that this concept can be used in a number of ways.

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Chapter 4

THE EFFECT OF IRRIGATION WATERS PREPARED FROM SEA AND TAP WATER AND SILICON APPLICATION ON FRUIT YIELD, SHOOT *DRY MATTER WEIGHT* AND A NUMBER OF BLOSSOM-END ROT OF TOMATO FRUIT

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1. Introduction

Irrigation water to be used in soilless culture should have an EC value of less than 0.5 dS/m, sodium concentration of less than 35 ppm, chlorine concentration of less than 50 ppm, bicarbonate concentration of less than 250 ppm and boron concentration of less than 0.5 ppm. Irrigation water pH values should be between 5.0-7.0 (Gül, 2012).

Full seawater may contain some ions and elements at hazardous levels able to influence plant growth and nutrition levels. Therefore, present research should focus on potential use of diluted seawater in irrigation of cultural crops. In case of use of poor-quality irrigation waters, water, plant and management strategies should be determined to minimize existence of soluble salts in irrigation water and soil and potential effects of these salts on plants. Saline waters may be used in irrigations by taking plant response to saline conditions at different periods into consideration. In recent years, potential use of saline waters in irrigations is gaining an acceptance. The studies on plant cultivation and breeding, soil-plant-water management, irrigation and drainage technologies significantly increased potential use of saline waters in irrigation with the minimum hazard on soil fertility and environment (Shalhevet, 1994).

The simplest effect of salt on plants is to inhibit plant water uptake and recess the nutrient uptake from the soil. Due to increased osmotic potential within the root zone, plants are not able to get sufficient water or due to toxic effect of excessive sodium and chlorine ions, water up take of plants is reduced. Destructed ion balance of the plants under saline conditions of the root zone also leads to significant changes in mineral concentrations. Excessive uptake of salts destructs cellular functions, resultant damages on cell and organelle membranes interrupt photosynthesis, respiration and similar critical functions. Excessive salt accumulation within the root zone ultimately ends up with physiological drought with irreversible damages on plants. In case of physiological drought, plants are not able to take available water of soil with their roots due to high osmotic pressure (Ayyıldız, 1990).

Yield decreases were reproted in tomatoes due to decreased fruit sizes at EC values of between 4.6 - 8.0 mS cm^{-1}; decreases were reproted both in furit size and numebr of fruits at EC level of 12 mS cm^{-1} (Adams, 1991; Gormley & Maher, 1990; Hao et al., 2000).

In soilless culture, salinity of the root zone could be modified through changing nutrient solution composition or alteration of irrigation frequency and it was reported that tomato could tolerate salt concentrations of root zone of between 2.5-2.9 dS m^{-1} without any losses in yields (Sonneveld & Van der Burg, 1991).

Salt levels of plant growth media may vary based on sensitivity of the species and environmental conditions (Li et al., 2001). High salt levels of the root zone may reduce fruit sizes, thus yields (Navarro et al. 2005). Besides, excessively high salt levels reduce number of fruits per plant. Adams & Ho (1989) and Olympios et al. (2003) indicated that reductions were encountered in number of fruits at root zone salinity of greater than 8.0 dS m^{-1}.

It was reported that increases were observed in ratio of the first-class tomato when the salt concentration of the nutrient solution was increased over the recommended levels (Adams & Ho, 1989; Adams, 1991). However, salinity of nutrient solution reduced fruit weights of tomato (Chretien et al. 2000) and increased the number of fruits with Blossom-end rot (Schwarz et al., 2001). Therefore, it was indicated that positive effects of salinity on ratio of the first class fruits were compensated with increasing ratios of smaller fruits and the fruits with Blossom-end rot (Chretien et al., 2000). Improved fruit quality and decreased yields levels were reported in tomatoes subjected to moderate salinity levels, but such decreases in yields were lower than the other fruity species (Savvas, 2001). Therefore, recommended salinity levels in soilless tomato culture should be decided by taking these two opposite effects into consideration. It was indicated that proper salinity level in tomatoes should be arranged through salt additions to increase 2.6 dS m^{-1} electrical conductivity of normal nutrient solution to 3.5-3.7 dS m^{-1} (Sonneveld & Straver, 1994).

Al-Omran et al. (2012) indicated that negative effects of saline irrigation water on total dry matter weight and fresh fruit yields of tomatoes were resulted from decreasing irrigation water use efficiencies calculated by taking total dry matter weight and total fresh fruit yields into consideration. Zhu & Gong (2014) indicated that silicon increased water uptake through the roots, reduced water loss of leaves, provided nutrient balance and improved photosynthesis rates. It was also reported that silicon increased activity of antioxidant enzymes and contents of non-antioxidant enzymes and prevented plants from oxidizing effects of salt and silicone also had contributions to osmotic regulation and increased activity of photosynthetic enzymes. Researchers indicated that silicon treatments reduced sodium accumulation in root and shoots.

Coşkun et al. (2016) indicated that although silicon is not an essential element for plants, it provides various contributions to plant growth and development under stress conditions like salinity and drought. Silicon provides suberization, lignification and silicification in cell wall, then reduce transpiration of water and salt-induced oxidative damage.

Reina-Sanchez et al. (2005) conducted a study under soilless

greenhouse conditions to determine the effects of salinity (0, 25, 50 and 75 mM NaCl) on fruit yield, water uptake and water use efficiency of 4 tomato cultivars (Floradade, L1, L5 and L9). Researchers indicated that 70% of fresh plant weight was composed of fruits, 22% leaves and 8% shoots and fruits are the most sensitive parts of the plants to salinity. It was reported in 4 tomato cultivars that 28 g reduction in fruit yield was encountered for 1 mM increase in NaCl dose or 290 g reduction was encountered for 1.0 dS m^{-1} increase in EC. In terms of tomato yield, threshold EC value varied between 0.0-3.4 dS m^{-1} and Blossom-end rot incidence increased with increasing salinity levels. Fruit soluble solids and acid contents were greater in plants grown under saline conditions than the plants grown under unsaline conditions. The plants grown under highly saline conditions had 405 greater water consumptions than the control plants. There was a linear correlation between plant total water uptake and salinity (R^2 = 0.94-1.0). Control plants had greater water use efficiencies than the plants grown under saline conditions and water use efficiencies were reported as between 13-25 g fruit yield / L.

This study was conducted to investigate the effects of irrigations waters prepared from sea and tap water and silicon treatments on tomato fruit traits, shoot dry matter weight and a number of BER fruit.

2. Material and Methods

2.1. Experiment

Plastic pots (3 liters) were filled with 1100 g substrate (1:1 peat:perlite mixture) materials. Tybiff Aq tomato seedlings were planted into the pots as to have one seedling per pot. Four different types of irrigation water were applied. Irrigation waters included: I) Full sea water, II) ½ sea water + ½ tap water, III) ¼ sea water + ¾ tap water, IV) Full tap water (control). Irrigation waters were supplemented with silica gel ($SiO_2 \cdot xH_2O$) (0, 0.5, 1 and 2 mM Si). Experiments were conducted in randomized plots 4×4 factorial design with 3 replications.

From planting to harvest (70 days), following nutrient solutions with a pH of 6.0 were applied to tomato plants as recommended by Alpaslan et al. (1998):

1.25 mM KH_2PO_4; 15 µM Fe (Fe-EDDHA); 4.25 mM $Ca(NO_3)_2 \cdot 4H_2O$; 10 µM Mn ($MnCl_2$); 1.25 mM NH_4NO_3; 5 µM Zn ($ZnSO_4 \cdot 7H_2O$); 4.0 mM KNO_3; 30 µM B (H_3BO_3); 2.0 mM $MgSO_4 \cdot 7H_2O$; 0.75 µM Cu ($CuSO_4 \cdot 5H_2O$); 1.75 mM K_2SO_4; 0.5 µM Mo [$(NH_4)_6Mo_7O_{24}4H_2O$]

From planting to the first fruit set, 150 mL nutrient solution and 300 mL irrigation water was applied in each day; from the first fruit set to the

harvest, 300 mL nutrient solution and 600 mL irrigation water was applied in each day. Following the application of irrigation water and nutrient solution, experimental pots were freely drained.

The total fresh fruit weight, stem dry matter, the number of fruits, the average fruit weight and a number of BER fruit from per tomato plant were determined at harvest time.

2.2. Irrigation water analysis

The pH, EC, SAR values, carbonate, bicarbonate, chlorine, calcium, magnesium contents (Sağlam, 2008); sulphate (Kacar, 1994); boron (Bayraklı, 1987) contents of irrigation waters were determined. SAR values were calculated with the use of the following equation:

$$SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{+2} + Mg^{+2}}{2}}}$$

Where; Na^{+}, me/L; Ca^{+2}+Mg^{+2}, me/L.

Water analysis results are provided in Table 1.

Table 1. *Chemical properties of irrigation waters prepared from sea and tap water*

Irrigation water parameter	Full sea water	½ Sea water + ½ tap water	¼ Sea water + ¾ tap water	Full tap water
pH	8.05	8.20	8.0	7.70
$EC_{25°C}$, dS m^{-1}	62.40	37.20	18.70	0.70
$CO_3^{=}$, me L^{-1}	0.46	0.25	0.03	0.00
HCO_3^{-}, me L^{-1}	6.13	5.12	4.69	3.56
CI^{-}, me L^{-1}	316.40	168.10	89.20	8.70
$SO_4^{=}$, me L^{-1}	6.40	7.30	4.80	0.80
Ca^{++}, me L^{-1}	10.90	7.25	5.40	3.40
Mg^{++}, me L^{-1}	62.14	36.59	20.10	2.32
Na^{+}, me L^{-1}	220.70	89.80	43.05	0.75
B, mg L^{-1}	1.42	1.07	0.91	0.71
SAR	36.54	19.20	12.10	0.44

Entire parameters of full sea water, ½ sea water + ½ tap water and ¼ sea water + ¾ tap water were not suitable for irrigations to be conducted in soilless culture and field farming. On the other hand, entire parameters of tap water were ideal for irrigations (Sağlam, 2008).

2.3. Statistical analysis

Experimental data were subjected to variance analysis (ANOVA) in accordance with randomized plots – factorial experimental design with the use of SPSS 17.1 software. Significant means were compared with the use of Duncan's test at $p < 0.05$ level. Regression analysis was conducted to identify correlations of irrigation water quality traits with tomato fruit yield and shoot dry matter weight

3. Results and Discussion

3.1. Effects of irrigation waters and silicon doses on fruit yield, shoot dry matter weight and the other yield components

Effects of different irrigation waters and silicon doses on tomato fruit yield, shoot dry matter weight, number of fruits, average fruit weight and a number of Blossom-end rot (BER) fruit are provided in Table 2.

Table 2. *Effects of different irrigation waters and silicon doses on tomato fruit yield, shoot dry matter weight, number of fruits, average fruit weight and a number of Blossom-end rot fruit*

Parameters	Irrigation waters	Si doses, mM				Average
		0.0	**0.5**	**1.0**	**2.0**	
Fruit yield, g dry matter plant -1	Sea water	289.67	362.68	254.10	225.87	**283.08D****
	½ sea water+ ½ tap water	618.15	660.35	674.30	692.43	**661.31C**
	¼ sea water + ¾ tap water	1181.43	1203.33	1078.87	1042.47	**1126.53B**
	Tap water	2051.40	2226.05	1971.77	2115.17	**2091.10A**
	Average	1035.16	1113.11	994.76	1018.98	
Number of fruits, plant -1	Sea water	15.67	14.00	14.33	13.33	**14.33C****
	½ sea water+ ½ tap water	30.00	28.33	23.33	29.00	**27.67B**
	¼ sea water + ¾ tap water	31.33	32.33	30.33	34.33	**32.08A**
	Tap water	24.67	29.00	28.33	30.33	**28.08B**
	Average	25.42	25.92	24.08	26.75	
Average fruit weight, g	Sea water	19.76f**g***	27.28d-f	17.93g	17.90g	**20.72D****
	½ sea water+ ½ tap water	20.58fg	23.34e-g	29.75de	23.88e-g	**24.39C**
	¼ sea water + ¾ tap water	37.72c	38.01c	34.62cd	30.39c-e	**35.19B**
	Tap water	75.03ab	78.82ab	69.34b	77.67a	**74.72A**
	Average	38.27	41.36	37.91	37.46	

Shoot dry matter weight, g plant $^{-1}$	Sea water	12.83	17.37	16.16	18.29	**16.16D****
	½ sea water+ ½ tap water	50.46	53.86	54.83	54.42	53.39C
	¼ sea water + ¾ tap water	77.44	74.19	79.88	71.51	**75.75B**
	Tap water	89.86	81.25	85.03	81.79	**84.48A**
	Average	57.65	56.67	58.98	56.50	
A number of Blossom-end rot fruit, plant $^{-1}$	Sea water		1,00	1,33	0.00	
	0, 33 **0,67B**					
	½ sea water+ ½ tap water		4,00	5,67	4,67	
	4,00 **4,58A**					
	¼ sea water + ¾ tap water		2,67	4,67	3,33	
	5,00 **3,92A**					
	Tap water		0,00	0,33	0,33	
	0,00 **0,17B**					
	Average		**1,92**	**3,00**	**2,08**	
	2,33					

As can be inferred from Table 2, effects of irrigation waters on fruit yield, number of fruits, average fruit weight, shoot dry matter weight and a number of Blossom-end rot (BER) fruit were found to be significant at $p < 0.01$ level, but the effects on silicon doses were not found to be significant. Effects of irrigation water × silicon dose interactions on average fruit weight were found to be significant at $p < 0.05$ level, but the effects of interactions on fruit yield, number of fruits, shoot dry matter weight and number of BER fruit were not found to be significant.

Fruit yields significantly decreased with increasing sea water ratio of the irrigation water. While tap water treatments had an average fruit yield of 2091.05 g plant^{-1}, fruit yield per plant decreased to 1126.11 g plant^{-1} with ¼ sea water-containing irrigation water, to 661.30 g plant^{-1} with ½ sea water-containing irrigation water and to 283.08 g plant^{-1} with full sea water. The correlations between sea water ratio of the irrigation water and yield loss revealed that 20% yield loss was seen at 6.5% sea water ratio, 40% yield loss was seen at 25.2% sea water ratio, 50% yield loss was seen at 43.45% sea water ratio, 80% yield loss was seen at 80.49% sea water ratio and 86.51% yield loss was seen at 100% sea water ratio (full sea water). Kahlaoui et al. (2011) indicated that tomato fruit yields were badly influenced when 70% of plant water need was met with saline irrigation waters. Researchers reported that saline irrigation water reduced number of lowers, number of fruits, fruit size and fruit yields and increased titratable acidity, soluble solids content and Blossom-end rot incidences.

As compared to full sea water treatments, increasing number of fruits per plant was observed with increasing tap water ratio of the irrigation

water. While the average number of fruits per plant was 14.38 at full sea water, the value was observed as 27.65 at ½ sea water ratio, as 32.05 at ¼ sea water ratio and as 28.05 at full tap water. Present findings revealed that ¼ sea water ratio increased fruit set, thus had the greatest number of fruits per plant. Gül (2012) indicated that high EC irrigation waters or nutrient solutions balance vegetative and generative development in tomatoes and promoted fruit set.

Significant decreases were observed in average fruit weight with increasing sea water ratios of the irrigation water. While average fruit weight was measured as 74.77 g at full tap water irrigations, the value decreased to 35.14 g at ¼ sea water ratio, to 24.39 g at ½ sea water ratio and to 20.72 g at full sea water irrigations. Increasing salinity levels of irrigation water reduced water transport to fruit, thus resulted in small fruit sizes. Chretien et al. (2000) reported reduced fruit weights with increasing salinity of nutrient solution.

Effects of increasing silicon doses on average fruit weight were somehow different from the effects of irrigation water. Significant increases were observed in average fruit weights at full sea water with 0.5 mM Si dose and at ½ sea water ratio with 1 mM Si dose. Silicon fertilization reduced the negative effects of sea water and increased fruit weight. The rate decrease in average fruit weight was 25% at 7.5% sea water ratio of the irrigation water, such a decrease was 50% at 46.56% sea water ratio and 75% at 85.6% sea water ratio.

Significant decreases were observed in shoot dry matter (DM) quantities of tomato plants with increasing sea water ratio of the irrigation water. While the shoot dry matter weight was 84.48 g DM at full tap water irrigations, the value decreased to 75.76 g DM at ¼ sea water ratio, to 53.39 g DM at ½ sea water ratio and to 16.16 g DM at full sea water irrigations. The rate of decrease in shoot dry matter weight was 10% at 17.5% sea water ratio, such a decrease was 25% at 35.35% sea water ratio, 50% at 65.11% sea water ratio and 75% at 94.88% sea water ratio.

Significant increases were observed in a number of BER fruit per plant at ¼ and ½ sea water ratios. However, a number of BER fruits were almost zero in full sea and tap water treatments. Such a low number of BER fruit in full tap water treatments were attributed to sufficient calcium nutrition of tomato plants; increasing number of BER fruit with sea water supplementations was attributed to insufficient calcium transport to the fruits.

3.2. Correlations of irrigation water quality traits with tomato fruit yield and shoot dry matter weight

Correlations coefficients for correlations of irrigation water quality traits with tomato fruit yield and shoot dry matter weight are provided in Table 3.

Table 3. *Correlations coefficients for correlations of irrigation water quality traits with tomato fruit yield and shoot dry matter weight*

Irrigation water quality traits	Fruit yield, g plant $^{-1}$	Shoot dry matter weight, g plant $^{-1}$
pH	-0.840**	-0.613*
EC, dS m^{-1}	-0.941**	-0.964**
$CO_3^{=}$ me L^{-1}	-0.836**	-0.923**
HCO_3^{-}, me L^{-1}	-0.953**	-0.912**
CI^{-}, me L^{-1}	-0.928**	-0.983**
$SO_4^{=}$, me L^{-1}	-0.794**	-0.586**
Ca^{++}, me L^{-1}	-0.902**	-0.986**
Mg^{++}, me L^{-1}	-0.940**	-0.982**
Na^{+}, me L^{-1}	-0.885**	-0.985**
B, mg L^{-1}	-0.927**	-0.979**
SAR	-0.934**	-0.974**

Correlations coefficients for the correlations of irrigation water pH, EC, SAR values, carbonate, bicarbonate, chlorine, calcium, magnesium, sodium and boron content with tomato fruit yield and shoot dry matter weight were all negative and mostly significant at $p < 0.01$ level. In other words, significant decreases were observed in tomato fruit yield and shoot dry matter weight with increasing irrigation water pH, EC, SAR values, carbonate, bicarbonate, chlorine, calcium, magnesium, sodium and boron contents. The correlation coefficients for correlations of irrigation water pH and sulphate content with a number of BER fruit were respectively identified as r = 0,572* and r = 0,504*. In other words, a number of BER fruit increased with increasing irrigation water pH values and sulphate contents. Increasing number of BER fruit was attributed to reduced calcium contents of the fruits. Accordingly, there was an insignificant negative correlation between a number of BER fruit and fruit calcium content (r = -0,257).

4. Conclusion

Significant decreases were observed in fruit yields with increasing sea water ratios of the irrigation water. The correlations between sea water ratio of the irrigation water and yield loss revealed that 20% yield loss was

seen at 6.5% sea water ratio, 40% yield loss was seen at 25.2% sea water ratio, 50% yield loss was seen at 43.45% sea water ratio, 80% yield loss was seen at 80.49% sea water ratio and 86.51% yield loss was seen at 100% sea water ratio (full sea water). As compared to full sea water treatments, increasing number of fruits per plant was observed with increasing tap water ratio of the irrigation water. Significant decreases were observed in average fruit weight with increasing sea water ratios of the irrigation water. Silicon fertilization reduced the negative effects of sea water and increased fruit weight. The rate of decrease in average fruit weight was 25% at 6.5% sea water ratio, such a decrease was 50% at 46.56% sea water ratio and 75% at 85.6% sea water ratio. Significant decreases were observed in shoot dry matter quantities of tomato plants with increasing sea water ratio of the irrigation water. The rate of decrease in shoot dry matter weight was 10% at 17.5% sea water ratio, such a decrease was 25% at 35.35% sea water ratio, 50% at 65.11% sea water ratio and 75% at 94.88% sea water ratio.

Significant decreases were observed in tomato fruit yield and shoot dry matter weight with increasing irrigation water pH, EC, SAR values, carbonate, bicarbonate, chlorine, calcium, magnesium, sodium and boron contents. Significant increases were observed in a number of BER fruit per plant at ¼ and ½ sea water ratios.

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Chapter 5

EVALUATION OF THE EFFECTS OF CHLORIDE AS A NUTRIENT ON PLANT GROWTH, NUTRITION AND YIELD COMPONENTS

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Introduction

Plants need various nutrients at different quantities to survive in different environments. Plants absorb around ninety different elements from the air, water and soil. Some of these elements are essential for plant growth and development and some others are beneficial for plant growth and development. Essential nutrients are required directly for plant metabolism and survival of plants and they are not compensated by the other nutrients. In other words, plants are not able survive in the absence of these nutrients. Plants need at least 17 different nutrients for optimal growth and development. Each nutrient aids in different plant functions providing plant growth and development. Therefore, nutrients are divided into two categories based on the amount in plants as of: "macro" and "micro" elements. Micronutrients are composed of chlorine, iron, copper, manganese, zinc, molybdenum, boron and nickel. Amount of plant nutrients is largely dependent on plant species, age, root growth, soil physical, chemical and biological characteristics, type and amount of soil available elements, agronomic practices, climate conditions and various other factors (Bolat and Kara, 2017; Kacar and Katkat, 2018; Fageria et al., 2002; Rice, 2007).

Chlorine (Cl) is an essential micronutrient for plants (Marschner, 1995). Chlorine exists in soil and plants dominantly in the form of Cl^- ion (chloride) (Chen and Mahadevan, 2008). It is a highly mobile element. Plant uptake of Cl^- ion is an easy and quick process. Although being a micronutrient, play a great role in several physiological processes of the plants. Since it is a plant nutrient, it is also important for soil fertility. Cl^- participates into several physiological metabolism processes including photosynthesis, preservation of leaf water balance, regulation of stomal actions, cell reproduction, disease resistance and tolerance. Furthermore, Cl^- is used as a main osmoticum in the vacuoles and contributes to cell elongation through increasing cell hydration (Maas, 1986; Marschener, 1995; Kacar and Katkat, 2018).

Climate change, increasing soil salinity and freshwater deficits negatively influence plant production worldwide. Dissolved salts in soil solution limit water uptake of roots. Such a case then results in osmotic stress and high concentration of toxic salts results in nutritional imbalance. Additionally, accumulation of toxic ions hinders photosynthesis, respiration and nitrogen fixation-like physiological processes (Hussain et al., 2013; Shrivastava and Kumar, 2015; Farooq et al., 2015). Chloride and sodium constitute the primary ions contributing to soil salinity in several regions. Excessive chloride accumulation emerges as the primary component of salt stress and may have toxic impacts on plants. Rather than deficiency, chloride toxicity is more prevalent and effective in plants. Besides chloride

salts, sulphate salts have also toxic effects on plants (Esna-Ashari and Gholami, 2010).

Plant chloride sources

Chlorine sources of the plants grown in soil could be gathered under four groups. These are; chlorine in soil solution, chlorine concentration of irrigation water, atmospheric chlorine, organic and inorganic fertilizers (Goos, 1987).

Soil: Chlorine is found in soils generally in the form of chlorine compounds (NaCl, $CaCl_2$ and $MgCl_2$). Total chlorine contents of the soils vary between 50-500 mg kg^{-1} and available chlorine quantities between 0-37 mg kg^{-1}. Negatively loaded Cl^- ions are not absorbed by soil exchange complexes. Therefore, they move up and down through the soil profile easily. Cl^- quantity is less in precipitated soils because of leaching. On the other hand, accumulation is greater in semi-arid and arid lands. Chlorine quantities may reach to toxic levels in poorly-drained sandy soils. Cl^- anion is not adsorbed onto soil particles at neutral and alkaline pH values, therefore can easily be leached (Fixen, 1993). High concentrations of NO_3, SO_4 and H_2PO_4 anions in soils reduce chloride uptake (Kacar and Katkat 2018). Seas with high salt concentrations are the greatest chlorine sources worldwide. The soils formed through evaporation of seas contain large quantities of chlorine stored in the form of salt (Flowers, 1988).

Irrigation water: Cl^- accumulation is encountered in irrigable lands. Substantial Cl^- content of irrigation waters, insufficient water use to leach Cl^- accumulation within the root zone, so poor drainage conditions as to provide sufficient leaching, high groundwater levels and excessive capillary movement of chlorine within the root zone all may result in chlorine accumulation in soils. Excess chloride increases osmatic pressure of soil solution and such a case then result in insufficient water uptake of plants from the soils. Irrigation waters generally contain about 200 g m^{-3} Cl^- (Xu et al., 2000). Chloride deficiency is encountered in soils with water soluble Cl^- content of less than 2.0 mg kg^{-1} (Kacar and Katkat, 2018). In terms of Cl^- concentrations, irrigation waters are classified as low for Cl^- concentrations of < 4 meq L^{-1}; medium for Cl^- concentrations of between 4-10 meq L^{-1}; high for Cl^- concentrations of > 10 meq L^{-1}. Upper limit for Cl^- concentrations of irrigation waters is specified as 30 meq L^{-1} (Palacios et al., 1997).

Groundwater chlorine may come from different sources. Sea water intrusion, agrochemicals and geogenic contamination may constitute some of these sources (Milnes, 2011). Groundwater could be accepted as safe up to Cl^- concentrations of 70 mg L^{-1}, but Cl^- concentrations of greater than 350 mg L^{-1} may exert serious problems on several cultural crops (Naseem

et al., 2010). Long-term use of high Cl^- containing groundwater may further aggravate such risks. A research conducted on municipal waste repositories revealed that leachate waters of these repositories were rich in Cl^- and these leachates may exert serious risk on receiving aquifers and rivers as a long-term source of Cl^- (Mullaney et al., 2009).

Atmosphere: Atmosphere-originated (atmospheric) Cl^- is especially important in coastal regions (Flowers, 1988). Onshore soils receive sufficient or excessive quantities of chloride through wind-drifted rain and snow (McWilliams and Sealy, 1987). Annual atmospheric chloride quantities vary between 17.6 - 36.0 kg ha^{-1} (Reynolds et al., 1997). Salt concentration of atmospheric air depends on topography, wind direction and storm frequency and distribution (Yaalon, 1963). Air chloride concentration decreases exponentially as moved away from the coast. Chlorine concentrations are specified as 20-50 g m^{-3} in rain waters close to coast and 2-6 g m^{-3} in inner regions far from the oceans (Yaalon, 1963). Atmospheric Cl^- concentrations generally reach to high levels in coal-burning heavy industry regions (Fixen, 1993).

Organic and inorganic fertilizers: Livestock manure, plant and animal-originated wastes are also considered as source of Cl^- in soils. Generally, Cl^- rich animal wastes or industrial and municipal wastes may result in excessive chlorine accumulation in soils (Geilfus, 2019). Fertilization with Cl^- rich animal wastes may aggravate soil salinity problem in dry regions. Such a case should be taken into consideration in regions with greater evapotranspiration than the precipitation where animal wastes were used to improve soil fertility (Krichmann and Witter, 1992). Among the livestock manures, cattle manure contains about 8.10 g kg^{-1} dw. (dry-weight) Cl^- (Miller et al., 2017) and has a capacity to accumulate significant quantities of Cl^- in soils. The process relies on precipitations and leachate waters (Miller et al., 2011). Of the other animal manures, pig manure has 1.70 g L^{-1} (Krapac et al., 2002), poultry manure has 4-9 g kg^{-1} dw (Quiroga et al., 2010), pigeon manure has 6.1g kg^{-1} dw (Li-Xian et al., 2007) Cl^- concentration.

Plants meet their chlorine requirements also from chemical fertilizers. Chemicals applied to soil for fertilization purposes contain more or less quantity of chloride. Among these chemical fertilizers, magnesium chloride (74%), ammonium chloride (66%), calcium chloride (65%), sodium chloride (60%) and potassium chloride (47%) are prominent with their high chloride contents (Kacar and Katkat, 2018).

Plant chloride contents

Despite low requirement, plant average Cl^- contents are quite greater than requirement as a micronutrient (Xu et al., 2000). Varying with the

species, plant Cl^- contents generally range between 2.0-20 mg g^{-1} of dw. It was indicated in a study conducted on tomatoes that for reliable growth and yield levels, leaf dry matter Cl^- contents should be between 0.67–1.02% (Kowalczyk et al., 2008). It was also reported that leaf Cl^- contents of 2.5-3.0% negatively influenced yields (Nukaya and Hashimoto, 2000). In sensitive plants, toxicity symptoms are encountered when leaf Cl^- accumulations reached to 0.3-1.0%, but plant sensitivity varies with the species (Ayers and Westcot, 1989). Critical tissue concentration is specified as 4-7 mg g^{-1} dw for sensitive plants and as 15-50 mg g^{-1} dw for tolerant plants. Cl^- accumulation is largely encountered in vegetative organs of the plants, especially in leaves (maize, lettuce, wheat, soybean and paddy) (Wei et al., 1989; Pan et al., 1991). Chloride up taken by the roots is transferred to entire parts of the plant and the greatest concentration is encountered in old leaves. As compared to young leaves, Cl^- accumulation is greater in old leaves. Cl^- concentrations are also greater in grain, fruit and seeds as compared to other tissues (Zhou and Zhang, 1992). Since soil Cl^- contents are generally high and plant chloride need is low, deficiency symptoms are less encountered. For reliable growth and development of cultural crops, it is sufficient to have soil Cl^- content of 0.2-0.4 mg g^{-1} dw (Greenway and Munns, 1980; Marschener, 1995; Xu et al., 2000; White et al., 2001; Kacar and Katkat, 2018). For an average yield, 4-8 kg ha^{-1} Cl^- will be sufficient. Jarosz (2006) reported Cl^- concentration of nutrient solution supplied to tomatoes grown in rockwool as 35 mg L^{-1} and root zone concentration as 70 mg L^{-1}.

Metabolic functions of chloride in plants

In saline soils, toxic and antagonistic effects of chlorine reduce plant nitrate uptake, thus negatively influence yield levels. Chloride therefore is considered as harmful for agricultural practices. However, it prevents excessive nitrate accumulation especially in green-leaved vegetables, thus improve crop performance and quality. It has positive effects on water use efficiency, crop water balance and plant-water relations, thus chloride are also defined as a beneficial micronutrient (Rosales et al., 2020). Geilfus (2019) reported chlorine, a nutrient for cultural crops, as an important parameter for soil fertility. Komosa and Gorniak (2015) pointed out the importance of sufficient chloride nutrition in tomatoes and recommended chloride contents of 60-90 mg L^{-1} for reliable yields. Research also determined that increasing chloride contents influenced nutrient contents of tomato leaves. Increasing nutrient solution chloride content over 90 mg L^{-1} and 90-120 mg L^{-1} respectively reduced leaf Ca^{2+} and K^+ concentrations. Besides these findings, a relationship of applied chlorine concentrations with leaf P^+ and Mg^{2+} contents was not able to be identified. It was found in a study conducted on paddy plants that sufficient chloride nutrition

positively influenced root osmatic pressure and improved root growth and development (Kimura et al., 2004). Couple studies conducted in laboratory and field revealed that even low Cl^- concentrations negatively influenced ammonification and nitrification processes of the soils (Souri, 2010; Vieira-Megda et al., 2014; Mariano et al., 2016). According to Christensen et al. (1986), nitrification-inhibiting effect of chloride is encountered especially in moderate and highly acidic soils. Supplementing soils with excessive Cl^- through KCl fertilization results in biocidal effect in soils, reduces soil microbial activity and inhibits nitrogen cycle (Pereira et al., 2019).

Chloride is a nutrient needed for photosynthesis and preservation of leaf turgor. It also plays a role in activation of adenosine triphosphatase enzyme. It is quite effective in regulation of stomal actions, cell proliferation and shoot expansion (Plaster, 1992; Bosgelmez et al., 2001; McCauley et al., 2009; Kacar and Katkat, 2018; Franco-Navarro et al., 2016). It was determined that Cl^- played a retrogressive effect on nitrification and had significant positive effects on conversion of Mn^{+3} and Mn^{4+} oxides into available Mn^{2+}. White et al. (2001) defined Cl^- as an important osmotic solution existing in vacuole and indicated that Cl^- played a role in preservation of cell pH balance and cell membrane stabilization.

It was reported that chlorinated fertilizers had retrogressive effects on diseases encountered in various plants (Gardiner and Miller, 2008; Kacar and Katkat, 2018). It was also reported that some disease in maize, millet, wheat and barley-like several crops were suppressed through Cl^- fertilization (Heckman, 2007). Effects of chlorides on control of root and leaf diseases of wheat and barley-like crops also contribute top and nutrition (Crovetto, 1999). According to Kleinhenz (1999), Cl^- rather reduces the severity of diseases. Increasing yields were reported in previous studies with Cl^- containing fertilizers (Xu et al., 2000). Some growers use chlorination technology for disinfection of irrigation systems and waters. Chlorine provides disinfection through altering the chemical structure of microorganisms (Newman, 2004). Besides organic material, HOCl (hypochlorous acid) like oxidizing compounds also burn pathogens (Newman, 2004). Reduction of severity of anthracnose with chlorinated water may reduce the number of fungicide treatments. Results suggested that irrigation water treated with 2.4 $mg \cdot L^{-1}$ of free chlorine for 5 min could be used to prevent the spread of common plant pathogens. However, it should be kept in mind that excessive chlorine may result in phytotoxic damage (Bhat et al., 2018). Dick and Dick (2014) indicated chloride as a commonly used disinfectant for seeds contaminated with bacterial pathogens causing cancer, blemish and spot diseases. For disinfection of tomato seeds, researchers recommended to keep seeds within Cl^- solution at 5000 mg L^{-1} concentration for an hour provided that chlorine concentration

was continuously monitored with a chlorine meter. Chloride also used in weed control. For this purpose, chlorate, a chloric acid salt, and the other chlorine-containing substances are used (Mullaney et al., 2009).

Effects of chloride deficiency on plants

Plant symptoms encountered in Cl^- deficiency include: affected transpiration, development of chlorosis, swells in leaf contours, recessed cell proliferation, clear slowdown in leaf growth (Bosgelmez et al., 2001). Other symptoms include root dwarfs and suppression of side-roots. Reduction of fruit size and number of fruits are also encountered under Cl^- deficiency. Majority of cereals, vegetable, fruit and citrus species are sensitive to Cl^- throughout the growing seasons.

Effects of chloride toxicity on plants

Toxicity initially emerges as leaf burns and interveinal chlorosis. Besides, sufficient accumulations result in low yield levels. More tolerant annual plants are not sensitive to low concentrations of toxic ions, but all plants are damaged by sufficient concentrations of toxic ions and are not able to survive then. The primary toxic ions include chlorine, sodium and boron. The most common toxicity comes from chlorine in irrigation waters. Chlorine could not be hold in soil or not absorbed. It is up taken by the plants with water, transported within the plant through transpiration and accumulates in leaves. When the chlorine concentration of the leaves exceeded the tolerance thresholds, leaf burns or dry out of leaf tissues are encountered as damage symptoms. Plant damage normally commences from the leaf tips and moves back along the leaf edges. Excessive necrosis (dead tissues) is accompanied by abscission or defoliation **(**Ayers and Westcot, 1989). Tobacco is one of the most influenced plants from Cl^- toxicity. Cl^- reduces burning quality of tobacco and negatively influences aroma and taste (Karaivazoglou et al., 2006, Yamini et al., 2018). Cl^- accumulation reduces nitrate uptake, thus negatively influences nitrogen and phosphorus uptake of tomato plants (Papadopoulos and Rendig, 1983). As it was in nitrogen, chloride has a reducing effect on sulphur content. Such a case emerges as a result of competition between Cl^- and SO_4^{2-} as it was between Cl^- and NO_3^- (Muraka et al., 1973).

Cl^- toxicity is commonly encountered in plants grown in saline soils with high chloride contents. In this case, burnings, bronzing, transparency and curling are seen on leaf apex and margins and early abscission is experienced (Brown et al., 1990, Karaivazoglou et al., 2005; Bosgelmez et al., 2001; Ozbek et al., 2001). High Cl^- concentrations of soil solution increase osmatic potential of soil water. Plants cannot uptake sufficient water under high osmatic potential, and then Cl^- induced drought is encountered (Guzel et al., 2004; Kacar and Katkat, 2018).

Measures to be taken against negative impacts of chloride

Excessive Cl^- quantities destruct agricultural land use through reducing soil fertility and generating product toxicity. Therefore, soil Cl^- contamination is an important issue and fertility of contaminated soils should be regained (Geilfus, 2019). Especially fertilization, coal burning or residues of burnable wastes may contribute to Cl^- contamination of soils. Improvement of Cl^- contaminated soils requires a series of measures. Such measures include; alteration of anion exchange capacity of root zone through supplementation of nature or chemical amendments with high anion exchange capacity (Nishanthiny et al., 2010), leaching highly soluble Cl^- from the root zone through pooling (Mohammed, 2011), use of phytoremediation-hyper accumulators (Ayers and Westcot, 1985) or ready-to-use macro nutrient anions to replace Cl^- (Geilfus, 2019).

NaCl, an important pollutant in soils, produces sodium (Na^+) and chloride (Cl^-) ions when ionized with water. These toxic ions generate stress in tall plants, especially in sensitive or glycophyte species (Mansour and Salama, 2000; Chinnusamy et al., 2005). There are several effective means of improving salt-affected lands such as leaching, chemical treatments and plant breeding. Gypsum, calcite, calcium chloride and organic matter (livestock manure, green fertilizers, organic breeding and municipal solid wastes) are widely used in amendment of saline lands as efficient, easy and low-cost approaches (Mitchell et al., 2000; Hanay et al., 2004; Sharma and Minhas, 2005; Tejada et al., 2006).

Fertilization may constitute a source for soil salinization. To mitigate such negative effects, fertilizer characteristics, fertilizer application method, irrigation water quality, fertilization timing and special chlorine requirements of the plants should be taken into consideration. Excessive nutrient uses should be avoided and non-chlorine and low salt-containing fertilizers should be selected (Fixen, 1987; Grattan, 2002; Machado et al., 2008). Hütsch et al. (2018) tested potassium sulphate and potassium chloride fertilizers in different potato cultivars and as compared to potassium sulphate, indicated potassium chloride as a reliable and cheap source of fertilizer to be applied without any risks on tuber yield and quality. It was indicated in another study that potassium sulphate should be preferred instead of potassium chloride in acidic soils on which vegetables are cultivated intensively (Kleinhenz, 1999). In tobacco cultivation, irrigation water optimum chloride tolerance threshold was specified as 20 mg L^{-1}, but such a tolerance level was increased to 40 mg L^{-1} in cases where nitrate fertilizers are used (Karaivazoglou, 2006). Combined application of irrigation water and fertilizers (fertigation) may improve fertilizer use efficiency and reduce soil salinization. Fertigation also improves availability of plant nutrients and allows better timing and dosing of

fertilizers (Machado, 2002; Machado et al., 2014). Since plants are not able to uptake sufficient quantities of water and minerals under stress conditions, foliar nutrient treatments were reported as a better approach (Dordas 2009). It was reported that potassium fertilizers yielded successful outcomes in reduction of salt stress in soybean farming (Adhikari et al., 2020). Foliar application of micronutrients positively influences yield and quality (Turhan et al., 2021).

Selection of irrigation methods may either aggravate or reduce Cl^- damages. Drip irrigation offers the most efficient use of water. However, this system may result in local salt spots due to increasing evaporations (Ayers and Westcot, 1985). The salt accumulated on soil surface reach to root zone when drip irrigation was used (Hachicha et al., 2006). Application of high Cl^- or Na^+ containing waters to plants through sprinkler systems is an inconvenient method of application. In sprinkler irrigation, salt absorption is facilitated in leaves wetted with saline water and such a case then result in further yield losses in salt-affected soils (Aragues et al., 1992; Benes et al., 1996). Grattan et al. (1994) conducted a study on barley and reported that sprinkler irrigation increased Cl^- accumulation in young leaves. Sub-surface drip irrigation was developed for better salinity management and to improve water use efficiency. Sub-surface drip irrigation was reported to reduce salt accumulation in root zone and result in better yield and fruit quality (Phene et al., 1991; Oron et al., 1998). Such a case was reported in tomato (Ayars et al., 2001; Hanson et al., 2006), beans (Gencoglan et al., 2006), onion (Enciso et al., 2007), cotton (DeTar, 2007) and potato (Patel and Rajput, 2008).

Sub-surface irrigation with perforated pipes (leakage irrigation) could also be used efficiently to prevent accumulation of salts in soil. Qadir et al. (2000) defined leakage irrigation as a method of irrigation applied to facilitate movement of salts from surface soil to deeper layers of the soil. Required leaching frequency relies on levels of salinity, quantity of evaporation and plant sensitivity to salts (Levy and Syvertsen, 2004). Leaching could be practiced after each irrigation in arid regions (Silvertooth, 2005). In drip irrigation, leaching frequency for moderately sensitive and sensitive plants could respectively be twice or three times in a week and daily (Hanson and May, 2011). For better and reliable plant production, equal emphasis should be put on preservation of soil water availability and leaching salts from the root zone before salt concentrations reach to plant tolerance levels (Ayers and Westcot, 1985).

Productivity is dependent on both soil quality and irrigation water quality. Since chlorine is highly soluble in water, it is accepted as the most common toxic ion in irrigation water and used as a criterion in water quality assessments (Nishanthiny et al., 2010; Mohammed, 2011).

Acceptable chloride level of irrigation water relies on the product and the method of irrigation. Remediation target for chloride of irrigation water is 350 mg L^{-1}. Groundwater quality assessment or inspection for irrigation is quite a significant issue in semi-arid and arid regions (Bhat et al., 2018). In case of availability of couple water resources with different qualities, poor quality water and good quality water should be mixed to reduce or prevent Cl^- damage. On the other hand, improper irrigation and poor drainage conditions may result in soil salinity. Besides unconscious irrigations, insufficient drainage and high water-table levels also play an important role in soil salinization. Soil salinization through irrigation practices is a current problem in regions with irrigated farming practices. Drainage systems should be constructed to get expected benefits from irrigations. Irrigations systems without proper drainage facilities or with improper drainage facilities will result in serious soil salinization problems. Groundwater surveys should be well-conducted to solve drainage problems. Spatial and temporal changes in groundwater levels and salinity levels should be analyzed; origin of salinity and potential sources of salts should also be well-assessed for success in agricultural practices (Ergene, 1982; Tekinel and Kanber, 1987).

In salt-affected regions, soil physical, chemical and biological characteristics are improved with the use of organic substances and such a case then improve plant growth and development. In this sense, organic matter treatments to improve soil properties play a great role in sustainable land use and crop productivity (Choudhary et al., 2004; Wong et al., 2009). Organic matters supplied through livestock manure and green fertilizers act as salt-binding materials and converts especially Na^+ and Cl^- ions into harmless forms (Zaka et al., 2003; Hanay et al., 2004; Tejada et al., 2006; Zahid and Niazi, 2006). In a study conducted on paddy plants, organic matter treatments were found to be highly effective in amelioration of salt-affected soils and improvement of paddy yields (Cha-um and Kirdmanee, 2011). In another study, high quantities of banana waste treatments increased soil Cl^- content and facilitated nitrate immobilization. On the other hand, KCl (above 400 mg dm^{-3}) application to plant residue covered soils reduced nitrogen mineralization capacity and microbial activity of the soil (Pereira et al., 2019).

Humic substances could also be used as an efficient tool to improve growth and development of plants exposed to salt stress. Humic substances reduce uptake of some toxic elements and increase uptake of beneficial elements, thus provide a kind of protection against harmful elements (Masciandro et al., 2002). Kulikova et al. (2005) and Xudan (1986) defined humic substances as anti-stressor substances under abiotic stress conditions.

Biofertilizers are used to alleviate salt effects and to improve plant tolerance against salt stress. Biofertilizer is defined as formulation containing one or more microorganisms (rhizobacters, endo and ectomycorrhizal fungi and the other various beneficial microscopic organisms). Biofertilizers alter nutrient composition of the soils, convert nutrients into more available forms and facilitate plant access to nutrients. Such a case then improves root and shoot growth, increases dry weights and positively influences fruit and seed yields (Bacilio et al., 2016).

Soil amendment methods are economic and technical approaches. Phytoremediation is defined as use of metal-removing plants for amelioration of polluted soils. Cleaning polluted lands with the use of plants is a cheap, environment-friendly and adoptable technique. The primary target of phytoremediation technology is to clean water, sediment and soils through decomposition, fixation and removal of pollutants (Yurdakul, 2015). Phytoremediation or vegetative bioremediation method is also used to reduce soil salt contents and improve plant tolerance to salinity. With the use of this method, salt ions are removed from the soil by growing salt-accumulating or salt-resistant plants (Qadir and Oster, 2002).

Grafting and selection of salt-resistant rootstocks offer different opportunities for reduction of damages induced by high leaf Cl^- accumulation in sensitive cultivars (Walker at al., 1982). Cl^- sensitivity of grafted Citrus species is designated by scions. On the other hand, leaf Na^+ levels are designated both by scion and rootstock (Lloyd et al., 1989). It was reported that excluding rootstocks used in grapevines grown under saline conditions reduced leaf Cl^- accumulation by about 60% (Stevens and Harvey, 1995). Advantages of the use of salt-resistant rootstocks in grafted plants were also identified in avocado. Analysis revealed that rootstocks reduced Cl^- accumulation in avocado leaves by about 33% (Lahav et al., 1992). Similar findings were also reported for soybean (Velagaletti et al., 1990).

There are large differences in chloride tolerance of the plants. Cultural crops exhibit a tolerance to chloride concentrations ranging from 350 mg L^{-1} to 2800 mg L^{-1} without a loss in yield. Fruits are generally the most sensitive species and they are followed by vegetables, field crops and forage crops. For instance, squash, beans, peas, onion, lettuce, soybean, sugarcane, pineapple, potato, tobacco, tea, kiwifruit, grape, citrus and coffee are sensitive to chlorine and negatively influenced by high chloride concentrations (Kleinhenz, 1999; Kacar and Katkat, 2018). Tomato is moderately sensitive, sugar beet, spinach, rape, cotton and barley are tolerant species (Maas and Hoffman, 1977; Xu el al., 2000). Use of tolerant species and cultivars in soils with Cl^- problem should be taken into consideration. Halophytes need Cl^- to increase their osmotic potentials

and sustain stomatal activity. Tolerant plants limit Cl^- uptake from the soil, reduce chlorine transport from the roots to shoots and accumulate chloride in special organs.

Conclusion

Problems encountered in agricultural production factors constituting soil and irrigation water quality result in physiological problems in plants and yield and quality losses. Cl^- toxicity resulted from high chlorine concentrations are among these problems. Cl^- the primary component of salt stress and rather than chloride deficiency, toxicity is a prevailing problem in world soils. As indicated by several researchers, chloride is also an essential micronutrient for plants. Cl^- plays a significant role in plant growth and development, photosynthesis, osmotic and stomal regulation, disease resistance and various other physiological processes. Chlorine dominantly exists in the form of Cl^- ion (chloride) in soils and plants. Important chlorine sources include soil structure, atmosphere, organic and mineral fertilizers and irrigation water.

There are various methods to be used to improve growth and development of the plants exposed to chloride stress. For this purpose, chloride content of ground and surface waters should be monitored and if the chlorine contents are high, alternative water resources should be used. High chloride-containing waters could be mixed with cleaner waters. Sub-surface drip irrigation with perforated pipes is also efficiently used to prevent salt accumulation in soils. Equal emphasis should also be put on leaching salts from the root zone before the concentrations reached to tolerance levels. Poor drainage conditions and high groundwater levels result in soil salinity. In this sense, drainage systems should be improved to prevent soil salinization. Sub-surface drip irrigation improves salinity management and water use efficiency. Sub-surface irrigation reduces salt accumulation within the root zone and results in better yield and fruit quality. Combined application of fertilizers with irrigation water (fertigation) improves fertilizer use efficiency and prevents soil salinity. Drip irrigation offers the most efficient use of water. Besides irrigation water, chloride accumulation may also come from fertilizers used. In this sense, non-chloride containing fertilizers or organic and chemical fertilizers with low chloride content should be used. Plants are not able to get sufficient water and nutrients from the soil under stress conditions. Nutrients are then applied from the leaves (foliar) to meet nutritional needs of the plants. Humic substances reduce uptake of some toxic elements and facilitate uptake of beneficial elements, thus positively influence plant growth and development. With similar effects, biofertilizers are also used as an alternative material under stress conditions. Phytoremediation is used as a cheap and environment-friendly method to reduce salt accumulation in soils and improve plant

tolerance to saline conditions. There are differences in chloride tolerance of plant species and tolerance limits of several cultural crops are known. Selection of tolerant species will provide significant advantages in chlorine toxicity-encountered fields. Use of chloride-resistant rootstocks will also significantly alleviate negative effects of toxicity.

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Chapter 6

A LITERATURE REVIEW ON THE WOOD CHEMICAL COMPOSITION OF FRUIT TREES

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INTRODUCTION

In a rapidly developing world, the increasing waste quantity significantly influences the health of ecosystems and the human community (Yusuf, 2017). Globally, lignocellulosic wastes are an important and historic source of energy, constituting 10–14% of the energy supply of the world (McKendry, 2002). Lignocellulosic wastes (plant biomass wastes) have mainly consisted of cellulose, lignin, and hemicellulose. They may be divided into several categories such as wood residues, grasses, waste paper, waste from tree pruning and from the forest maintenance, agricultural residues, food industry residues, and etc. (Mtui, 2009). According to European Union regulations, waste materials should be recycled and reused as much as possible to obtain value-added products to avoid depleting natural resources (Malinauskaite et al. 2017; Bruno et al. 2021). In recent years, the production of high value-added bioproducts from various biomass wastes has received significant attention from several communities such as the academic, civil, and medical industries (Yu et al. 2021).

Fruit orchards in the World covered 65 293 377 ha in 2019 (FAO, 2021). Fruit tree pruning is annual or biannually common operation. This operation to rejuvenate trees and increase production causes the production of large quantities of lignocellulosic biomass. These residues are not used commercially and are generally burned in the orchards and left on the field as soil enrichers (Romero-García et al. 2016). These residues are usually considered wastes, not resources (Spinelli and Picchi, 2010). Therefore, the management of this residue has often represented a disposal issue, rather than an opportunity for additional income. (Brand and Jacinto, 2020).

Fruit tree prunings have important levels of lignocellulosic polysaccharides. These polysaccharides can be converted to xylose, glucose, and other monomeric sugars (Muhlack et al. 2018). Also, the production of second-generation bio-products such as biodiesel, bioethanol, biohydrogen, and methane from lignocellulosic wastes are increasing rather than from energy crops (switchgrass, jatropha, hybrid poplar and, willow) (Mtui, 2009).

The fruit tree prunings can be converted to value-added products such as paper, particleboard, bioethanol, and fiberboard. Also, high value-added materials such as lignin, xylan, and nanocellulose can be obtained from them. For example, olive tree prunings could also be used to produce value-added products (antioxidants, materials, or chemicals) of interest to the several industries in biorefineries (Romero-García et al. 2016). Toledano et al. (2011) focused on the enhancement of the organosolv lignin produced from olive tree pruning. The utilization of orange (Gonzaléz et al. 2011),

olive (Requejo et al. 2012), kiwi (Gençer, 2015), hazelnut (Gençer and Özgül, 2016), and pomegranate (Gülsoy et al. 2015) tree prunings in the paper industry was reported by several authors. Antioxidant capacity of apricot pruning extracts investigated by Bruno et al. (2021). On the other hand, some studies focused on bioethanol production from olive tree prunings (Martínez-Patiño et al. 2015, 2018; Fernandes-Klajn et al. 2018).

It is very important to know the chemical structure of the wood in order to determine the potential usage area in the various industries. For example, cellulose in the pulp industry is the fundamental strength-giving component, hemicelluloses facilitate pulp beating at the refiner, and lignin inhibits strength development through refining. On the other hand, the lipophilic extractives in pulp cause problems in paper machine and paper (Annergren, 1999).

Many studies have been reported on the chemical composition of stem wood and pruning residues of fruit trees. This chapter reviews the literature on the wood chemical compositions of stem or pruning residues from 22 fruit trees.

WOOD CHEMICAL COMPOSITIONS OF SOME FRUIT TREES

The wood chemical compositions of fruit trees are given in the tables below (Table 2-23). As can be seen in the tables, the wood chemical compositions of fruit trees resemble other hardwoods such as beech, hornbeam, maple, poplar, and oak (Table 1). Wood chemical compositions of olive, apple, fig, and cherry have been extensively studied, but wood chemical compositions of other species have been received less attention.

Table 1: Wood chemical composition of some hardwood species.

Species	H (%)	C (%)	L (%)	HWS (%)	CWS (%)	1% NaOH (%)	E (%)	A (%)	Reference
Fagus orientalis	78.70	46.90	21.50	3.30	1.70	15.00	-	-	Istek et al. (2005)
Quercus robur	68.00	42.40	24.50	9.90	6.50	22.30	6.60[a]	0.63	Gülsoy et al. (2005)
Acer campastre	75.20	50.90	23.80	5.70	3.40	16.70	4.10[b]	-	Eroğlu and Gülsoy (2008)
Carpinus betulus	79.60	49.60	18.90	6.30	4.60	19.70	4.90[b]		Eroğlu and Gülsoy (2008)
Populus tremula	82.68	49.03α	16.69	3.04	1.73	15.34	3.22[b]	0.31	Gulsoy and Tufek (2013)

H: Holocellulose, C: Cellulose, L: Klason lignin, HWS: Hot water solubility, CWS: Cold water solubility, 1% NaOH: 1% NaOH solubility, E: Extractives, A: Ash, α: α-cellulose, [a]: alcohol-benzene solubility, [b]: alcohol solubility.

Table 2: Chemical composition of olive wood.

Species	H (%)	C (%)	L (%)	HWS (%)	CWS (%)	1% NaOH (%)	E (%)	A (%)	Reference
Olea europaea	61.10	-	21.50	-	-	-	-	0.80	Giachi et al. (2003)
Olea europaea (trimmings)	61.50	37.5α	19.70	-	-	-	-	-	López et al. (2001)
Olea europaea (pruning)	-	30.60	20.9	-	-	-	-	-	Romero et al. (2007)
Olea europaea	61.47	35.67α	19.71	-	-	-	-	-	Jiménez et al. (2000)
Olive tree prunings	69.14	41.09α	17.55	-	-	30.04	12.24[a]	1.04	Jiménez and López (1993)
Olea europaea (pruning)	-	36.40	17.10	-	-	-	-	2.30	Martín et al. (2010)
Olea europaea (pruning)	66.80	58.4α	23.20	23.30	-	34.40	9.50[a]	3.10	Toledano et al. (2011)
Olea europaea (pruning)	-	-	26.50	-	-	-	5.06[c]	-	Requejo et al. (2012a)
Olea europaea (pruning)	69.23	40.95α	19.51	-	-	-	9.00[a]	1.18	Requejo et al. (2012b)
Olea europaea (pruning)	-	20.24	27.43	-	-	-	-	5.50	Garcia-Maraver et al. (2013)
Olea europaea	-	31.48	23.50	-	-	-	-	1.43	Garcia-Maraver et al. (2013)
Olea europaea (pruning)	-	-	21.30	-	-	-	21.40[c]	4.70	Mateo et al. (2013)
Olea europaea (pruning)	60.83	33.61α	23.97	-	-	-	3.86[b]	3.01	Egüés et al. (2013)
Olea europaea (pruning)	64.63	51.16α	22.84	15.53	-	31.26	11.72[b]	3.54	Erdocia et al. (2014)
Olea europaea (pruning)	69.20	-	19.50	-	-	-	9.00[a]	1.20	Serrano et al. (2014)
Olea europaea (pruning)	-	32.60	28.00	22.2	-	33.3	-	2.80	García et al. (2014)
Olea europaea (pruning)	-	50.01α	22.33	-	-	-	-	-	Fernández-Rodríguez et al. (2017)
Olea europaea (pruning)	-	29.34α	24.44	-	-	-	12.19[b]	1.43	Sequeiros and Labidi (2017)
Olea europaea (pruning)	-	-	21.00	-	-	-	-	-	Rencoret et al. (2019)
Olea europaea (pruning)	-	-	-	21.48	-	-	9.72[a]	-	Pérez et al. (2018)
Olea europaea (middle)	-	40.70α	19.40	-	-	-	-	1.90	Ververis et al. (2004)
Olea europaea (Aydın)	70.42	39.76α	23.00	12.49	11.00	20.44	4.88[a]	1.15	Kılıç Penezoğlu (2019)
Olea europaea (Kahraman-maraş)	58.58	36.01α	25.30	20.72	15.86	28.27	16.98[a]	0.79	Kılıç Penezoğlu (2019)

H: Holocellulose, C: Cellulose, L: Klason lignin, HWS: Hot water solubility, CWS: Cold water solubility, 1% NaOH: 1% NaOH solubility, E: Extractives, A: Ash, α: α-cellulose, [a]: alcohol-benzene solubility, [b]: alcohol-toluene solubility, [c]: total extractives.

Table 3: Chemical composition of apple wood.

Species	H (%)	C (%)	L (%)	HWS (%)	CWS (%)	1% NaOH (%)	E (%)	A (%)	Reference
Apple tree prunings	-	-	-	14.22	-	-	2.58[a]	-	Passialis and Grigoriou (1999)
Apple tree pruning	62.84	30.60	17.00	17.98	-	49.24	1.09[c]	9.28	García et al. (2012)
Apple tree pruning	57.44	27.32α	26.15	-	-	-	10.71[c]	2.75	Egüés et al. (2013)
Apple tree pruning	71.00	-	29.00	8.60	7.88	33.61	3.23[b]	-	Sahin and Arslan (2013)
Apple tree pruning	-	27.30	26.70	-	-	-	-	2.80	García et al. (2014)
Malus domestica (branch wood)	57.44	27.32α	26.15	16.73	-	32.00	10.71[b]	3.25	Prado et al. (2012)
Malus domestica	-	-	22.70	-	-	-	-	-	Belyy et al. (2019)
Malus domestica (pruning)	-	32.50α	31.21	-	-	-	8.06[c]	2.24	Sequeiros and Labidi (2017)
Apple tree pruning	70.74	-	29.26	-	-	-	13.72[d]	-	Brand et al. (2018)

H: Holocellulose, C: Cellulose, L: Klason lignin, HWS: Hot water solubility, CWS: Cold water solubility, 1% NaOH: 1% NaOH solubility, E: Extractives, A: Ash, α: α-cellulose, [a]: dichloromethane solubility, [b]: alcohol-benzene solubility, [c]: alcohol-toluene solubility, [d]: total extractives.

Table 4: Chemical composition of Pyrus sp. (pear) wood.

Species	H (%)	C (%)	L (%)	HWS (%)	CWS (%)	1% NaOH (%)	E (%)	A (%)	Reference
Pear prunings	-	-	-	12.10	-	-	2.02[a]	-	Passialis and Grigoriou (1999)
Pyrus communis	76.05	46.89	22.83	-	-	-	3.60[b]	0.53	Tümen (1999)
Pyrus communis	-	32.47	25.90	-	-	-	3.69[b]	0.44	Fengel and Grosser (1975)
Pyrus pyraster	-	41.01	33.99	-	-	-	1.37[b]	0.57	Španić et al. (2018)

H: Holocellulose, C: Cellulose, L: Klason lignin, HWS: Hot water solubility, CWS: Cold water solubility, 1% NaOH: 1% NaOH solubility, E: Extractives, A: Ash, [a]: dichloromethane solubility, [b]: alcohol-benzene solubility.

Table 5: Chemical composition of peach wood.

Species	H (%)	C (%)	L (%)	HWS (%)	CWS (%)	1% NaOH (%)	E (%)	A (%)	Reference
Peach prunings	-	-	-	14.32	-	-	2.04[a]	-	Passialis and Grigoriou (1999)

H: Holocellulose, C: Cellulose, L: Klason lignin, HWS: Hot water solubility, CWS: Cold water solubility, 1% NaOH: 1% NaOH solubility, E: Extractives, A: Ash, [a]: dichloromethane solubility.

Table 6: Chemical composition of cherry wood.

Species	H (%)	C (%)	L (%)	HWS (%)	CWS (%)	1% NaOH (%)	E (%)	A (%)	Reference
Cherry prunings	-	-	-	15.99	-	-	3.71[a]	-	Passialis and Grigoriou (1999)
Cerasus avium	-	46.64	18.25	3.52	-	16.92	-	0.41	Bodîrlău et al. (2007)
Cerasus avium (sapwood)	77.10	39.96α	16.20	9.92	6.47	26.63	10.84[b]	0.53	Gençer and Gül Türkmen (2016)
Cerasus avium (heartwood)	77.33	39.38α	17.83	6.75	4.57	23.71	6.27[b]	0.55	Gençer and Gül Türkmen (2016)
Prunus avium	69.10	40.70	18.10	-	-	-	7.10[b]	0.80	Nikitin (1966)
Prunus avium	67.00	-	26.40	-	-	-	-	-	Telmo and Lousada (2011)
Cherry tree pruning	79.90	-	20.1	14.48	8.51	39.73	6.25[c]	-	Sahin and Arslan (2013)
Prunus avium	-	44.57	26.16	-	-	-	9.98[c]	0.44	Španić et al. (2018)
Prunus cerasus	-	43.00	-	-	-	-	2.10[d]	-	Gallina et al. (2018)
Prunus padus	80.70	36.30	20.50	4.60	3.00	-	2.30[c]	0.58	Fengel and Grosser (1975)
Prunus padus	-	41.17	20.24	-	0.56	-	0.72[b]	0.19	Fengel and Grosser (1975)
Prunus pensylvanica (sapwood)	80.96	59.98	12.27	4.03	1.96	-	2.97[c]	0.17	Fengel and Grosser (1975)
Prunus pensylvanica (heartwood)	81.58	58.26	14.82	2.48	0.67	-	1.18[c]	0.47	Fengel and Grosser (1975)
Prunus sargentii	-	53.00	16.10	-	-	-	-	-	Cha et al. (2017)
Prunus serotina	78.49	59.11α	37.20	-	-	-	19.64[f]	0.68	Ruiz-Aquino et al. (2019)
Prunus serrulata	-	-	19.30[g]	11.80	-	-	1.90[e]	-	Song et al. (2017)

H: Holocellulose, C: Cellulose, L: Klason lignin, HWS: Hot water solubility, CWS: Cold water solubility, 1% NaOH: 1% NaOH solubility, E: Extractives, A: Ash, α: α-cellulose, [a]: dichloromethane solubility, [b]: alcohol solubility, [c]: alcohol-benzene solubility, [d]: n-hexane solubility, [e]: acetone solubility, [f]: total extractives, [g]: total lignin.

Table 7: Chemical composition of lemon wood.

Species	H (%)	C (%)	L (%)	HWS (%)	CWS (%)	1% NaOH (%)	E (%)	A (%)	Reference
Citrus lemon var. *lamas*	83.17	47.36α	23.92	4.45	3.23	14.42	1.23[a]	1.57	Tutuş et al. (2018)
Citrus limon (branch)		44.40	25.10	2.50	3.00	18.90	1.0[b]	3.50	Khider et al. (2021)

H: Holocellulose, C: Cellulose, L: Klason lignin, HWS: Hot water solubility, CWS: Cold water solubility, 1% NaOH: 1% NaOH solubility, E: Extractives, A: Ash, α: α-cellulose, [a]: alcohol-benzene solubility, [b]: ethanol-cyclohexane solubility.

Table 8: Chemical composition of plum wood.

Species	H (%)	C (%)	L (%)	HWS (%)	CWS (%)	1% NaOH (%)	E (%)	A (%)	Reference
Prunus domestica (stem)	-	51.66	32.26	4.17	-	-	2.85[a]	-	Kiaei et al. (2014)
Prunus domestica (branch)	-	53.24	33.62	3.44	-	-	1.53[a]	-	Kiaei et al. (2014)
Prunus domestica	-	43.53	32.40	-	-	-	13.42[b]	0.02	Španić et al. (2018)

H: Holocellulose, C: Cellulose, L: Klason lignin, HWS: Hot water solubility, CWS: Cold water solubility, 1% NaOH: 1% NaOH solubility, E: Extractives, A: Ash, [a]: alcohol-acetone solubility, [b]: alcohol-benzene solubility.

Table 9: Chemical composition of apricot wood.

Species	H (%)	C (%)	L (%)	HWS (%)	CWS (%)	1% NaOH (%)	E (%)	A (%)	Reference
Prunus armeniaca (stem)	-	49.30	31.34	3.39	-	-	4.72[a]	0.86	Tajik et al. (2015)
Prunus armeniaca (branch)	-	51.57	31.67	2.74	-	-	3.68[a]	0.37	Tajik et al. (2015)
Prunus armeniaca	80.06	49.50	30.03	7.74	4.20	27.40	5.88[b]	0.48	Tutuş et al. (2016a)
Prunus armeniaca	79.50	42.33α	16.43	8.94	6.75	-	-	-	Gençer et al. (2018)
Apricot prunings	-	-	-	13.87	-	-	2.58[c]	-	Passialis and Grigoriou (1999)

H: Holocellulose, C: Cellulose, L: Klason lignin, HWS: Hot water solubility, CWS: Cold water solubility, 1% NaOH: 1% NaOH solubility, E: Extractives, A: Ash, α: α-cellulose, [a]: alcohol-acetone solubility, [b]: toluene-acetone-alcohol solubility, [c]: dichloromethane solubility.

Table 10: Chemical composition of kiwi wood.

Species	H (%)	C (%)	L (%)	HWS (%)	CWS (%)	1% NaOH (%)	E (%)	A (%)	Reference
Actinidia deliciosa (pruning)	73.50	38.30 α	25.26	-	-	-	2.01[a]	-	Gençer (2015)
Actinidia sinensis	-	38.40 α	24.90	-	-	40.40	-	-	Ashori et al. (2012)
Actinidia sinensis (pruning)	70.57	38.38	26.27	18.43	9.97	41.62	6.24[b]	2.05	Nemli et al. (2003)

H: Holocellulose, C: Cellulose, L: Klason lignin, HWS: Hot water solubility, CWS: Cold water solubility, 1% NaOH: 1% NaOH solubility, E: Extractives, A: Ash, α: α-cellulose, [a]: alcohol solubility, [b]: alcohol-benzene solubility.

Table 11: Chemical composition of pomegranate wood.

Species	H (%)	C (%)	L (%)	HWS (%)	CWS (%)	1% NaOH (%)	E (%)	A (%)	Reference
Punica granatum	-	39.00	21.00	-	-	-	4.00[a]	1.20	Pettersen (1984)
Punica granatum (stem)	73.50	39.92α	25.29	6.90	4.53	-	2.53[b]	-	Gülsoy et al. (2015)
*Punica granatum (*branch)	72.98	38.37α	21.04	11.29	10.18	-	4.17[b]	-	Gülsoy et al. (2015)

H: Holocellulose, C: Cellulose, L: Klason lignin, HWS: Hot water solubility, CWS: Cold water solubility, 1% NaOH: 1% NaOH solubility, E: Extractives, A: Ash, α: α-cellulose, [a]: alcohol solubility, [b]: acetone-water solubility.

Table 12: Chemical composition of almond wood.

Species	H (%)	C (%)	L (%)	HWS (%)	CWS (%)	1% NaOH (%)	E (%)	A (%)	Reference
Prunus dulcis	50.66	31.34 α	34.35	16.70	12.17	29.01	7.02[a]	3.39	Moussa et al. (2018)
Prunus dulcis	-	35.30	-	-	-	-	7.10[b]	-	Gallina et al. (2018)
Prunus dulcis	60.70	40.70α	19.20	12.30	11.30	28.70	5.00[a]	3.60	Mechi et al. (2016)
Prunus dulcis (pruning base)	-	40.70α	27.30	-	-	-	-	2.20	Ververis et al. (2004)
Prunus dulcis (pruning middle)	-	39.70α	26.50	-	-	-	-	2.40	Ververis et al. (2004)
Prunus dulcis (pruning top)	-	37.10α	25.70	-	-	-	-	2.30	Ververis et al. (2004)

H: Holocellulose, C: Cellulose, L: Klason lignin, HWS: Hot water solubility, CWS: Cold water solubility, 1% NaOH: 1% NaOH solubility, E: Extractives, A: Ash, α: α-cellulose, [a]: alcohol-toluene solubility, [b]: n-hexane solubility.

Table 13: Chemical composition of hazelnut wood.

Species	H (%)	C (%)	L (%)	HWS (%)	CWS (%)	1% NaOH (%)	E (%)	A (%)	Reference
Corylus avellana	-	47.00	22.00	-	-	-	3.00[a]	0.40	Pettersen (1984)
Corylus avellana (prunings)	82.07	41.33	15.89	3.70	2.90	18.48	2.83[a]	0.72	Gençer and Özgül (2016)
Corylus colurna	68.80	43.50α	23.6	7.40	6.30	28.5	7.42[b]	0.30	Akgul (2016)

H: Holocellulose, C: Cellulose, L: Klason lignin, HWS: Hot water solubility, CWS: Cold water solubility, 1% NaOH: 1% NaOH solubility, E: Extractives, A: Ash, α: α-cellulose, [a]: alcohol solubility, [b]: alcohol-benzene solubility.

Table 14: Chemical composition of mango wood.

Species	H (%)	C (%)	L (%)	HWS (%)	CWS (%)	1% NaOH (%)	E (%)	A (%)	Reference
Mangifera indica	-	37.60 α	31.80	-	-	-	-	1.29	Chakrabarti et al. (2006)
Mangifera indica	-	58.60	19.31	-	-	-	-	-	Silva (2018)

H: Holocellulose, C: Cellulose, L: Klason lignin, HWS: Hot water solubility, CWS: Cold water solubility, 1% NaOH: 1% NaOH solubility, E: Extractives, A: Ash, α: α-cellulose.

Table 15: Chemical composition of orange wood.

Species	H (%)	C (%)	L (%)	HWS (%)	CWS (%)	1% NaOH (%)	E (%)	A (%)	Reference
Citrus aurantium	81.18	48.84α	19.73	7.94	5.66	14.92	7.94[a]	2.69	Tutuş et al. (2016b)
Citrus aurantium	-	40.4	20.0	-	-	-	-	-	Agarwal et al. (2012)
Citrus pruning	-	-	19.95	-	-	-	-	3.37	González et al. (2011)
Citrus sinensis (pruning)	73.20	48.00α	20.00	-	-	-	3.60[b]	3.40	González et al. (2013)
Citrus sinensis	80.47	50.68α	20.82	11.80	6.80	14.30	13.66[c]	2.42	Kesik et al. (2017)
Citrus sinensis	78.10	-	19.63	4.11	-	-	4.19[c]	2.84	Porto (2017)
Citrus sinensis (pruning)	-	48.04α	19.95	-	-	-	-	3.40	Espinosa et al. (2020)
Citrus sinensis	-	-	22.00	-	-	-	-	-	Kravetz et al. (2020)
Citrus sinensis (pruning)	75.95	49.05α	20.80	-	-	-	2.45[b]	1.95	Espinach et al. (2020)

H: Holocellulose, C: Cellulose, L: Klason lignin, HWS: Hot water solubility, CWS: Cold water solubility, 1% NaOH: 1% NaOH solubility, E: Extractives, A: Ash, α: α-cellulose, [a]: alcohol-toluene solubility, [b]: alcohol-benzene solubility, [c]: alcohol solubility.

Table 16: Chemical composition of persimmon wood.

Species	H (%)	C (%)	L (%)	HWS (%)	CWS (%)	1% NaOH (%)	E (%)	A (%)	Reference
Diospyros celebica	76.59	50.62	26.72	13.54	-	-	9.71[a]	0.97	Asdar et al. (2016)
Diospyros kaki	70.75	39.46	29.82	3.54	2.08	13.27	4.45[b]	0.42	Tutuş et al. (2014)

H: Holocellulose, C: Cellulose, L: Klason lignin, HWS: Hot water solubility, CWS: Cold water solubility, 1% NaOH: 1% NaOH solubility, E: Extractives, A: Ash, [a]: ethanol-toluene solubility, [b]:toluene-acetone-alcohol solubility.

Table 17: Chemical composition of fig wood.

Species	H (%)	C (%)	L (%)	HWS (%)	CWS (%)	1% NaOH (%)	E (%)	A (%)	Reference
Ficus altissima		48.04	30.35	9.59	9.24	-	9.91[c]	3.02	Nasser (2012)
Ficus carica	55.90	-	23.30	-	-	-	-	2.60	Giachi et al. (2003)
Ficus carica	60.11	47.06	19.64	12.70	9.24	21.57	4.18[a]	5.10	Moussa et al. (2018)
Ficus carica (Aydın)	72.20	38.47α	22.71	8.42	7.43	19.62	1.00[b]	3.13	Odabaş Serin and Kılıç Penezoğlu (2020)
Ficus carica (Kahraman-maraş)	64.43	41.78α	16.18	16.60	15.47	24.53	7.92[b]	3.70	Odabaş Serin and Kılıç Penezoğlu (2020)
Ficus exasperata	-	-	-	-	-	-	-	1.85	Ogunkunle and Oladele (2008)
Ficus exasperata (base)	-	-	18.07	12.69	11.18	10.44	-	-	Anguruwa et al. (2020)
Ficus exasperata (middle)	-	-	17.78	11.63	10.52	9.77	-	-	Anguruwa et al. (2020)
Ficus exasperata (top)	-	-	18.98	13.81	12.16	11.08	-	-	Anguruwa et al. (2020)
Ficus ingens	-	-	-	-	-	-	-	1.97	Ogunkunle and Oladele (2008)
Ficus lutea	-	-	-	-	-	-	-	2.16	Ogunkunle and Oladele (2008)
Ficus mucuso	-	-	-	-	-	-	-	1.98	Ogunkunle and Oladele (2008)
Ficus natalensis	-	-	-	-	-	-	-	1.73	Ogunkunle and Oladele (2008)
Ficus ottonifolia	-	-	-	-	-	-	-	2.22	Ogunkunle and Oladele (2008)
Ficus ovata	-	-	-	-	-	-	-	2.01	Ogunkunle and Oladele (2008)
Ficus polita	-	-	-	-	-	-	-	2.01	Ogunkunle and Oladele (2008)
Ficus populifolia	-	-	-	-	-	-	-	1.93	Ogunkunle and Oladele (2008)
Ficus septica	-	-	-	-	-	-	-	2.22	Amirta et al. (2016a)
Ficus sur	-	-	-	-	-	-	-	1.99	Ogunkunle and Oladele (2008)
Ficus thonningii	-	-	-	-	-	-	-	1.39	Ogunkunle and Oladele (2008)
Ficus umbellata	-	-	-	-	-	-	-	1.89	Ogunkunle and Oladele (2008)
Ficus sycomorus	61.10	-	31.10	-	-	-	5.50[c]	2.30	Tamburini et al. (2017)

H: Holocellulose, C: Cellulose, L: Klason lignin, HWS: Hot water solubility, CWS: Cold water solubility, 1% NaOH: 1% NaOH solubility, E: Extractives, A: Ash, α: α-cellulose, [a]: alcohol-toluene solubility, [b]: alcohol-benzene solubility. [c]: total extractives.

Table 18: Chemical composition of mulberry wood.

Species	H (%)	C (%)	L (%)	HWS (%)	CWS (%)	1% NaOH (%)	E (%)	A (%)	Reference
Morus alba	-	47.20	23.17	-	-	-	11.96[a]	1.39	Španić et al. (2018)
Morus alba	-	-	-	-	-	-	-	0.83	Abe et al. (2007)
Morus alba (stem)	85.98	53.08	21.30	14.83	6.04	14.83	11.13[b]	-	Gündüz et al. (2009)
Morus alba (branch)	85.63	51.35	21.15	15.35	6.09	14.35	11.65[b]	-	Gündüz et al. (2009)
Morus alba	79.98		18.30	1.89	0.74	18.12	-	-	Ji et al. (2018)
Morus nigra	69.15	45.00α	21.42	4.98	3.90	18.00	2.60[a]	0.85	Walia (2013)
Morus rubra (sapwood)	-	-	-	12.56	9.12	-	-	-	Hawley et al. (1924)
Morus rubra (heartwood)	-	-	-	10.20	7.08	-	-	-	Hawley et al. (1924)

H: Holocellulose, C: Cellulose, L: Klason lignin, HWS: Hot water solubility, CWS: Cold water solubility, 1% NaOH: 1% NaOH solubility, E: Extractives, A: Ash, α: α-cellulose, [a]: alcohol-benzene solubility, [b]: alcohol solubility.

Table 19: Chemical composition of dogwood wood.

Species	H (%)	C (%)	L (%)	HWS (%)	CWS (%)	1% NaOH (%)	E (%)	A (%)	Reference
Cornus australis	72.27	43.24α	16.32	6.40	4.42	18.30	-	0.56	Keskin et al. (2018)

H: Holocellulose, C: Cellulose, L: Klason lignin, HWS: Hot water solubility, CWS: Cold water solubility, 1% NaOH: 1% NaOH solubility, E: Extractives, A: Ash, α: α-cellulose.

Table 20: Chemical composition of avocado wood.

Species	H (%)	C (%)	L (%)	HWS (%)	CWS (%)	1% NaOH (%)	E (%)	A (%)	Reference
Persea americana	73.29	55.05α	14.85	2.64	1.51	19.75	4.50[a]	-	Altunışık Bülbül and Gençer (2021)

H: Holocellulose, C: Cellulose, L: Klason lignin, HWS: Hot water solubility, CWS: Cold water solubility, 1% NaOH: 1% NaOH solubility, E: Extractives, A: Ash, α: α-cellulose, [a]: alcohol solubility.

Table 21: Chemical composition of highbush blueberry wood.

Species	H (%)	C (%)	L (%)	HWS (%)	CWS (%)	1% NaOH (%)	E (%)	A (%)	Reference
Vaccinium corymbosum (bush residue)	63.8	51.9α	26.6	-	-	-	6.90[a]	1.80	Pacheco et al. (2018)

H: Holocellulose, C: Cellulose, L: Klason lignin, HWS: Hot water solubility, CWS: Cold water solubility, 1% NaOH: 1% NaOH solubility, E: Extractives, A: Ash, α: α-cellulose, [a]: acetone solubility.

Table 22: Chemical composition of cashew wood.

Species	H (%)	C (%)	L (%)	HWS (%)	CWS (%)	1% NaOH (%)	E (%)	A (%)	Reference
Anacardium occidentale	78.62	-	20.46	-	-	-	0.92[a]	0.99	Montenegro et al. (2010)

H: Holocellulose, C: Cellulose, L: Klason lignin, HWS: Hot water solubility, CWS: Cold water solubility, 1% NaOH: 1% NaOH solubility, E: Extractives, A: Ash, [a]: total extractives.

Table 23: Chemical composition of Artocarpus sp. (breadfruit, jackfruit) wood.

Species	H (%)	C (%)	L (%)	HWS (%)	CWS (%)	1% NaOH (%)	E (%)	A (%)	Reference
Artocarpus altilis	69.39	46.73α	26.87	-	-	-	-	-	Amirta et al. (2016b)
Artocarpus elasticus	68.8	49.05α	31.97	-	-	-	-	-	Amirta et al. (2016b)
Artocarpus elasticus	78.00	50.70α	28.70	3.20	-	14.60	1.50[a]	1.50	Istikowati et al. (2016)
Artocarpus integrifolia	-	38.05α	33.10	-	-	-	-	0.48	Chakrabarti et al. (2006)

H: Holocellulose, C: Cellulose, L: Klason lignin, HWS: Hot water solubility, CWS: Cold water solubility, 1% NaOH: 1% NaOH solubility, E: Extractives, A: Ash, α: α-cellulose, [a]: alcohol-toluene solubility.

CONCLUSIONS

The pruning of fruit trees can present a significant amount of residues, which are usually considered waste and not resource. Modern technologies for cost-effective recycling may change this situation. (Magagnotti et al. 2013). In the last years, the conversion to high value-added bioproducts of various lignocellulosic wastes such as fruit tree pruning residues has received significant attention from scientists. Lignocellulosic waste-based fuels provide energy and reduce the environmental impact. Processing and recycling of lignocellulosic wastes will reduce the amount of lignocellulosic waste reaching dumpsites or burning openly (Bhange et al. 2012).

Pruning residues of fruit trees exhibit the characteristic features of hardwoods in terms of the chemical structure of their woods. Therefore, these residues convert to biogas, bioenergy, biofuels, or bioproducts. Further environmental impact and techno-economic assessments are required to find the best biorefinery plans that contribute to sustainable energy supply and zero waste in the future (del Mar Contreras et al. 2020). Also, more research is needed for efficient and economically viable processes to convert to valuable products of lignocellulosic wastes such as fruit tree prunings (Bhange et al. 2012).

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Chapter 7

ANALYSIS OF BEE PRODUCTS IN TERMS OF GLOBAL PRODUCTION, CONSUMPTION, AND INTERNATIONAL TRADE

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INTRODUCTION

The tendency to provide the energy and nutrients needed by the body with natural resources, which emerged as a result of the desire to live a healthy life, has increased the importance of beekeeping. Besides being an important agricultural activity, beekeeping practices can also contribute to the pollination of crops, assuring high crop yields. It is known that bee colonies and beekeeping practices are needed for the sustainability of natural balance.

Beekeeping is an animal husbandry activity that can be performed without being dependent on the soil, carried out in harmony with other agricultural activities, and considered to be the second source of income for households. Factors such as not requiring much capital, not being dependent on the soil, and needing less labor force bring beekeeping to the fore (Kuvancı et al. 2013; Saner et al. 2018: 43).

Today, beekeeping is mostly undertaken as a small family business. This makes beekeeping important for rural development. Similarly, in the world, beekeeping is constantly evolving, and the variety of bee products makes beekeeping an important sector. Pollination-based beekeeping is widespread in the United States, while medical beekeeping in the Far East countries and beekeeping for food in Europe are more common. In the USA, millions of colonies go on a cross-country trip for almond pollination every year, and renting hives out to almond farmers is preferred during flowering periods in order to get more quality products (Merdan and Durmuş, 2018: 1103).

As a result of beekeeping, bee products such as honey, beeswax, royal jelly, pollen, bee venom, and propolis are obtained. These products have antibacterial, antimicrobial, antiviral, and antiparasitic properties due to their significant vitamin, mineral, and enzyme content. Bee products and apitherapy practices such as royal jelly, apilarnil, bee bread, propolis, and bee venom have become widespread in the world in recent years. Today, bee products such as honey, bee venom, propolis, and royal jelly are used in many countries within the scope of "Apitherapy," which is defined as "Treatment with Bee Products." Apilarnil (drone larvae) and queen larvae were first discovered and developed in Romania. Bee products make an important contribution to creating resistance to diseases and to leading a healthy life (Monte et al., 2013). Such reasons make beekeeping an indispensable agricultural activity all over the world.

Taking these as a starting point, the present study offers an analysis of bee products in terms of global production, consumption, and international trade. The study attempts to provide a global overview of bee products such as honey, beeswax, pollen, propolis, royal jelly, and bee venom.

1. AN OVERVİEW OF BEE PRODUCTS

Bee products are of great importance for human life and health. Among bee products, especially honey is the most known and preferred food source. Honey contains 80% sugar and 17% water. The remaining 3% consists of amino acids, minerals, vitamins, coloring agents, and enzymes (Mutlu et al. 2017). The most important feature that distinguishes honey from other sweet substances is its enzyme content. The classification of honey varies depending on the production-marketing style and the source from which it is obtained. Honey is named strained honey or comb honey depending on its production-marketing style or flower honey or honeydew depending on its source. Flower honey is obtained by bees collecting the nectar secreted by the nectar glands on flowering plants. Honeydew is a type of honey produced by colonies gathering sweet foods secreted by insects living on forest trees such as pine, beech, spruce, and oak. Honey that does not have drug residues and contains enzymes in certain proportions is classified as high-quality and valuable honey. Crystallization of honey may occur earlier, depending on the plants from which the honey is obtained. Honey has antioxidant (Saral et al. 2016) and antimicrobial (Isla et al. 2011) properties and is also used in wound healing (Molan and Betts 2004) and ulcer treatment (Ajibola et al. 2012. Albayrak and Albayrak 2008. Ulusoy 2012).

Besides honey; pollen, propolis, royal jelly, beeswax, and bee venom have important benefits for human health. Pollen is a rich source of protein containing vitamins, lipids, carbohydrates, and minerals (Campos et al. 2003. Andelkovic et al. 2012). Pollen also has antioxidant (Saral et al. 2016) and antibacterial (Garcia et al. 2001) properties. Propolis is a resinous material produced by honeybees mixing plant exudates collected from fresh shoots and buds with beeswax and their own secretions (Tosi et al. 1996. Doğan and Hayaloğlu 2012, 39. Hegazi et al. 2013). Produced in large quantities in countries such as Brazil, China, and Japan, propolis finds use in traditional and modern medicine and prevents the development of cancerous cells, reduces the proliferation of tumor cells, and has high antioxidant and antimicrobial effects (Banskota et al. 2001; Inoue et al. 2008. Saral et al. 2016. Mutlu et al. 2017, 80. Saral and Yavuz 2020, 173). Royal jelly is a special nutrient secreted from the glands in the heads of worker bees; it is used in the nutrition of larvae and of adult queens and contains important vitamins for human health and nutrition (Merdan and Durmuş 2018, 1104). Royal jelly, which has a white-creamy color, contains protein, lipid vitamins, sugar, amino acids, and bioactive compounds (Zong and Wu 2014). Royal jelly also lowers cholesterol, increases sex hormones, and has positive effects against aging (Guo et al. 2007). Beeswax finds a wide range of uses in honeycomb production, in the cosmetics industry, in

paint making, in dentistry, and in waterproof material production. Beeswax color varies a great deal depending on the process (Merdan and Durmuş 2018, 1104). Beeswax contains high amounts of hydrocarbons, free fatty acids, and alkali esters, and small amounts of free alcohol (Doğaroğlu 2008). Bee venom is used in the treatment of many diseases such as rheumatism, pain, and cancer (Hegazi et al. 2013). Bee venom contains important components such as melittin, apamin, and phospholipase A2 (Son et al. 2007).

2. BEEKEEPİNG ACROSS THE WORLD

Beekeeping is carried out for different purposes across the world. It is performed to generate export income in countries in the Middle East and Central and South America, to generate rural income in countries such as Spain, Hungary, Poland, Turkey, and Greece, and to ensure pollination in plants in countries such as the USA, Japan, and Canada (Uzundumlu et al. 2011). In the top agricultural producing countries, in the USA, for example, plant producers pay $ 41 million annually to beekeepers to ensure pollination in the plants, and, more importantly, they earn $ 3.2 billion themselves due to the contribution of bees to their production. Similarly, another study conducted in the USA reported that approximately 1/3 ($ 10 billion) of the total product value of $ 30 billion obtained from about 40 plant species was provided by the contributions of honey bees.

According to the 2018 global honey production data, China ranks first, Turkey ranks second, and Argentina ranks third among the top honey-producing countries. China accounts for 24.1% of the total honey production in the world. EU countries, on the other hand, have a 13.9% share in global honey production. Regarding the number of hives, India ranks first with a share of 17.4%, China ranks second with a share of 9.8%, and Turkey ranks third with a share of 8.6% (FAO, 2020).

On the other hand, China is the first, New Zealand is the second, and Argentina is the third-largest exporter of honey. Finally, the USA is the first-largest importer of honey, followed by Germany and Japan (FAO, 2020).

Table 1. Beekeeping Industry by Country (2018)

Countries	Number of Hives (hives)	Honey production (tons)	Honey yield (kg/ hive)
India	13,048,275	67,442	5,17
China	9,048,546	446,900	49,39
Turkey	7,947,687	114,113	14,36
Iran	6,601,394	77,567	11,75
Ethiopia	6,018,223	50,000	8,31
Russia	3,182,399	65,006	20,43
Argentina	3,020,370	79,468	26,31
Tanzania	3,019,784	30,584	10,13
Spain	2,965,557	36,394	12,27
The United States of America	2,803,000	69,104	24,65
Mexico	2,172,107	64,253	29,58
Korea	2,165,616	26,720	12,34
Central African Republic	1,679,762	16,200	9,64
Romania	1,602,453	29,162	18,20
Poland	1,586,063	23,472	14,80
Greece	1,556,404	21,400	13,75
Kenya	1,533,668	20,525	13,38
Angola	1,153,618	23,411	20,29
Brasil	1,017,506	42,346	41,62
Serbia	914,134	11,427	12,50

Source: FAO Statistics, http://www.fao.org/faostat/en/#data/HS, 25.12.2020

Table 1 summarizes the global beekeeping industry by country. According to the 2018 data, the countries with the highest number of hives are India, China, and Turkey, respectively. India is the country with the most hives (13,048,275), followed by China (9,048,546) and Turkey (7,947,687). China is the top honey-producing country (446,900 tons), followed by Turkey (114,113 tons) and Argentina (79,468 tons). Among the countries with the highest honey yield, China ranks first with 49.39 kg/hive, followed by Brazil (41.62 kg/hive) and Mexico (29.58 kg/hive) (Table 1).

Table 2. Global Beekeeping Industry Data by Years

Year	**Number of Hives**	**Honey Production (tons)**	**Beeswax Production (ton)**	**Honey Yield (kg/hive)**
2018	92,291,583	1,851,541	69,633	20,06
2017	90,998,348	1,879,818	68,972	20,66
2016	90,232,111	1,863,243	68,842	20,65
2015	88,042,819	1,824,191	67,481	20,72
2014	87,421,183	1,763,742	66,396	20,18
2013	84,854,694	1,722,109	64,878	20,29
2012	83,058,317	1,650,335	64,355	19,87
2011	80,403,600	1,615,914	64,887	20,10
2010	79,683,687	1,545,379	64,991	19,39
2009	77,095,057	1,505,462	63,567	19,53
2008	76,119,908	1,517,882	63,717	19,94
2007	74,967,203	1,453,661	60,833	19,39
2006	75,517,406	1,514,376	60,826	20,05
2005	74,276,467	1,423,232	60,676	19,16
2004	72,973,593	1,364,392	60,406	18,70
2003	72,009,100	1,336,968	58,757	18,57
2002	71,829,008	1,288,264	60,381	17,94
2001	70,393,523	1,241,533	57,674	17,64
2000	69,300,054	1,260,084	58,714	18,18
1999	67,075,297	1,245,018	57,653	18,56
1998	66,613,419	1,190,787	54,801	17,88
1997	65,941,668	1,161,107	54,856	17,61
1996	66,000,573	1,096,758	52,790	16,62
1995	66,171,863	1,154,136	52,564	17,44
1994	66,110,859	1,118,863	52,235	16,92
1993	66,712,015	1,142,401	52,240	17,12
1992	67,499,709	1,122,511	48,140	16,63
1991	69,960,216	1,226,000	47,591	17,52
1990	69,237,913	1,172,611	48,168	16,94

Source: FAO Statistics, http://www.fao.org/faostat/en/#data/HS, 25.12.2020

From the 1990s to 2018, the number of hives, honey production, beeswax production, and honey yield in the world have been in a continuously increasing trend. The number of hives increased from 69,237,913 in 1990 to 92,291,583 in 2018. Honey yield increased from 16,94 kilograms per hive in 1990 to 20,06 kilograms in 2018. Honey production increased from 1,172,611 tons in 1990 to 1,851,541 tons in 2018. Similarly, beeswax production increased from 48,168 tons to 69,633 tons (Table 2).

Table 3. Global Beeswax Production (Ton)

Countries	2011	2012	2013	2014	2015	2016
India	23,000	23,100	23,200	23,300	23,400	23,500
Ethiopia	5,000	5,000	5,000	5,310	5,523	5,542
Argentina	4,700	4,700	4,794	4,897	4,863	4,880
Turkey	4,235	4,222	4,241	4,053	4,756	4,440
Republic of Korea	3,063	3,063	3,063	4,018	3,620	3,456
Kenya	2,500	2,500	2,500	2,500	2,506	2,504
Angola	2,300	2,300	2,300	2,303	2,318	2,313
Mexico	1,966	1,868	2,010	1,862	1,439	1,844
Tanzania	1,830	1,850	1,870	1,881	1,844	1,842
Brasil	1,850	1,650	1,650	1,700	1,746	1,761
USA	1,600	1,606	1,612	1,615	1,614	1,613
Spain	1,614	1,545	1,712	1,688	1,617	1,485
Uganda	1,300	1,330	1,284	1,290	1,299	1,308
Uruguay	1,000	1,058	1,086	1,073	1,086	1,100
Dominican Republic	1,020	1,024	1,039	1,054	1,069	1,084
Central African Republic	775	799	781	790	800	810
Chile	600	605	611	614	617	620
Pakistan	462	462	463	464	465	466
France	426	425	428	430	433	435
Portugal	239	208	283	308	378	417
Madagascar	410	410	405	407	411	413
Greece	408	384	364	538	434	412
Senegal	300	310	310	319	350	351
Bulgaria	302	315	312	314	316	318
Cameroon	300	300	298	299	300	301
Czech Republic	303	276	278	254	275	293
New Zealand	268	268	273	274	278	280
Australia	303	298	293	288	282	277
Jamaica	250	250	250	250	252	252
El Salvador	215	217	218	218	218	218
Burundi	175	175	175	176	190	195
Paraguay	150	153	157	157	159	160
Sierra Leone	131	134	137	140	142	145
Guinea	132	134	137	138	140	142
Syria	128	130	133	135	138	140
Egypt	180	175	147	115	100	131
Slovakia	151	122	113	114	118	121
Guinea-Bissau	100	100	100	100	100	100
Other	1,209	1,017	999	1,001	996	994
World	64,895	64,483	65,026	66,387	66,592	66,663

Source: Beekeeping Product Report, 2017

Considering the data after 2011, there has been an increase in beeswax production. Beeswax production increased from 64,895 tons in 2011 to

66,663 tons in 2016. Approximately 35% of the total beeswax in the world is produced in India. India is followed by Ethiopia and Argentina.

The beekeeping industry differs in countries. Table 4 summarizes the number of hives and the main use of beekeeping in different countries.

Table 4. Beekeeping Industry across the World (2018)

Countries	Number of Hives	The Use of Beekeeping
China	9,048,546	Apitherapy, Bee Products
Turkey	7,947,687	???
Argentina	3,020,370	Propolis
USA	2,803,000	Pollination
Korea	2,165,616	Bee Products, Apitherapy
Romania	1,602,453	Apitherapy, Bee Products
Poland	1,586,063	Beekeeping Supplies
Brasil	1,017,506	Propolis
Egypt	841 (2016)	Propolis Studies
France	794 (2016)	Bee Products (Lavender Honey)
Hungary	772 (2016)	Bee Venom, Hive Air
Chile	453 (2016)	Apitherapy
Bulgaria	747 (2016)	Beekeeping Practices
Germany	743 (2016)	R&D Medicines, Hive Air

Source: FAO Statistics, http://www.fao.org/faostat/en/#data/HS, 25.12.2020

Table 4 presents the countries with the highest number of hives and the main use of beekeeping in these countries. Accordingly, China is mostly known for apitherapy and bee products. Turkey, on the other hand, is not known a lot in the global beekeeping industry, although it has a very high number of hives. According to the recent data, there are 7,947,687 hives in Turkey, and 114,113 tons of honey are produced annually. Apart from these data, for example, the annual pollen production amount is not known, and there is no data on bee products other than honey. Here, consumer preferences come to the fore. At this point, it is necessary to promote other bee products, provide technical information, and build infrastructure for beekeeping. According to the table, beekeeping is performed mostly for pollination in the USA, for propolis practices in Argentina, Brazil, and Egypt, for apitherapy practices in China, Romania, and Korea, and for hive air therapy in Hungary and Germany. Also, other purposes of beekeeping

practices include honey, royal jelly, pollen, propolis, bee venom, bee bread, apilarnil, queen larvae, marketing, R&D, beekeeping supplies, apitherapy, and hive air therapy.

Beekeeping is carried out to generate export income in countries in the Middle East and Central and South America, to generate rural income in countries such as Spain, Hungary, Poland, Turkey, and Greece, and to ensure pollination in plants in countries such as the USA, Japan, and Canada (Uzundumlu et al. 2011).

3. GLOBAL BEE PRODUCTS TRADE

Honey is the most widely traded product among bee products across the world. The import and export of honey across the world increased continuously from 2011 to 2017. Global import of honey increased from 497,472 tons in 2011 to 689,095 tons in 2017. On the other hand, global honey export increased from 484,876 tons in 2011 to 651,220 tons in 2017 (UN Comtrade 2019).

Table 5. Top Honey Importing Countries (2018)

Country	Import Value ($)	Import Quantity (tons)	Unit Value ($)	The Amount of Increase between 2014 and 2018 (%)	Share in Global Imports (%)
USA	497,705,000	197,867	2,515	5	24,3
Germany	307,055,000	85,968	3,572	0	12,1
Japan	145,441,000	44,521	3,267	5	6,1
France	129,627,000	32,203	4,025	-1	5,6
England	128,288,000	50,597	2,535	6	5,6
Italy	100,314,000	27,833	3,604	6	3,9
S. Arabia	76,977,000	16,970	4,536	-4	3,5
Belgium	72,858,000	24,858	2,931	-4	3,4
China	70,129,000	3,824	18,339	-9	3,3
Spain	67,978,000	27,942	2,433	3	2,8
World	2,281,432,000	690,376	3,305	3	100

Source: Trademap, 2020. https://www.trademap.org/. 11.11.2020

According to the 2018 data, the total honey import value in the world is $ 2,281,432,000. The USA accounts for 24.3% of the total global honey imports, Germany 12.1%, Japan 6.1%, France 5.6%, and England 5.6%. The top honey-importing countries are the USA (197,867), followed by Germany (85,968) and Japan (44,521) (Table 5).

Table 6. Top Honey Exporting Countries (2018)

Countries	**Export Value ($)**	**Export Amount (tons)**	**Unit Value ($)**	**The Amount of Increase between 2014 and 2018 (%)**	**Share in World Exports (%)**
China	249,251,000	123,477	2,0	1	-1
New Zealand	245,491,000	8,033	30,5	0	11
Argentina	169,748,000	68,692	2,5	6	-3
Germany	141,172,000	22,778	6,2	1	0
Mexico	120,405,000	55,674	2,2	31	-8
Spain	105,737,000	23,111	4,6	10	-2
India	102,408,000	58,231	1,8	3	4
Ukraine	97,985,000	49,366	2,0	-7	6
Brazil	95,420,000	28,524	3,3	15	3
Hungary	90.622.000	22,018	4,1	5	2
World	2,262,341,000	-	-	4	100

Source: Trademap, 2020. https://www.trademap.org/. 11.11.2020

According to the 2018 data, the total honey export value in the world is $ 2,262,341,000. China ranks first among the countries with the highest export value. It is followed by New Zealand and Argentina. The country with the highest amount of exported honey is also China, followed by Argentina and India (Table 6).

CONCLUSION AND EVALUATION

Today, beekeeping is one of the common agricultural activities across the world. There are approximately 92 million beehives around the world, about 1/4 of the honey produced is traded, and around 20 producing countries export honey. The findings also reveal that the average yield of honey per hive is around 20 kg worldwide, 49 kg in China, 26 kg in Argentina, 25 kg in the USA, 20 kg in Russia, 18 kg in Romania, and 14 kg in Turkey.

The latest data also point to a significant increase in the number of hives and in honey and beeswax production. The number of hives increased from 69,237,913 in 1990 to 92,291,583 in 2018, honey production from 1,172,611 tons in 1990 to 1,851,541 tons in 2018, and beeswax production from 48,168 tons in 1990 to 69,633 tons in 2018.

Honey is the most traded product among bee products across the world. The import and export of honey across the world increased continuously

from 2011 to 2017. Global import of honey increased from 497,472 tons in 2011 to 689,095 tons in 2017. On the other hand, global honey export increased from 484,876 tons in 2011 to 651,220 tons in 2017. According to the 2018 data, the total honey export value in the world is $ 2,262,341,000. China ranks first among the countries with the highest export value. It is followed by New Zealand and Argentina. The total honey import value in the world is $ 2,281,432,000. The USA accounts for 24.3% of the total global honey imports, Germany 12.1%, Japan 6.1%, France 5.6%, and England 5.6%. Beekeeping is performed to generate export income in countries in the Middle East and Central and South America, to generate rural income in countries such as Spain, Hungary, Poland, Turkey, and Greece, and to ensure pollination in plants in countries such as the USA, Japan, and Canada.

Also, other purposes of beekeeping practices include honey, royal jelly, pollen, propolis, bee venom, bee bread, apilarnil, queen larvae, marketing, R&D, beekeeping supplies, apitherapy, and hive air therapy. Besides, beekeeping is performed mostly for pollination in the USA, for propolis practices in Argentina, Brazil, and Egypt, for apitherapy practices in China, Romania, and Korea, and for hive air therapy in Hungary and Germany.

The obtained findings indicate that the most important problems of the beekeeping industry are the scarcity of product diversity and incorrect identification of consumer preferences and marketing strategies. Beekeeping does not attract much attention from researchers and academics, who are usually reluctant to engage in this activity mostly due to bee stings.

Apart from all these developments, it is thought that the COVID-19 pandemic and the quarantine measures taken as a result will have negative effects on the bee colonies of many countries, especially China. This situation may cause inadequate feeding of bees and market problems depending on logistics.

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