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CONTENTS

Chapter 1

DOMESTIC TERMS OF TRADE FOR OLIVE PRODUCTION IN TURKEY (2009-2019)

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1.Introduction

Agriculture area in Turkey economy is a sector that maintaining its importance consistently in the ways of population and employment, feeding, agricultural produce, domestic consumption, the contribution of agriculture to industry, national income and statements of payments. Especially, Turkey has wealthy agricultural potential in terms of geographical position, its climate and product range.

Agriculture is one of the leading sectors in Turkey's economic development. Share of the agricultural sector in GDP is 7-10%, and its share in employment is 25%. The quarter of the working population is in agriculture. Agricultural production growth rate is under 1%, and population growth rate is close to 2%. Thus the contribution of agriculture to nutrition increases day by day (Rehber ve Vural, 2018). The share of agriculture in exports is 3 to 5 %. These contributions increases when agriculture supplies input to other sectors, mainly to industry. The facts that agriculture's dependence on natural conditions, the difficulty of living conditions in rural areas, problems in employment and lower income levels causes agriculture to be aided by remedial and coordinative policies (Yelboğa ve ark., 2019).

The total survey of Turkey is 783.577 km^2 in other saying it is 78 million hectares. When dams and natural lakes are taken out, the remaining space is 769.600 km^2. Mountains take more than half of Turkey's land space. The total amount of farming areas in Turkey is 37.817.000 hectares, which is approximately 38 million hectares. When the total amount of the cultivated area had approximately 41 million hectares in 2001, it was 38 million hectares in the year 2018. Almost 3 million hectares of farming areas have decreased for the last 17 years (Rehber ve Vural, 2018).

According to the first population census in Turkey, the population was 13,6 million people. It was a %75,78 percentage of people living in the rural side while the city population had only 24,22%. Turkey population has 82.003.882 people since December 31, 2018. While 92,3% of the total population was residing in cities and the center of counties, 7,7& resides towns and villages.

It is known that nearly 90% of the population had been employed at agriculture between the years 1923 and 1925. This situation has decreased quickly especially after the year 1960. When the year 2018, the rate of the employees in the agriculture area has descended to 18,40% (Turkısh Statistical Institue 2018).

Turkey has positive characteristics in terms of geographic and economic structure of agricultural production (Doğaka, 2011). It has an important place in the world agriculture, even if not in terms of animal production, but in terms of plant production. Turkey's hazelnut, cherry, quince, apricots and figs ranks first in production.

Our number of buffaloes decreased from 2000 to 2010 and increased in the following years. There is a continuous increase in our culture breeds from 2000 to 2018 (GTB, 2013). Although there was no continuous increase in our cross-breed cattle, there was a general increase from 2000 to 2018. There is a general decrease in our domestic cattle breeds. This is due to the fact that the meat and milk yield of our domestic cattle is low compared to the culture breeds. While the total number of cattle was 10,761,000 in 2000, the total number of cattle increased to 17,042,506 in 2018. There is an increase in sheep breeds and hair goats from 2000 to 2018. However, there was a decrease in mohair goat. The mohair goat decreased from 2000 to 2009, and after the ministry studies, the breeding of mohair goats was protected and started to increase in number.

According to the examinations, it is recorded that there is an increase in the use of balers, drip, and sprinkler irrigation systems, sprayers, hand tractors, and sewing machines. There has been a significant decrease in the use of the animal plow. This is due to the development of agricultural mechanization. In the past years, the production made with primitive methods has given its place to agricultural tools thanks to technological developments.

Chemical fertilizers and pesticides are among the important production inputs in Turkey. The chemical fertilizer production amount does not defray the consumption amount. In 2018, approximately 3 million tons of chemical fertilizers were imported. Nitrogenous fertilizers are the most produced and consumed in our country. The least produced and least consumed are potash fertilizers.

The terms of trade are used to refer to the export price index and the import price index proportion. In Turkey, these indices are calculated by TURKSTAT (Anonim, 2021). It is also known as net barter terms of trade. Export and import price indices are calculated on a base year basis. In the TURKSTAT calculations, the base year is 2010, and foreign trade indices are calculated by assuming a base year index value of 100. The fact that export prices are higher than import prices and that foreign trade is in favor of the country if it is higher than 100 as of the base year. The foreign trade limit is below 100 shows that foreign trade has developed as opposed to the country. From 2015 to 2018, the terms of trade had decreased regularly.

Homeland of olives (Olea europaea L.) which is a member of Olacea family is the Upper Mesopotamia and Güney Ön Asya which includes Southeast Anatolia (Dara, 2010). The homeland of olves that has never lost its importance through centuries is considered to be the area that includes Mardin, Hatay, Syria, Palestine and Cyrprus (GTB, 2013). Olive which is a Mediterranean has traveled to Greece, Italy and Spain through islands and is produced in all of the Mediterranean countries (DOĞAKA, 2011).

Olive is a fruit that plays an important role especially in the agriculture of Mediterranean countries and has a high economic value (Özdizbay, 2004). In addition to its use at the table, its ability to be processed into oil, being a valuable nutrient and its importance in terms of human health, especially in recent years, makes it much more valuable (Anonim, 2017). Approximately 90% of the product produced worldwide is used as oil and 10% is used at the table. The leading countries in olive production and foreign trade are the European Union countries, and studies have been started to develop the sector in Australia, Israel and North African countries recently. With the adoption of olive and olive oil, which are the basic elements of the Mediterranean diet, the increase in the interest in the consumption of these products leads to an increase in the amount of consumption in olive and olive oil producing countries in the world, or the participation of new consumer countries in the olive and olive oil market (Tunalıoğlu, 2009).

Although our country is among the most important producers of the world in olive production, it has not yet reached its targets in production, domestic consumption and foreign trade (Ünsal, 2011). Olive is an important agricultural product that provides foreign currency input to our country due to being an export product, is a staple food for people in domestic consumption, has a significant impact on the formation of healthy societies and generations, and is the livelihood of approximately 500 thousand families' directly and indirectly 10 million people in Turkey (Yurtoğlu, 2019). However, due to the important structural problems experienced in the olive sector on a global and national basis, the inability to provide sufficient economic returns causes the sector to regress (ATB, 2013).

2. Olive Production in The World and Turkey

In addition to being evaluated as table olives, the fact that it can be processed into oil, is a valuable nutrient and has come to the forefront in terms of human health, especially in recent years, increases the importance of olives (Erdal and Vural, 2017). Approximately 17 million tons of olives are obtained from 900 million olive trees in approximately 9 million hectares of land in the world. The five countries that come first in terms of olive planted areas are respectively; Spain (27%), Tunisia (16%), Italy (13%), Turkey (8%) and Greece (7%) (Gönenç, 2011). A large amount of olives produced in Turkey are directed to domestic consumption. 85% of table olives produced in Turkey are processed as black, 15% as green and colored. Turkey sells 35 thousand tons of table olive production, mainly to Romania, Bulgaria, Russia and Germany. The livelihood of 400 thousand families is olive cultivation. Considering these aspects, we see that olive has an important place in the country's economy.

Looking at the last years of world olive production between 2000 and 2018, the average total production was 18 million tons and it was estimated by to be 22.4 million tons in 2019 and 22.5 million tons in 2020 by taking into account the previous years' production amounts. Spain, Italy and Greece, which are EU countries, are among the top three countries in the world olive production rankings (Table 1). Although the share of EU countries in total production varies between years, it is around 70% on average (Anonymous, 2019). When the estimated figures of olive production in Turkey for 2020 is examined, it is seen that it is estimated to be around 1.6 million tons (Table 1).

Table 1. World olive production (million tons)

Years	EU	Turkey	Morocco	Egypt	Syria	Algeria	Argentia	Other	Total
2000	10,5	1,8	0,4	0,3	0,9	0,2	0,1	1,4	15,6
2005	10,7	1,2	0,8	0,3	0,6	0,3	0,2	1,9	15,9
2010	13,5	1,4	1,5	0,4	1,0	0,3	0,2	2,1	20,4
2015	12,4	1,7	1,1	0,7	0,8	0,7	0,2	2,9	20,6
2018	13,7	1,5	1,6	0,8	0,9	0,9	0,2	2,1	21,6
2019*	14,0	1,6	1,5	0,8	1,0	0,9	0,2	2,5	22,5
2020*	13,9	1,6	1,6	0,8	1,0	0,9	0,2	2,5	22,5

Reference: FAO (2020)

According to According to TUİK (Turkish Statistical Institute) and FAO (Food and Agriculture Organization of United Nations) data olive production areas, which was 556,209 ha in 1995, increased to 846,062 ha in 2018, an increase of 52% in 23 years. While the total olive production was 515,000 tons in 1995, it was 1,500,467 tons in 2018, 427,000 tons of which was for table use (Table 2).

Table 2. Olive area and production amounts in Turkey

		Number of trees (000)			Production (ton)		
Years	Area (ha)	Bearing trees	Non-bearing trees	Total	Table	Oiler	Total
1995	556209	81 437	6 144	87 581	206 000	309 000	515 000

2000	600000	89 200	8 570	97 770	490 000	1 310 000	1 800 000
2005	662000	96 625	16 555	113 180	400 000	800 000	1 200 000
2010	784031	111 398	45 050	156 448	375 000	1 040 000	1 415 000
2015	836935	144 760	27 232	171 992	400 000	1 300 000	1 700 000
2018	846062	151 069	26 774	177 843	426 995	1 073 472	1 500 467

Reference: Anonim (2021), FAO (2020)

The main purpose of the study; is to determine the periods in which domestic terms of trade (DTT) has developed in the long term (2009-2019) in favor or against olive producers. It is aimed to determine how the net exchange terms of trade for olive have been affected in the examined period. In the calculation, olive prices received by farmers (PFI) and domestic producer price index (DPPI) were used. When we look at the studies carried out in previous years, it was seen that there was no DTT study on olives. Olive is an important agricultural product of our country and it is known that it will continue to be important in the coming years. This study was carried out in order to fill the gap in this regard.

3. Material and method

This study covers the period of 2009-2019 and deals with the evaluation of 10 years of data. The data constituting the material of the study were obtained from TUİK and FAO. DTT in the study; is calculated by using the net exchange trade rate of the selected agricultural product, the price index received by the farmer and the domestic producer price indices. In the calculation of DTT, the net change terms of trade method was used. The base year in the study was determined as 2003. In addition, since the world olive production amount for 2019 has not been determined yet, a production forecast for 2019 and 2020 was made with the help of 2016 MS Excel Professional program.

3.1 Domestic Terms of Trade

Domestic terms of trade determines the movements of the gap between the prices received by the farmer and the prices paid to the industrial sector, the course of the distribution relations between the industrial capital and the farmer. These scissors are defined as “domestic terms of trade” (Uzunöz, 2009). The purpose of calculating DTT is to determine to what extent different sectors in the market are affected by price movements and how the transfer of resources between sectors should be (Süslü and Yanardağ, 2002).

Indices are used in the calculation of DTT. Indices are calculated with the numerical value to be seen and the numerical value compared. The domestic terms of trade are calculated with the Laspeyres index, which is one of the composite weighted index methods. In addition to showing how many units of industrial products can be purchased with one unit of agricultural product, it can also be calculated in terms of sectors (Yelboğa, 2018: 883).

$I_{ND} = P_T / P_S$

I_{ND} : Net Change Domestic Trade Rate

P_T : The wholesale price index of the products produced by the farmer

P_S : The wholesale price index of industrial products purchased by the farmer

There are different methods used in calculating the domestic terms of trade, but the most used ones are net domestic terms of trade and income domestic terms of trade. Net terms of exchange are expressed as the ratio of the price index received by the farmer to the index of prices paid by the farmer. Since the net domestic terms of trade do not include the changes in the trade volume between the agriculture and industry sectors, the net terms of trade do not include the changes in the trade volume between the agriculture and industry sectors. In addition, the net terms of trade are considered insufficient to show the economic welfare changes in the agricultural sector and do not fully reflect the economic welfare level of the producers. Income terms of trade, on the other hand, show the changes in the purchasing power capacity of the agricultural sector based on the goods purchased. For this reason, it can also be defined as the 'purchasing power' index and better reflects the economic welfare levels in the agricultural sector. In other words, it gives more effective results in explaining purchasing power (Uzunöz & Akçay, 2004). When DTT is >1, agricultural sector prices increase relatively and DTT develops in favor of agricultural products; When DTT is < 1, it shows that the prices of the agricultural sector decrease relatively and DTT develops against agricultural products (Yelboğa, 2018: 884). It can be stated that the return of the domestic terms of trade in favor of agriculture or industry has a significant effect on the development direction and degree of the country's economy (Akçay et al, 2000: 1). However, since the 1970s, the Domestic Terms of Trade have continuously developed against the manufacturer (Kip, 1981).

An increase in agricultural product prices can increase both input costs and labor costs (assuming real wages are constant) in the industrial sector. In the face of this development, if the industrial sector reflects its increasing costs to its prices, it may cause a decrease in the real incomes and purchasing power of agricultural producers. On the other hand, the negative impact of DTT on the real incomes of agricultural producers can be balanced with the increase in productivity in the agricultural sector (Dağdemir, 2011). According to the report published by (TMMOB) Chamber of Agricultural Engineers in 2018, the producer price index of agricultural products increased by 14.37% compared to the previous year. On the other hand, since the prices of the inputs used in production increased much more than the inflation, although the increase of 14.37% in the Agricultural-PPI showed the increase in the price of the products supplied to the market, the inflation rate of 21.62% in the same period decreased the purchasing power of farmers. When we look at the olive prices of TUİK in December 2019, it was seen that there was an increase of 5.9% compared to the same month of the previous year. In other words, there has been an increase in the prices received by the farmer for the olive product. While the olive farmer was expected to become rich in this situation, the inflation rate of 11.84% in the same period showed that the input costs required for olive production were higher than the yield of olives, causing the farmer to become poorer rather than enriched, contrary to expectations.

4. Results and discussion

4.1. Net Change in Domestic Terms of Trade using Agricultural Products Producer Price Index and Consumer Price Index

According to the agricultural producer price index and consumer price index, using the agriculture, industry and animal products sector index published by TUİK; the net terms of trade method was used in the calculation of NTDT and is given in Table 3. The base year for the domestic terms of trade is 2003 and it is calculated for the period 2009-2019. NTDT, which shows how many units of non-agricultural goods and services can be purchased with one unit of agricultural product produced by the agricultural sector, followed a course in favor of agriculture during the period under review. During this period, the agricultural sector bought more non-agricultural goods and services with one unit of agricultural product it produced. The domestic terms of trade reached the highest value for the agricultural sector in 2010 and can purchase 1.11 units of non-agricultural goods and services for one unit of agricultural product. In 2013 and 2016, the prices received by the farmers remained below the prices paid to the industrial sector.

Table 3. Net terms of domestic trade in Turkish agriculture

Years	Agriculture(PPE)	Industry(CPE)	Net terms of dom.trade in agri. (NTDT)
2009	166,02	164,3233	101,0325
2010	199,0892	178,4	111,5971
2011	209,7742	189,9458	110,4389
2012	222,4492	206,835	107,5491
2013	219,4733	222,3333	98,7136
2014	243,3734	242,02	100,5592
2015	270,6251	260,585	103,8529
2016	278,4416	280,8458	99,1439
2017	307,5068	305,398	100,6905
2018	379,2533	363,125	104,4415
2019	445,8625	418,2358	106,6055

Reference: NTDT was calculated by authors.(PPE: Producer price index, CPE: Consumer price index)

4.2. Net Change Terms of Trade for Olive According to the Price Index Received by the Farmer

The net exchange terms of trade according to the price index received by the farmer are shown in Table 4. DTT is obtained as a result of the ratio of the price index received by the farmer to the domestic producer price index (Table 4). In the studies years for olives, DTT was below 100 and followed a course against the olive producers. DTT has shown a general decrease since 2010. Although the Net Change Terms of Trade in Olive increased by 19% in 2015 compared to the previous year, it continued to decrease in the following years. In 2019, it reached its lowest value with 30.67.

Tablo 4. Term of Domestic Trade According to the Price Index Received by the Farmer for Olive Product

Years	DPPI	FPI (olive)	Terms of domestic trade (olive)* TDT
2009	159,3742	102,3183	64,2
2010	172,9458	114,1783	66,0197
2011	192,1175	95,2142	49,5604
2012	203,8225	101,1767	49,6396
2013	212,9558	99,1183	46,5441
2014	234,7833	104,7533	44,617
2015	247,1867	131,4367	53,2459

2016	257,8108	114,6442	44,4683
2017	298,6033	118,85	39,802
2018	379,2533	134,3192	35,4166
2019	445,8625	136,765	30,6742

Reference: TDT* was calculated by authors (DPPI: Domestic producer price index, FPI: Farmer price index).

5.Conclusion

In this study, DTT was examined in olive production in Turkey for 2009-2019 period. When the findings are taken into account, although the DTT has followed a course in favor of agriculture in the period under consideration, there is a decrease in the DTT for olives. When the DTT is analyzed according to the price index obtained by the farmer for the agricultural sector, it can be said that the olive producer is more affected by the changes in prices. Achieving positive developments for the olive producer depends on the effective implementation of policies that can maintain the balance between product and input prices.

In economies with high inflation, the effects of inflation are not felt at the same level in all sectors. It is thought that policies aimed at reducing inflation should be on a sectoral basis so that the sectors that provide economic development and growth are not under the price pressure of other sectors. While the effect of inflation creates different effects in the sectors, it is also felt differently in the agricultural sector, whose main output is food, on a product basis. The policies expected to be made on a sectoral basis also need to be made on a product basis in order to protect the producers and ensure the continuity of production.

In many regions, there are no producer organizations or cooperatives active in the processing and marketing of olive oil or table olives. The absence of such organizations reduces the effectiveness of marketing services and weakens the market position of manufacturers against buyers. With the establishment of marketing cooperatives or similar organizations, problems rising from processing and marketing will be reduced and marketing services will be provided more effectively. In addition, vertical and horizontal integrations are needed to solve the negativities caused by the fact that the sector consists of a large number of enterprises of various qualities and scales. Providing regional integration will contribute to the reduction of problems arising from production and marketing (TEPGE, 2012). In addition, importance should be given to branding and creating the image of the region. Considering the scattered and small-scale nature of businesses, entrepreneurs should be made aware, encouraged and supported in establishing and managing a common trademark. In this way, the creation of a common brand will contribute to both increasing the product quality and providing more effective marketing services (TEPGE, 2012).

Geographical indication will increase the value of the product in the national and international markets and will contribute to the formation of the regional product image. However, there is currently no geographical indication registration for olive varieties specific to the regions and olive oil or table olives obtained from these varieties. Geographical indication registration studies should be focused on local varieties (TEPGE, 2012). There are serious difficulties in accessing reliable data on the processing industry. This situation causes problems in making long-term projections and developing policies. In order for the olive sector to develop, companies that produce olive and olive oil, use it in the industry and trade it, associations related to the sector, cooperatives, research institutes, universities, public institutions and organizations should work together and in a coordinated manner (KUTO, 2012).

References

Akçay, Y., K. Esengün, H. Kızılaslan, Uzunöz, M. 2000. "Türkiye'de Önemli Bazı Tarla Ürünlerinde İç Ticaret Hadleri ve Belirsizlik Analizleri (1978-1998)". Türkiye IV. Tarım Ekonomisi Kongresi, Tekirdağ.

Anonim, 2017. GTHB. TAGEM (Tarımsal Araştırmalar ve Politikalar Genel Müdürlüğü). Dünya'da ve Türkiye'de Zeytincilik.

Anonim, 2021. http://tuik.gov.tr/Start.do

Dağdemir, E. 2011. Türkiye'de Ticaretin Serbestleşmesi Sürecinde İç Ticaret Hadlerine Yönelik Bir Analiz: 1990-2009. Anadolu Üniversitesi Sosyal Bilimler Dergisi, 11 (3): 121-134.

Dara, Ramis. 2010. Sofralara Geldi Bahar Baharatlar- Kokulu Otlar Yerel ve Evrensel Tatlar. İstanbul: Yapı Kredi Yayınları.

DOĞAKA, 2011. Hatay, Kahramanmaraş ve Osmaniye Zeytincilik Sektör

Raporu ve Fizibilite Çalışması. Doğu Akdeniz Kalkınma Ajansı. Hatay, 103 s.

Erdal, B., Vural, H. 2017. Türkiye'de Zeytin Pazarlama Yapısı: Pazarlama Marjının Ekonometrik Analizi U. Ü. Ziraat Fakültesi Dergisi, 31(2): 37-44.

FAO, 2020.www.fao.org

Gönenç, S. 2011. TR63 Bölgesi Zeytincilik Sektör Raporu ve Fizibilite Çalışması, T.C. Doğu Akdeniz Kalkınma Ajansı.

GTB, 2013. 2012 Yılı Zeytin ve Zeytinyağı Raporu. Gümrük ve Ticaret

Bakanlığı Kooperatifçilik Genel Müdürlüğü. Ankara, 23 s.

Kip, E. 1981. Tarımsal Ürünlerde İç Ticaret Hadleri, Ata.Ü. Yayınları Yayın

No. 580, Ziraat Fakültesi Yayınları No: 263, Araştırma Serisi No:174,

Ata.Ü. Basımevi, Erzurum.

KUTO, 2012. Türkiye'de Zeytin ve Zeytinyağı. Kuşadası Ticaret ve Sanayi

Odası, İzmir, 10 s

Özdizbay, Aşkım. 2004. Eski Yunan'da Tarım. İstanbul: Türk Eskiçağ Bilimleri Enstitüsü Yayınları.

Rehber E. ,Vural H. , (2018) , TarımEkonomisi , (2) , Bursa: Ekin Basım Yayın Dağıtım.

Süslü, B., Yanardağ, M. 2002 «İç Ticaret Hadleri Kavramı ve Türkiye'de

1980 Sonrası 1İç Ticaret Hadlerindeki Gelişmeler», Mevzuat Dergisi, (56):

1-13.

TEPGE, 2012. Doğu Akdeniz Bölgesi'nde Zeytin ve Zeytinyağı Üretimi,

Pazarlaması ve Bölgede Zeytinciliği Geliştirme Olanakları. Tarımsal

Ekonomi ve Politika Geliştirme Enstitüsü, Ankara, 144 s.

Uzunöz, M., Akçay, Y., Esengün, K., 2004. Türkiye'de Süt Üretiminde İç Ticaret Hadleri ve Risk Analizleri. *Gaziosmanpaşa Üniversitesi Ziraat Fakültesi Dergisi*, 21(2):39-49.

Uzunöz, M. 2009. Türkiye'de Baklagil Ürünlerinde İç Ticaret Hadleri. Gaziosmanpaşa Üniversitesi Ziraat Fakültesi Dergisi, 26(1): 29-37.

Ünsal, Artun. 2011 (8. Baskı). Ölmez Ağacın Peşinde-Türkiye'de Zeytin ve Zeytinyağı. İstanbul: Yapı Kredi Yayınları.

Yelboğa, M., Sayın, C., Eryiğit, F. D. 2018. Türkiye'de Turunçgil Üretiminde İç Ticaret Hadleri. *Üçüncü Sektör Sosyal Ekonomi*, 53 (3): 881-888.

Yelboğa, M., Sayın, C., Eryiğit, F. D. 2019. Türkiye'de Domates Üretiminde İç Ticaret Hadleri. *Ziraat Mühendisliği*, (367): 6-12.

Yurtoğlu, N. 2019. Türkiye Cumhuriyeti'nde Zeytin ve Zeytinyağı Üretimi ile Ticareti Üzerine Tarihsel Bir Bakış (1923-1960). *VAKANÜVİS-Uluslararası Tarih Araştırmaları Dergisi*, 4 (1), 473-510.

Chapter 2

FUNCTIONALITY OF IRRADIATION FOR CEREAL GRAINS IN SENSE OF FOOD SECURITY AND COVID-19 PANDEMIC

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1. INTRODUCTION

Food systems are complex entities that affect food, human health and a range of other outcomes, including economic growth, natural resources and environmental resiliency, as well as socio-cultural factors. However, food systems contribute to and are vulnerable to ongoing climate and environmental changes that threaten their sustainability (Fanzo et al., 2020). As a new factor, WHO declared the 2019-nCoV outbreak a major international public health emergency on 30 Jan. 2020 and COVID-19 can be characterized as a pandemic on 11 Mar. 2020. (WHO, 2020a; 2020b). Later, countries have begun to take some measures, namely travel controls, road closures, 'stay-at-home' requirements or lockdowns, and unprecedented measures that limit farmers' movement within cities and countries for regular activities, for instance, seeding, fertilizing, irrigating, harvesting, etc. As a next step, some countries have raised their national grain stocks. Since then, using grain stocks to provide readily available emergency food reserves targeted at the most vulnerable has proven to be a more effective instrument to improve food security outcomes (WB, 2012). Moreover, major producer countries have applied or considered export restrictions on cereal grains to ensure the food security of their citizens and many of these limitations are still in effect (ITC, 2021). Accordingly, it is not difficult to understand the countries' perspective on these products due to the historical place of grain cereals and related agricultural products in human nutrition. The most important reason why grains are classified as dietary staple products together with milk, fruits and vegetables is their contribution to dietary energy and nutrients (Thielecke et al., 2020).

Generally, essential grains consist of 17 different crops suchlike wheat, rice, barley, maize, popcorn, rye, oats, millet, buckwheat, sorghum, etc. (mostly from the gramineous family) which are harvested as a whole in a dry state (FAO, 1994). In terms of farmlands in the world, three of the cereals (maize, wheat and rice) occupy the most important place and people directly get more than half of their calories from these grains (Spaggiari et al., 2019). Consequently, one of the most important issues facing our community in the coming decades will be seeking a sustainable balance between food supply and demand and ensuring the long-term future of mankind (Boye and Arcand, 2013). Currently, complicated food supply chains, compelling prolonged transport periods of staple crops (wheat, maize, corn, soybeans, and oil seeds), and encountering powerful environmental and sustainability challenges and quality loss have derived from advanced farming applications and increased urbanization in the world (Bakalis et all., 2020).

Principally, considering post-harvest loss reduction (PHL) is the most important issue of many countries' efforts to improve food security to provide a sufficient supply of food (Stejskal et al., 2018). Specifically, a decrease in grain production, higher food prices, and concerns about physical shortages of staples have put food safety at the top of many national agendas (Magnan et al., 2011). Nevertheless, the current situation has shown how important food security is in times of shock and crisis. Because the COVID-19 outbreak that we are facing has significantly affected the entire food chain. Movement stipulations, as well as free circulation of (agricultural and other) the required material and workforce are prone to interrupt stages of production, logistics and services of foods, further will affect the system's ability to provide adequate, low-cost, and nutritious food for humans (Bakalis et al., 2020). This pandemic situation has led to an increase in food insecurity in the world and also highlighted the threat of long-term malnourishment and negative health consequences (Zimmerer and de Haan, 2020). The results are prone to impact food security through 2020 and 2021. Besides, other factors must be taken into account as well, such as extreme weather conditions, crises in the financial system, and ongoing economic conflicts. The implications of a pandemic on food security will last longer in the form of economic recession, reductions in agricultural investment, government expenditure, and aid to farmers (Udmale et al., 2020).

2. FOOD SECURITY

In reality, the global population is projected to hit 8.1 billion in 2025, which is expectable to further rise to 9.6 billion in 2050 (UN, 2016). The changing nature of climate change and extremes has a negative impact on all dimensions of food security (food availability, access, usage, and stability), as well as increasing other underlying causes of malnutrition linked to childcare and feeding, health services, and environmental health. In 2017, approximately 10% of the world's population were vulnerable to severe food insecurities, affecting about 770 million people, according to the latest FAO figures. Regarding FIES (Food Insecurity Experience Scale), food insecurity in Africa, Asia and Latin America is 29.8%, 6.9% and 9.8% of the population, respectively, just 1.4% of Europe's and North America's population (FAO, 2018). Because of the global population growth and other climate factors, it will be necessary to increase agricultural production by 75 percent by 2050 in order to provide food for the population (Godfray et al., 2010).

COVID-19 has revealed is the issue on food insecurity faced from a large part of the population (Bakalis et al., 2020). In the worst-case scenario, what if food production declines or food stocks are widely depleted or international trade declines worldwide due to the increase in more protectionist policies? Such a situation is unlikely, but if it does occur, it could potentially have serious repercussions in food supply in countries dependent on food imports and worsen the food supply in countries already suffering from severe food shortages (Udmale et al., 2020). In this context, food security will ensure that it is possible to reach the adequate amount of food that meets the need at the right time and at the right location (FAO, 2001). Specifically, the following four pillars or dimensions are the basic components of the food security: food availability, access, stability, and biological utilization (Gibson, 2012). In this respect, Calicioglu et al., (2019) stated that one of the nutritional security and accessibility issues is to prevent cross-border pests and diseases. A growing concern about the safety of agricultural and food products transported across country borders has led to rising food safety and agricultural health standards being introduced for the protection of consumers and agricultural producers in the importing country. Agricultural products, like grains are the main food source for humans and the majority of domesticated animals. In many developing countries, post-harvest losses of cereals and legumes are quite common about 10-15 percent (Kumar and Rai, 2013).

3. IMPORTANCE OF GRAINS ON FOOD SECURITY BASIS

3.1. Food Loss

At any post-harvest system, losses in food quantity (weight or volume) and changes in physical condition or its characteristics (quality) may occur (Hodges et al., 2011). In this sense, the FAO defined 'Food Loss' as the decrease in the quantity or quality of food. Food waste is part of food loss and refers to discarding or alternative (non-food) use of food that is safe and nutritious to human consumption throughout the entire food supply chain, from primary production to consumer end-of-household use (FAO, 2016). Foods are eventually lost or wasted at each point of the value chain for instance pre-harvest, post-harvest, manufacturing, transportation, and retail within the current food system (FAO, 2014).

Generally, food loss is consistent throughout the world, estimated at an average of 33 percent of the total volume of food waste during agricultural production, 21% during post-harvest handling and storage and specifically, about 30% of cereals have been lost (FAO, 2013; 2015). In particular, PHL (post-harvest losses) for grain crops occurs during delivery, storage, and processing in post-harvest activities. Grain respiration, drying, and spillage may cause quantity loss and quality loss as a natural consequence of this. When the market value decreases, economic losses are inevitable (An and Ouyang, 2016). In developing countries, losses from insect pests, rodents and birds are common in the staple grains, as well as physical changes caused by biotic or abiotic factors (post-harvest damage) (Bokusheva et al., 2012).

3.2. Insect Infestation

Infestation and subsequent postharvest losses in agricultural products including stored grains and cereals have been derived from insect damage and humanity will continue to be faced with this problem in long-term storage. Unfortunately, invasive agricultural pests are capable of causing extensive damage to crops and can require the infested country to undertake expensive control methods (Karel and Lund, 2003; Torres-Rivera and Hallman, 2007). Previous reports showed that a large group of insects (grain pests) is occurring in the stored commodity ecosystem. Grain pests are easily organized into two major groups, i.e., primary and secondary pests. Primary pests chose to affect whole grain and can pass into a seed's undamaged coat and feed on an embryo endosperm or cotyledon. They prefer a narrow range of products, including cereals and pulses. After primary pest activity or the effect of post-harvest stages, in particular, harvesting, handling, and shipping, secondary pests attack grains. Compared to primary pests, they select a wide range of products as well as damaged whole grains, milled products (such as flour), processed or manufactured food products (Nayak and Daglish, 2018). Most of the insects encountered in grains stored originate from tropical and subtropical countries. Existing temperatures and relative humidity in these regions provide favorable opportunities to increase the growth rate of insects. In this sense, beetles (red flour beetle (Tribolium castaneum), confused flour beetle (Tribolium confusum), Saw-toothed beetle (Oryzaephilus surinamensis), flat grain beetle (Laemophloeus pusillus), Khapra beetle (Trogoderma granarium)), weevils (the granary weevil (Sitophilus granarius)) and moths (Indian meal moth (Plodia interpunctella), Lesser grain borer (Rhyzopertha dominica) and Angoumois grain moth (Sitotroga cerealella)) create enormous losses and spoiling in stored grains. For example, they reduce the quality by degrading the remaining product and also generate a grain mass of hotspots (Bala, 2017).

3.3. Control of Infestation

Fumigation has been widely applied to prevent the introduction and spread of the regulated pests. However, fumigant gases like methyl bromide may have negative impacts on the environment due to the emission of methyl bromide into the atmosphere, which is known to deplete the ozone layer. The possible phytosanitary treatment of grain, cereals, and oil seeds, including rice (not for planting), for replacement or reduction of methyl bromide is specified under IPPC as heat, irradiation, ethyl formate, carbonyl sulphide, phosphine (+ carbon dioxide) and controlled atmosphere (CO_2, N_2) (IPPC, 2017). Grains and other stored products are less likely to suffer damage, although multiple fumigations may result in noticeable changes in color, shine, or other attributes. Many fumigants have deleterious effects on germination, on emergence, and on seedling vigor. They may also affect the quality of the grains used in the malting. Comparison of the current quarantine procedures as shown in Table 1 (Heather and Hallman, 2008). It is important to consider the features that treatments under certain conditions have varied and more efficient. Among these uses, irradiation plays a key role in insect disinfestation.

Table 1. Comparison of the various quarantine treatments.

Treatment	Commodity tolerance	Cost	Speed
Cold	Moderate	Low	Very slow
Heated air	Moderate	Moderate	Moderate
Hot water immersion	Moderate	Low	Fast
Radiofrequency heating	Moderate	Moderate	Fast
Ionizing irradiation	High	Moderate	Fast
Methyl bromide fumigation	Moderate	Low	Fast
Sulfuryl fluoride fumigation	Low	Low	Fast
Phosphine fumigation, solid formulations	Low	Low	Moderate
Phosphine, gaseous formulations	Moderately low	Low	Moderate
Modified atmosphere (MA)	Moderate	Moderate	Slow
MA/heated air	Moderate	Moderate	Fast
Non-gaseous pesticides	High	Low	Fast

4. RADIATION TREATMENT FOR POST-HARVEST LOSSES

4.1. Ionizing Radiation

The term ionizing radiation is given to the series of the emissions of subatomic particles and electromagnetic radiation of nuclear or atomic origin, which on interacting with matter are capable of ionizing it. In other words, it is radiation, which acts on matter, making it lose electrons, which leads to the production of the ions. Radiation is a form of the energy, and every person receives natural radiation from the sun and other natural components of the environment. In the same way as with other forms of the radiant energy, the radiation waves used to treat the foods form part of the electromagnetic spectrum (Ibarz, 2008). Food irradiation is basically the process of exposing a food item to a sufficient dose of ionized radiation in accordance with a desired technological purpose and method. The average amount of radiation energy absorbed per 1 kg of irradiated food in kilojoules, that is, the dose is expressed in Kilo Gray (kGy). The maximum absorbed dose delivered to food to achieve a technological purpose cannot exceed 10kGy. The food irradiation process involves exposing packaged or bulk food to a controlled amount of the ionizing radiation to achieve specific desired goals. Suitable radiation sources for these applications are gamma rays from radioactive nuclides (radionuclides such as ^{60}Co or less frequently by ^{137}Cs), energetic electrons from particle accelerators (energies up to 10 MeV), or x-rays (energies up to 5 MeV) emitted by the high-energy electron beams. All of these energy sources can penetrate substantial thicknesses of the solid materials and produce similar effects in any irradiated material (CAC, 2003; Cleland, 2013). Irradiation is possibly the most widely applicable treatment for commodity disinfestation. It is effective with the broad spectrum of the pests that infest stored products, perishable food, and nonfood commodities (Marcotte, 2006). Most countries have already adopted the Codex General Standard and approval to irradiate foods are given by the class or items. In 1980, the Joint Expert Committee of FAO/IAEA/WHO on Food Irradiation declared irradiated foods safe and wholesome for human consumption (Silvestre et al., 2017). Today, approximately 70 countries have regulations on food irradiation and / or food irradiation facilities (IAEA, 2012; Eustice, 2018; Koutchma et al., 2018).

4.2. Irradiation Treatment for Insect Disinfestation

Several international developments followed upon each other in quick succession in insect disinfestation by using ionizing radiation between 1950 and 1970. It was revealed that ionizing radiation could be used for disinfestation of insects in grains more effectively than chemical techniques during the 1950s (IAEA, 1971). After intensive research and wider safety considerations, some countries approved the irradiation for disinfestation of grains e.g. Russian Federation (former USSR) endorsed for disinfestation of grains and rice (Jan. 1, 1959). USA allowed for disinfestation of wheat and wheat powder (Aug. 21, 1963), Canada approved for disinfestation of wheat and wheat products (Feb. 25, 1969) (IAEA, 2006). Considerable researches have been done to measure the effects of irradiation on grains, pulses and their products. There have been few recorded negative effects at the doses needed for insect control. Irradiation is approved for stored product use in at least 33 countries today. Irradiation of all stored products has been approved by fourteen countries (Hallman, 2013).

Compared to chemical or other physical methods, ionizing radiation is the best alternative because (Ahmed, 2001; Enu and Enu, 2014; Silvestre et al., 2017; Loy et al., 2019);

1. It can penetrate 20-50cm into a solid or whole grain.
2. Cause death at all stages of development: egg, larva, pupa, and adult.
3. No residues in the products.
4. The whole process is mechanized and remotely controlled.
5. It is less time-consuming.
6. There is no significant difference in terms of smell, taste and

appearance.

7. It can be exposed prepackaged or in bulk.

8. Nutritional value is essentially unchanged and does not become radioactive.

Irradiation doses (Table 2) required to kill insects and mites, or to prevent their reproduction, are relatively low (IAEA, 2004a). Irradiation at the doses used for disinfestation does not affect product quality or the quality of processed foods made from grains and cereals (Marcotte, 2006).

Table 2. The minimum irradiation treatment doses for some insect and mite pests.

Scientific name	Common name	Major host/ commodity	Category	Most tolerant stage present in/on commodity	Minimum dose required (Gy[a])	
					To inhibit development of immatures	To sterilize adults
Lasioderma serricorne (Coleoptera: Anobiidae)	Cigarette beetle	Various commodities of plant origin	PP[b]	Pupa	120	125
Tribolium castaneum (Coleoptera: Tenebrionidae)	Flour beetle	Cacao beans and power	SP[c]	Adults	120	—
Acanthoscelides obtectus (Coleoptera: Bruchidae)	Dry bean weevil	Beans	PP	Pupa	300	60
Oryzaephilus surinamensis (Coleoptera: Silvanidae)	Sawtoothed grain beetle	Wheat products	SP	Pupa	700	85
Rhizopertha dominica (Coleoptera: Anobiidae)	Lesser grain borer	Grain	PP	Pupa	120	60
Sitophilus granarius (Coleoptera: Curculionidae)	Grain weevil	Grain	PP	Pupa	80	—
Sitophilus oryzae (Coleoptera: Curculionidae)	Rice weevil	Rice, wheat, grain	PP	Pupa	80	—
Sitotroga cerealella (Lepidoptera: Gelechiidae)	Angoumois grain moth	Grain	PP	Pupa	600	600
Stegobium paniceum (Coleoptera: Anobiidae)	Drug store beetle	Grain, various plant products	PP	Pupa	120	250
Trogoderma granarium (Coleoptera: Dermestidae)	Khapra beetle	Cereal, dries fruits, nuts	PP	Pupa	200	200

[a] *1 Gy = 1 joule/kilogram (J/kg) and 1 kGy = 1 kilojoule/kilogram (kJ/kg),*

[b] *PP: Primary pests,*

[c] *SP: Secondary pests*

5. Grain Disinfestation Facilities

Much effort has been made to prevent post-harvest losses by using low dose radiation on insects. In the first stage, small-scale systems are specifically designed for disinfestation studies. In industrial applications, different commercial-scale devices have been developed for insect disinfestation (Table 3).

Table 3. Some parameters of the grain irradiation facilities in the world for grain disinfestations.

	Place	Type	Establishment	Capacity	Radiation source	Operation periods
1	USA	Experimental	Laboratory scale	1-5 tons/h	Gamma (^{60}Co)	1955-1995
2	Turkey	Commercial	Seaport silo installation	50 tons/h	Gamma (^{60}Co)	1967-1968
3	Indonesia	Commercial	Multipurpose	8-10.000 tons/mo	Gamma (^{60}Co)	1992-
4	Ukraine	Commercial	Seaport silo installation	200 tons/h	E-beam (ELV-2)	1980-
5	China	Commercial	Seaport silo installation	500 tons/h	E-beam (ELV-8)	2006-

5.1. Gamma Facilities (Cobalt 60)

5.1.1. Experimental grain irradiation in USA

The world's first experimental free-flowing ^{60}Co (Cobalt 60) bulk grain and the packaged-product irradiator was built by the USAEC at the Stored-Product Insects Research and Development Laboratory at Savannah, Georgia in 1966. As reported by Tilton (1974), the irradiator was composed of a ^{60}Co source (13 ^{60}Co assemblies had 26.565 curies) and source-handling system, a grain-handling and treatment system, and a packaged-product irradiation system. The grain-handling and treatment system was used to bulk grain. The grain flows slowly into the concrete cell, through the source plane in the spaces between the source rod tubes, surrounds the source and flows continuously past the source tubes. The rate of flow (1-5 tons/hour), hence the dose was controlled by a metering valve.

5.1.2. The first commercial-scale grain irradiation facility in the world

In 1967, the first commercial grain irradiation device with a ^{60}Co irradiation source (100 kilocuries) was built at the port grain silo installation in Iskenderun, Turkey. This site was selected owing to the grain had been infested with the dermestid Khapra beetle (Trogoderma granarium (Everts)) in this area, which against chemical methods had not been very effective. The constructed system was attached to the existing silo installation for 6000 h (hour) of plant operation per year. The unirradiated grain is transported from the silo to the feed hoppers at a high level (2x125 tons) were supplied by a system of chutes, sieves and conveyors from the existing plant. Grain flows by the gravity through a series of concentric annular channels past the completely surrounds the ^{60}Co source plaque source. Conveyors at a low level return irradiated grain to the silo installation for continuous process. The facility, designed to handle wheat, barley, rye and maize at a dose range of 150-250 Gy (Gray) which was capable of up to maximum 50 tons/h throughput were described (Baines and Mosely 1966; Carden, 1967; Anonymous, 1967a; 1967b; 1968; 1969).

5.1.3. Rice irradiation in Indonesia

For several years, a gamma irradiation plant in Indonesia was used to disinfest bagged rice before the rice was placed into storage for the Indonesian food security program. The Indonesian Government, through its National Logistics Agency, BULOG, is protecting its population and rice farmers from the effects of drought, floods and other natural disasters. In 1992, a multi-purpose ^{60}Co irradiation facility (with a design capacity of 6.000 kci) was built in Jakarta, Indonesia. The facility was a modified tote / carrier-product overlap irradiator, suitable for irradiating a wide product range. A commercial efficacy test was conducted in 1993 for irradiation of 50 kg bags irradiated at 400 Gy minimum doses against the rice weevil (Sitophilus oryzae). Irradiation was carried out by Rel-Ion (formerly known as Pt. Perkasa SteriGenics or Sterilindo) under contract to BULOG with rice storage in BULOG facility. Irradiation activities started commercially in August 1994 with the capacity of 3.000-5.000 tons/month. The volume of irradiated rice reached 8.000-10.000 tons/month in the 1994 harvest season (UNEP, 1995; IAEA, 2004b; Marcotte, 2006).

5.2. Electron Accelerator Facilities (E-beam)

Accelerated electrons are therefore particularly useful for the treatment of grain or animal feed that can be processed into thin layers; the high throughputs involved in grain handling and the ease of switching the system on and off at will make the electron beam irradiation particularly suitable for these applications. Low dose radiation (up to 500 Gy) kills or sterilizes all stages of the common grain insect pests, including eggs placed in the grain (WHO, 1988). According to the Codex General Standard (CAC, 2003), electrons generated from machine sources operated at or below an energy level of 10 MeV (million electron volt) can be used as a radiation source like ^{60}Co. It now has the advantage of being based on reliable equipment technologies that have been evolving since the 1950s for other applications. The penetration of an electron beam increase in proportion to the electron energy, so it is advantageous to use the energies of at least

3-5 MeV for packages of foods. Lower electron energies can be used for irradiating grains and fluids because their thicknesses can be controlled to match the penetration of the electron beam (Cleland, 2013). Electron beam irradiation has been used for the disinfestation of grain (Salimov et al., 2000) and is probably the most appropriate radiation technology for this purpose. The electron beam penetration is much shallower than gamma rays or x-rays and can only be used to treat loads of no more than 5-10 cm in depth, such as a thin stream of grain (Heather and Hallman, 2008). The advantages are that no viable alternative to removing the threat of invasive species via weed seeds is presently imaginable, weed seed deactivation can be accomplished while the grain is being loaded for export, and there is no risk of re-infestation after weed seed-infested grain is irradiated. Ships are loaded at the rate of about 600 tons/h at each loading spout and the e-beam system at Odessa treated up to 400 tons/h. Higher capacity irradiation systems are feasible (Hallman, 2013).

5.2.1. Commercial grain irradiation in Ukraine

In 1980, the first industrial bulk grain disinfestation facility was put into operation at the port elevator in Odessa (Ukraine). The main components of the electron accelerators were mounted on a tower between the elevator and the load berth on the port. The system was based on two ELV-2 electron accelerator of 200 tons/h capacities each and have an electron beam power of 20 kW (kilowatt) at an energy of up to 1.5 MeV (million electron volt) as shown in Table 4 (Bayanov et al., 1998).

Table 4. The basic parameters of the ELV type accelerators.

Type of ELV	Energy range (MeV)	Beam power (kW)	Maximum beam current (mA)
ELV-mini	0.2-0.4	20	50
ELV-0.5	0.4-0.7	25	40
ELV-1	0.4-0.8	25	40
ELV-2	0.8-1.5	20	25
ELV-3	0.5-0.7	50	100
ELV-4	1.0-1.5	50	50
ELV-6	0.8-1.2	100	100
ELV-6M	0.75-0.95	160	200
Torch	0.5-0.8	500	800
ELV-8	1.0-2.5	100	50
ELV-12	0.6-1	400	400

The irradiation zone has a dimension of 50 cm along the motion of the grain flow. The grain flow has the following parameters in the irradiation zone: width: 1.5 m, thickness: up to 7 mm and, speed: 6-7 m/s. The system was being consisted of a grain lift, a driving bin, a forming register, a channel for grain acceleration, a damping bin and a regulator valve. The channel for grain accelerator was a pipeline of rectangular cross-section, its lower plane forming the inclined surface of the grain flow to pass. The irradiation zone was the lower part of the acceleration channel. During the treatment, the grain and the insects could be received 200-300 Gy irradiation doses. The operation mode was continuous with a guaranteed operation time of no less than 5000 hours/year. The electron accelerators had been served for the disinfestation of import grain between 1980 and 1991. After that date, the facility had worked for irradiation of exported grains and domestic production (Zakladnoy, 1990; Salimov et al., 2000). Recently, Hallman (2013) reported that, the largest and longest use of irradiation to control insects was the annual treatment of 400.000 tons of grain imported by the Russian Federation continued until 2007. During the latter years of operation, the amount of grain irradiated at Odessa decreased to 70.000 tons/year because grains were being imported at other ports in the region after the dissolution of the Soviet Union.

5.2.2. New regeneration grain irradiation facility in China

Economic development of the Asia region gave rise to an opportunity for the accelerator industry over the past years. While, Asia region has been developed, produced increasing number of accelerators, and the accelerator market have been expanded (Tang, 2010). As a consequence of industrial demand, a second industrial electron accelerator plant was designed after the experiences from the Odessa Port facility for grain disinfestations. The Budker Institute of Nuclear Physics (Novosibirsk, Russia) established an electron accelerator (ELV-8) system from the ELV series in 2006 for the Xinshagang Grain Depot, State Grain Reserves, Guangdong in China (Guangzhou district). In this system, two 100 kW electron accelerators which carries the basic characteristics of the ELV series (Table 4). Each line has a 500 tons/h irradiation capacity installed in the detached building (Cherepkov et al., 2006; Salimov, 2006; BINP, 2007).

6. CONCLUSION

The most important issue in ensuring food security is the reduction of food losses during agricultural production and subsequent stages due to internal and external factors. Considering food security, cereal grains are one of the most important items in the agricultural production and food consumption chain in the world. However, post-harvest loss in grains due to different reasons, including insect infestation, should be reduced in order to provide safe food supplies and achieve food security. During the 2020 pandemic, the importance of effective and reliable pest management strategies has emerged once again. Although irradiation is a very effective, proven and versatile technology for a number of different applications accepted by the IPPC, it has not been properly emphasized for grains and has been ignored. Moreover, it has been revealed that ionizing radiation could be used to disinfest grains more effectively than chemical techniques. Firstly, this process can cause death at all stages of insects (egg, larva, pupa and adult). 60-700 Gy is sufficient for immediate complete sterilization of most insects, and it may also ensure partial protection against re-infestation through reproductive sterilization. Secondly, an extreme event like the COVID-19 pandemic that we encountered in 2020 has shown that other alternatives should be taken into consideration in addition to the existing possibilities for ensuring food security. The importance of using local, decentralized, and non-dependent solutions has emerged and was also highlighted during the pandemic. Solving the problems with the help of local irradiation facilities established in the country instead of using chemicals in most countries will both eliminate foreign dependency in case of crisis and reduce the environmental pollution caused by chemical use in order to prevent food losses. Thirdly, it could be easily integrated into the food system to provide food security for strategic grain reserves. Irradiation systems can be attached to existing silo installations in the countryside and ports. Finally, to prevent PHL derived from insect disinfestations and ensure food security, irradiation technology has adequate and proven scientific knowledge and commercial application experiences already exists in different countries. If we consider only grain irradiation facilities, existing grain irradiation systems in the world have been important facilities to increase food production and ensure food security.

REFERENCES

Ahmed, M. (2001). Disinfestation of stored grains, pulses, dried fruits and nuts and other dried fruits. in: Molins, R. A. (Ed.), Food Irradiation: Principles and Applications. John Wiley & Sons, USA, pp. 77-112.

An, K., Ouyang, Y. (2016). Robust grain supply chain design considering post-harvest loss and harvest timing equilibrium. Transp. Res. Part E 88, 110-128. https://doi.org/10.1016/j.tre.2016.01.009.

Anonymous, (1967a). Harwell ships 100 thousand curies of ^{60}Co to Turkish grain irradiator. Isotopes and Radiation Technology. U.S. Atomic Energy Commission. Division of Isotopes Development, Oak Ridge National Laboratory, 4 (2), p203.

Anonymous, (1967b). The world's first large-scale continuous grain irradiation plant Iskenderun, Turkey. Atom. United Kingdom Atomic Energy Authority, 124, 27-30.

Anonymous, (1968). Hearings and reports on atomic energy. United States. Congress. Joint Committee on Atomic Energy, U.S. Atomic Energy Commission, 125, p. 605.

https://babel.hathitrust.org/cgi/pt?id=mdp.35112204467338&view=1up&seq=1247/ (accessed 13 March 2019).

Anonymous, (1969). Ambar zararlılarına karşı radyasyonla mücadele konulu Birleşmiş Milletler İskenderun özel fon projesinin bu güne kadar geçirdiği safhalar. Rapor, 16 Haziran 1969, T.C. Atom Enerjisi Komisyonu, Ankara, Turkey, 44p, (in Turkish).

BINP, (2007). Annual report of 2006. Russian Academy of Science Lenin Order Siberian Branch, G.I. Budker Institute of Nuclear Physics, http://www.inp.nsk.su/images/pdf/annuals/2006_e.pdf/ (accessed April 2019).

Baines, B.D., Mosely, J. (1966). Economics of grain irradiation. Presentation at the meeting of the International Symposium on Food Irradiation Jointly Organized by the International Atomic Energy Agency and the Food and Agriculture Organization of the United Nations, Karlsruhe, Germany.

Bakalis, S., Valdramidis, V.P., Argyropoulos, D., Ahrne, L., Chen, J., Cullen, P.J.; Cummins, E., Datta, A.K., Emmanouilidis, C., Foster, T., Fryer, P.J., Gouseti, O., Hospido, A., Knoerzer, K., LeBail, A., Marangoni, A.G., Rao, P., Schlüter, O.K., Taoukis, P., Xanthakis, E., Van Impe, J.F.M. (2020). Perspectives from CO+RE: How COVID-19 changed our food systems and food security paradigms. Cur. Res. Food Sci. 3, 166-172. https://doi.org/10.1016/j.crfs.2020.05.003.

Bala, B.K. (2017). Drying and Storage of Cereal Grains, second ed. Wiley & Sons, Ltd., UK.

Bayanov, B.F., Belov, V.P., Bender, E.D., Bokhovko, M.V., Dimov, G.I., Kononov, V.N., Kononov, O.E., Kuksanov, N.K., Palchikov, V.E., Pivovarov, V.A., Salimov, R.A., Silvestrov, G.I., Skrinsky, A.N., Soloviov, N.A., Taskaev,

S. Yu., (1998). Accelerator-based neutron source for the neutron-capture and fast neutron therapy at hospital. Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment. 413(2-3), 397-426. https://doi.org/10.1016/S0168-9002(98)00425-2.

Bokusheva, R., Finger, R., Fischler, M., Berlin, R., Marín, Y., Pérez, F., Paiz, F. (2012). Factors determining the adoption and impact of a postharvest storage technology. Food Sec. 4, 279-293. https://doi.org/10.1007/s12571-012-0184-1.

Boye, J.I., Arcand, Y. (2013). Current Trends in Green Technologies in Food Production and Processing. Food Eng. Rev. 5, 1-17. https://doi.org/10.1007/s12393-012-9062-z.

CAC, (2003). Codex Alimentarius Commission. General Standard for Irradiated Foods (CODEX STAN 106-1983, Rev.1-2003). Codex Alimentarius, FAO/WHO, Rome. http://www.fao.org/input/download/standards/16/CXS_106e.pdf/ (accessed 6 December 2020).

Calicioglu, O., Flammini, A., Bracco, S., Bellù, L., Sims, R. (2019). The Future Challenges of Food and Agriculture: An Integrated Analysis of Trends and Solutions. Sustainability. 11(222), 1-22. https://doi.org/10.3390/su11010222.

Carden, J.E. (1967). Design of the worlds first industrial-scale grain-irradiation facility. Isot. Radiat. Technol. 4(4), 396-398.

Cherepkov, V.G., Golubenko, Yu.I., Kachalov, P.I., Nemytov, P.I., Salimov, R.A., Jingtian, Y. (2006). Based on two electron accelerators ELV disinsector of a grain in China (Capacity up to 1000 t/h). Presentation at the meeting of The XXth Russian conference on charged particle accelerators (RuPAC), Novosibirsk, Russia.

Cleland, M.R. (2013). Advances in electron beam and x-ray technologies for food irradiation. in: Fan, X., Sommers, C.H. (Eds.), Food Irradiation Research and Technology. Second Ed. Wiley-Blackwell, USA, pp. 9-27.

Enu, R., Enu, P. (2014). Sterilization of Grains Using Ionizing Radiation: The Case in Ghana. Eur. Sci. J. 10(6), 117-136. https://doi.org/10.19044/esj.2014.v10n6p%25p.

Eustice, R.F. (2018). Global status and commercial applications of food irradiation, in: Ferreira, I.C.F.R., Antonio, A.L. (Eds.), Food Irradiation Technologies: Concepts, Applications and Outcomes. The Royal Society of Chemistry, Sandra Cabo Verde, pp. 397-424.

FAO, (1994). Definition and classification of commodities, cereals and cereal products. FAO, Rome. http://www.fao.org/es/faodef/fdef01e.htm/ (accessed 6 December 2020).

FAO, (2001). Food insecurity in the world 2001. FAO, Rome. http://www.fao.org/3/a-y1500e.pdf/ (accessed 6 December 2020).

FAO, (2013). Food wastage footprint - impacts on natural resources. Summary Report, FAO, Rome. http://www.fao.org/docrep/018/i3347e/i3347e.pdf/ (accessed 6 December 2020).

FAO, (2014). The food wastage footprint (FWF)-full cost accounting. Final Report, FAO, Rome. http://www.fao.org/3/a-i3991e.pdf/ (accessed 6 December 2020).

FAO, (2015). Food losses and waste. http://www.fao.org/food-loss-and-food-waste/en/ (accessed 6 December 2020).

FAO, (2016). Food loss and food waste. FAO, Rome. Italy: http://www.fao.org/platform-food-loss-waste/food-waste/definition/en/ last/ (accessed 6 December 2020).

FAO, (2018). The state of food security and nutrition in the world. FAO, Rome. http://www.fao.org/3/I9553EN/i9553en.pdf/ (accessed 6 December 2020).

Fanzo, J., Bellows, A.L., Spiker, M.L., Thorne-Lyman, A.L., Bloem, M.W. (2020). The importance of food systems and the environment for nutrition. Am. J. Clin. Nutr. 113(1), 7-16. https://doi.org/10.1093/ajcn/nqaa313.

Gibson, M. (2012). Food Security-A Commentary: What Is It and Why Is It So Complicated? Foods. 1(1), 18-27. https://doi.org/10.3390/foods1010018.

Godfray, H.C.J., Beddington, J.R., Crute, I.R., Haddad, L., Lawrence, D., Muir, J.F., Pretty, J., Robinson, S., Thomas, S.M., Toulmin, C. (2010). Food security: the challenge of feeding 9 billion people. Science. 327, 812-818. https://doi.org/10.1126/science.1185383.

Hallman, G.J. (2013). Control of stored product pests by ionizing radiation. J. Stored Prod. Res. 52, 36-41. https://doi.org/10.1016/j.jspr.2012.10.001.

Heather, N.W., Hallman, G.J. (2008). Pest management and phytosanitary trade barriers. CAB International, UK.

Hodges, R.J., Buzby, J.C., Bennett, B. (2011). Postharvest losses and waste in developed and less developed countries: opportunities to improve resource use. J. Agricult. Sci. 149, 37-45. https://doi.org/10.1017/S0021859610000936.

IAEA, (1971). Improving on appert. IAEA Bulletin. 13(4), 28-33. http://www.iaea.org/Publications/Magazines/Bulletin/Bull134/13405402833.pdf/ (accessed 22 June 2014).

IAEA, (2004a). Irradiation as a phytosanitary treatment of food and agricultural commodities. IAEA-TECDOC-1427. Vienna, Austria, https://www-pub.iaea.org/MTCD/Publications/PDF/te_1427_web.pdf/ (accessed 22 June 2020).

IAEA, (2004b). Directory of gamma processing facilities in member states. IAEA, IAEA-DGPF/CD, VIENNA, Austria. https://www-pub.iaea.org/MTCD/Publications/PDF/dgpf-cd/PDF/Contents.pdf/ (accessed 22 June 2020).

IAEA, (2006). Database on approvals for irradiated foods. IAEA Food & Environmental Protection Newsletter 9 (1), 21-59. http://www-naweb.iaea.org/nafa/fep/public/fep-nl-9-1.pdf/ (accessed 11 May 2019).

IAEA, (2012). Food irradiation clearances database. International Atomic Energy Agency, http://nucleus.iaea.org/ifa/FoodAuthorisationDisplay.aspx/ (accessed 26 October 2012).

Ibarz, A. (2008). Ionizing irradiation of foods. in: Urwaye, A.P. (Ed.), New Food Engineering Research Trends. Nova Science Publishers, USA, pp. 1-43.

IPPC, (2017). Replacement or reduction of the use of methyl bromide as a phytosanitary measure. CPM recommendation. CPM R-03. Rome, IPPC Secretariat, FAO. https://www.ippc.int/en/publications/84230/ (accessed 27 November 2018).

ITC, (2021). COVID-19 temporary trade measures. III. Overview of adopted COVID-19 trade measures (January 15, 2021). International Trade Centre (ITC). https://macmap.org/content/images/static/trademeasure/Covid19-Measures.pdf/

(accessed 16 January 2021).

Karel, M., Lund, D.B. (2003). Nonthermal methods. in: Karel, M., Lund, D.B. (Eds.), Physical Principles Preservation of Food, Second Edition, Revised and Expanded. Marcel Dekker, Inc., New York. pp. 461-507.

Koutchma, T., Keener, L., Kotilainen, H. (2018). Global harmonization initiative (GHI) consensus document on food irradiation. Discordant international regulations of food irradiation are a public health impediment and a barrier to global trade, 18p. Retrieved from https://www.globalharmonization.net/sites/default/files/pdf/GHI-Food-Irradiation_October-2018.pdf/ (accessed 16 October 2018).

Kumar, G., Rai, D.V. (2013). Management strategies for storage, disinfestation and insect detection of grains and seeds. Internat. J. Forestry & Crop Improv. 4(2), 87-96.

Loy, N.N., Sanzharova, N.I., Gulina, S.N. (2019). Assessment of the efficiency of application of ionising radiation for grain disinfestation. IOP Conf. Series: Materials Science and Engineering. 487 012030 IOP Publishing. Retrieved from https://iopscience.iop.org/article/10.1088/1757-899X/487/1/012030/pdf/ (accessed 20 July 2020).

Magnan, N., Lybbert, T.J., McCalla, A.F., Lampietti, J.A. (2011). Modeling the limitations and implicit costs of cereal self-sufficiency: the case of Morocco. Food Sec. 3 (Suppl 1), S49–S60. https://doi.org/10.1007/s12571-010-0103-2.

Marcotte, M. (2006). Irradiation. in: Heaps, J.W. (Ed.), Insect Management for Food Storage and Processing, Second Ed. AACC International, USA, pp.147-152.

Nayak, M.K., Daglish, G.J. (2018). Importance of stored product insects. In: Athanassiou C.G., Arthur F.H. (Eds.), Recent Advances in Stored Product Protection. Springer, Germany, pp.1-17.

Salimov, R.A., Cherepkov, V.G., Kuksanov, N.K., Kuznetzov, S.A. (2000). The use of electron accelerators for radiation disinfestation of grain. Radiat. Phys. Chem. 57, 625-627. https://doi.org/10.1016/S0969-806X(99)00484-3.

Salimov, R.A. (2006). Status of ELV-type electron accelerators. Presentation at the meeting of The XXth Russian conference on charged particle accelerators (RuPAC), Novosibirsk, Russia.

Silvestre, C., Cimmino, S., Stoleru, E., Vasile, C. (2017). Application of radiation technology to food packaging. In: Sun, Y., Chemielewski, A.G. (Eds.), Applications of Ionizing Radiation in Material Processing. Institute of Nuclear Chemistry and Technology, Poland, pp. 461-484.

Spaggiari, M., Dall'Asta, C., Galaverna, G. (2019). Food safety management of whole grains. Whole Grains Processing, Product Development, and Nutritional Aspects. in: Mir, S.A., Manickavasagan, A., Shah, M.A. (Eds.), CRC, USA.

Stejskal, V., Hubert, J., Li, Z. (2018). Human health problems and accidents associated with occurrence and control of storage arthropods and rodents. in: Athanassiou, C.G., Arthur, F.H. (Eds), Recent Advances in Stored Product Protection. Springer. Germany, pp.19-43.

Tang, C.X. (2010). Present status of the accelerator industry in Asia. In: Proceedings of the 1st International Particle Accelerator Conference (IPAC'10), 23-28 May 2010, Kyoto, Japan, paper WEIRA02, pp.2447-2471. Retrieved from https://pdfs.semanticscholar.org/f676/504f4aeb03a5b8c31defeeca9b3ff5b8f485.pdf/ (accessed 11 May 2019).

Thielecke, F., Lecerf, J., Nugent, A. (2020). Processing in the food chain: do cereals have to be processed to add value to the human diet? Nutr. Res. Rev. 1-15. https://doi.org/10.1017/S0954422420000207.

Tilton, E.W. (1974). Achievements and limitations of ionizing radiation for stored-product insect control. Presentation at the meeting of the 1st International Working Conference on Stored-Product Entomology, Savannah, Georgia, USA.

Torres-Rivera, Z., Hallman, G.J. (2007). Low-dose irradiation phytosanitary treatment against Mediterranean fruit fly (Diptera: Tephritidae). Fla. Entomol. 90, 343-346.

https://doi.org/10.1653/0015-4040(2007)90[343:LIPTAM]2.0.CO;2.

Udmale, P., Pal, I., Szabo, S., Pramanik, M., Large, A. (2020). Short communication, global food security in the context of COVID-19: A scenario-based exploratory analysis. Prog. Disaster Sci. 7, 100120. https://doi.org/10.1016/j.pdisas.2020.100120.

UN, (2016). World population prospects. United Nations, The 2015 revision. Retrieved from https://esa.un.org/unpd/wpp/Graphs/Probabilistic/POP/TOT/27.02.19/(accessed 3 December 2020).

UNEP, (1995). Montreal protocol on substances that deplete the ozone layer. 1994 Report of the Methyl Bromide Technical Options Committee, 1995 Assessment. Retrieved from https://ozone.unep.org/sites/default/files/2019-05/MBTOC94.pdf/(accessed 3 December 2020).

WB, (2012). Using public food grain stocks to enhance food security. World Bank. Washington, DC. Retrieved from https://openknowledge.worldbank.org/bitstream/handle/10986/11878/712800ESW0P1130Foodgrain0Stocks0web.pdf?sequence=1&isAllowed=y//(accessed 10 December 2020).

WHO, (1988). Food irradiation - a technique for preserving and improving the safety of food. WHO, Geneva. 84p. https://apps.who.int/iris/bitstream/handle/10665/38544/9241542403_eng.pdf?sequence=1/ (accessed 11 December 2020).

WHO, (2020a). WHO Director-general's statement on IHR emergency committee on novel coronavirus (2019-nCoV). Retrieved from https://www.who.int/director-general/speeches/detail/who-director-general-s-statement-on-ihr-emergency-committee-on-novel-coronavirus-(2019-ncov)/ (accessed 21 December 2020).

WHO, (2020b). Archived: WHO timeline - covid-19. Retrieved from https://www.who.int/news/item/27-04-2020-who-timeline---covid-19/ (accessed 21 December 2020).

Zakladnoy, G.A. (1990). Modern technologies for stored-grain protection against insect-pests in the USSR. Presentation at the meeting of the 5th International Working Conference on Stored-Product Protection, Bordeaux, France. Retrieved from http://spiru.cgahr.ksu.edu/proj/iwcspp/pdf2/5/1983.pdf/ (accessed 29 December 2020).

Zimmerer, K.S., de Haan, S. (2020). Informal food chains and agrobiodiversity need strengthening-not weakening-to address food security amidst the COVID-19 crisis in South America. Food Secur. 12, 891-894. https://doi.org/10.1007/s12571-020-01088-x.

Chapter 3

FACTORS AFFECTING THE TREE SPECIES COMPOSITION OF KELTEPE MOUNTAIN FORESTS

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1. INTRODUCTION

The tree species composition can be briefly defined as the variety of trees found in a forest. The tree species composition is very important for the main ecological and environmental issues such as protecting species diversity, ensuring forest structural diversity, and reducing the effects of climate change by providing the resilience of forests, supplying different woody raw materials, and ensuring water supply needed by society. The importance given to ecological factors in several forest management approaches varies according to stand variables, and the intensify of preferred silvicultural practices (Duncker et al., 2012). It is a common view today that the resource capacity of forests depends on the determination of the ecological factors that reveal the ecosystem characteristics. The complexity in the composition of a forest ecosystem makes it difficult to synthesize information about forest dynamics or to perceive the consequences of knowledge and assumptions about forest growth (Botkin et al., 1972). Addressing the resource capacity of forests in this way highlights the management of ecological factors associated with sustainable use in a planning approach. Various forest growth models have been developed that calculate the effect of ecological factors on a single tree or stand growth dynamics (Pretzsch et al., 2008). These growth models are based on carbon and nitrogen uptake and use (Bergh et al., 2003) to provide forest yield estimation considering environmental impacts, including climate change (Landsberg et al., 2003), gap model in which individual environmental conditions directly affect individual growth (Bugmann, 2001) or landscape models that include heterogeneity in site conditions, neighborhood interactions, and potential feedback between different spatial processes (Shifley et al., 2017). However, site conditions determined by water and nutrient availability are generally assumed to be constant in forest growth studies (Pretzsch et al., 2008). In terms of forest ecology, it is important to examine the relationship between forests and site growth conditions. Thanks to this relationship, it is expected that forest dynamics will be better understood, and accordingly, the most valid planning and management decisions based on use and protection will emerge (Skovsgaard and Vanclay, 2008: Pyatt et al., 2001: Çepel, 1988). Furthermore, the mixing of tree species is influenced by three main interacting units of forest stand dynamics. The functioning of trees and stands, stand and tree structure, and environmental conditions can affect the functioning of the trees and are itself affected by the structure (Pretzsch et al., 2015). Forest trees show different growth properties in varying site conditions. The most prominent are tree species composition, stand cover, trunk diameter and volume, tree height, crown width and height, leaf and trunk biomass, etc. are featured (Otto, 1994: Fujimori, 2001). There are many studies in the literature examining the forest stand productivity of ecological unit factors such as climate, topography (Candel Perez et al., 2012), bedrock (Hahm et al., 2014), and the distribution pattern of trees in the forested areas (Acharya et al., 2011). However, there are still incomplete planning considerations in the preparation of forest management plans that do not take into account the spatial variability of climatic, physiographic, and edaphic properties of the growing sites.

It has been observed that soil moisture, average annual precipitation, soil organic matter, unstable C and mineralizable N, microbial activities, extractable ammonium, and denitrification potentials increase with increasing altitude in the forested areas (Siles et al., 2016: Garten et al., 1999). In contrast, biomass density, pH, and soil temperature were significantly lower at higher altitudes. It was also stated that the soil temperature decreased with the increase in altitude, as well as decreasing forest debris rates, soil organic matter decomposition rates, and N mineralization rates (Griffiths et al., 2009). The aspect significantly affects annual mean temperature and precipitation, soil moisture and temperature, soil organic matter, mineralizable N, extractable ammonium, denitrification, and microbial activities (Huang et al., 2015: Griffiths et al., 2009). It has been determined that the change depending on the altitude and climate data has a positive effect on the nutrition-grading development of the Calabrian pine (Kantarcı, 1985). The change in the climatic characteristics of the forest growing sites in the Western Mediterranean Region of Turkey has been shown as the reason for the differentiation of the vegetation of the Calabrian pine forests (Karatepe et al., 2014). In a study conducted to reveal the relationships between the stand development of red pine forests and its habitat characteristics, it was determined that the most effective variables in height development were temperature index and longitude-latitude (Çelik and Özkan, 2015). In an other study investigating the relationships between Taurus cedar afforestation and habitat characteristics, it was determined that climate characteristics have a greater effect on height development (Karataş and Özkan, 2017). By Günlü et al. (2006) was concluded that the height growth of eastern spruce is affected by slope, physiological and absolute soil depth, clay and sand amounts in Ah and B horizons provided that soil and air humidity are high. In a study conducted by Kantarcı (1980) in Bolu Aladağlar, the effect of elevation on vegetation cover and soil properties was revealed.

This study aims to determine the spatial properties of the ecological factors that affect tree species composition in a very rugged forested area. These spatial data can provide essential bases for decision-makers in forestry activities such as silviculture, afforestation, forest protection, forest planning and management, and climate change studies. The research area has great elevation changes between 210 - 1995 m. The data for precipitation and temperature, bedrock, soil, topography such as elevation, slope, aspect and landform types used as ecological factors in the research. GIS techniques and methods were used to determine the distribution characteristics of tree species according to ecological factors.

2. MATERIAL and METHOD

2.1 Study Site

The study site covers the Eğriova and Keltepe Forest Districts located on Keltepe Mountain that are affiliated to the Karabük Forestry Management Directorate (Figure 1). The study site is located between 32°24'2'.583 and 32°40'24'.805 east longitudes, 41°2'13'.322 and 41°11' 32'.945 north latitudes, and the total area size is 20,224.54 ha, including the deforested areas. The total of forested areas is 14,033.671 ha.

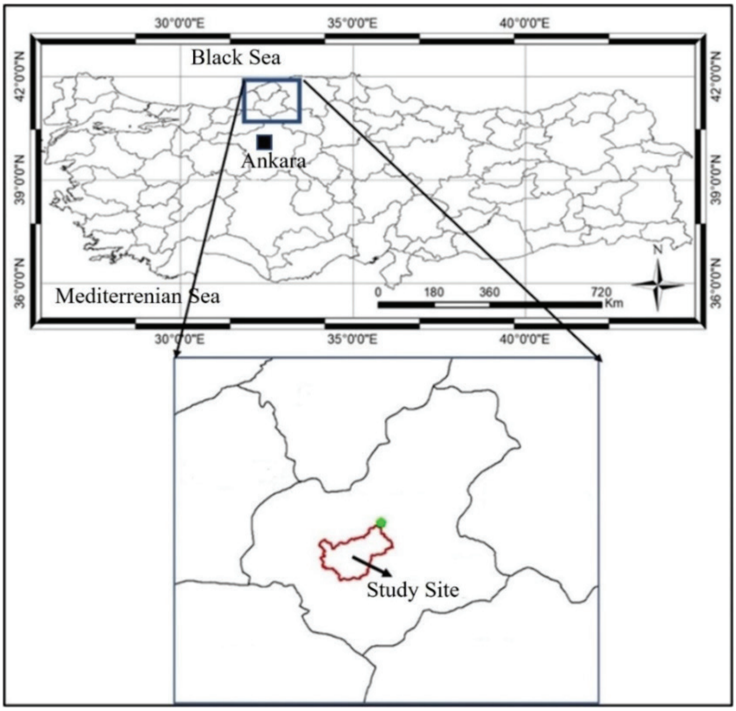


Figure 1. Location of the study site.

2.2 Method

Numerical and printed data of ecological factors and forest stand data required for the research were collected and classified. The printed maps were digitized by ArcMap 10.5 to use GIS studies.

2.2.1 Climate Data

It is known that climate and topography have a significant limiting effect on the distribution of forest tree species. Accordingly, the emerging features of climate and topography and the classification of forests depending on their ecological site characteristics are frequently used in some studies (Mendez Toribio et al., 2016: Dorman et al., 2013). The temperature and precipitation distribution maps for the study site were created by the climate data of eight stations located around the study site. These are located in different directions of the study site and at different elevations (Table 1). The Climate diagrams of the three stations closest to the research area were created. In addition, studies on the Emberger climate classification prepared by Coşkun and Coşkun (2017), according to Karabük Meteorology Station data covering the years 1970-2015, were used.

Table 1. Data from meteorological stations.

No	Station	AAT (°C)	ATR (mm)	Altitude (m)	N	E	OR
1	Karabük	13,4	487,5	269	41°11’45.9”	32°37’16.6”	1965-2014
2	Yenice	13,93	700,4	150	41°12’	32°19’59.8”	1994-2018
3	Eskipazar	11,1	453,3	757	40°56’39.1”	32°31’59.1”	1985-2018
4	Baklabostan	9,4	1151,6	860	41°16’27,89”	32°33’17.12”	1964-1991
5	Pazarköy	10	636,3	740	40°55’59.8”	32°10’59.8”	1965-1995
6	Safranbolu	12,4	500,5	400	41°15’	32°42’	1960-2004
7	Devrek	14,3	823	100	41°12’59.7”	31°56’59.9”	1964-2018
8	Ovacık	9,44	638.78	1100	41°4’40.1”	32°54’35.9”	2014-2018

AAT: Annual Average Temperature, ATR: Annual Total Rainfall, OR: Observation Period

Mapping of precipitation distribution

Schreiber’s equation was used to determine the amount of precipitation throughout the study site. It has been developed with some applications of GIS to increase its spatially effectiveness (Doğru and Güngöroğlu, 2022). In interpolating the precipitation data created according to the Schreiber formula to the field, firstly, the point (mean center) representing the geographical average of the field was found by GIS application. Generate Spatial Weight Matrix application of ArcMap 10.5. was used to find the distance of other stations from this point. The distance weights of stations to the midpoint of the study site were determined in the matrix. The precipitation values of stations by their altitude range and the distance weight values to the geographical midpoint of study site were multiplied to find the precipitation values by to the altitudinal range of the study site.

$$Y_{pm} = \Sigma \left[(I_p \text{ x } I_a) \pm I_p \right] \qquad [1]$$

Y_{pm}= Precipitation amount of altitudinal range (mm)

I_p= The amount of precipitation at the altitude where the station is located (mm)

I_a= Weight of the distance of the station to the site geographic midpoint

A cell size of 10 m produced the digital elevation map of the area covered by the stations in order to obtain 100 m altitude steps.Then, in accordance with the Schreiber formula, the total precipitation amount of each station was calculated as 54 mm up or down according to the altitude range, ± for each 100 m altitude range, in accordance with the equation below. On the other hand, the results of this developed method were compared with the results of the IDW method, which is frequently used in mapping precipitation with geostatistical methods. (Doğru ve Güngöroğlu, 2022).

Mapping the Distribution of Temperature

GIS-supported Lapse Rate (LR) method was used in mapping the monthly average temperature of meteorological stations for many years. LR was developed to predict air temperature based on altitude. LR is defined as the adiabatic rate of warming and cooling in the atmosphere and is explained as the variation of temperature with altitude. In this study, the LR method, which is suitable for the temperature in Turkey in 1x1 km grid range and 0.5 °C change in every 100 m (Demircan et al., 2013), was used to map the distribution of temperature in the study site. In accordance with the LR method, the annual average temperature values of all stations are reduced to sea level in accordance with the equation below.

$$T_d = T_i + (hi \times 0{,}005) \qquad [2]$$

In this equation, T_d is the sea level temperature, T_i is the average temperature of the station, and h_i is the altitude of the station. Then, specific to this study, the temperature values of the stations reduced to sea level were multiplied by the distance weight ratios of the stations to the mean center of the research area. The rated temperature values of the stations were then added to obtain a temperature value of the mean center reduced to sea level. Then, this value was calculated according to the elevation of the mean center by inverting the above equation, and the actual temperature value of the mean center was found. ± 0.5 °C is distributed to each 100 m altitude range from the altitude of the mean center. Finally, the difference between the highest temperature and the lowest temperature was transformed into five equally classes for the mapping with GIS.

2.2.2 Data for Physiographic Factors

Classified maps of elevation, aspect, slope and terrain morphology were produced with the spatial analyst application of ArcMap 10.5 GIS software based on the digital elevation map (DEM). It was produced with a cell size of 10x10 m (Figure 2).

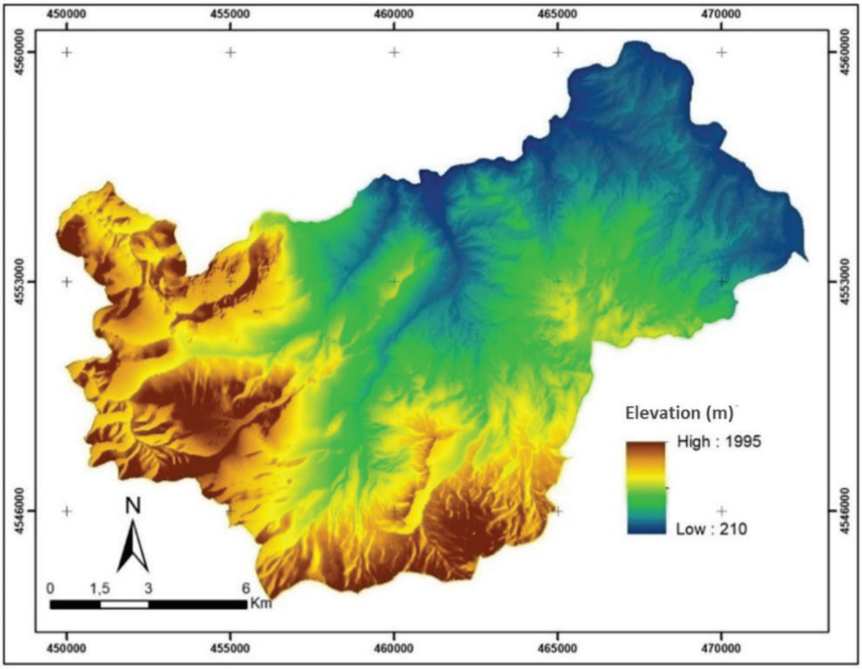


Figure 2. Digital elevation map of the study site.

The map of exposure was produced to represent four main directions and flat areas. The slope map was created in seven classes according to the degree of slope used in forestry applications. Terrain morphology map, using topographic position index (TPI) algorithm (De Reu et al., 2013). The basic approach in establishing the TPI is given in Figure 4. Values vary between low, high and flat areas in the TPI. If the TPI value gets closer to 0 in a raster, it is understood that the land is flat. Negative values in the TPI represent lowered areas and positive values indicate elevated areas.

2.2.3 Data for Soil and Bedrock

A digital geological map of 1/100000 scale was provided by the Turkish Mineral Research and Exploration Institute. Eleven different formation polygons belonging to the bedrock were regrouped as six main formations for this study. Soil types related to the site and their characteristics were determined from Coşkun (2020) and Dündar (2019). The soil types were obtained by overlaying the map of Dündar (2019) in the GIS environment to the study site. In addition, the soil types and their properties depending on the plant and bedrock characteristics were adapted based on these studies.

2.2.4 Forest Stand Data

The tree species and stand mixing characteristics of the forests were produced from the digital stand data of the Eğriova and Keltepe Forest

Chiefs, which were put into practice in 2020. Maps showing the distribution and mixing of tree species were created using GIS software.

2.2.5 Data Processing and Analysis with GIS

GIS is integrated into the stages of data acquisition, coordinating, digitization, registration of new data, and conversion, analysis and mapping of raster-vector data. For this purpose, ArcMap 10.5 module of ArcGIS desktop application was used. In this study, each ecological factor and stand properties were moved to a raster cell size of 20x20 m, and a database of all values in this cell size was obtained.

3. RESULTS

3.1 Climate

The closest meteorological stations to the study area are Karabük, Yenice, Eskipazar and Baklabostan. Their water deficit months are usually between June and October. There are differences in the temperatures and precipitation amounts of the stations. Eskipazar is the station with the lowest average precipitation. The station with the lowest average temperature is Baklabostan. This station has the highest altitude among the others with 860 m. Yenice and Baklabostan stations are the closest stations to the Black Sea coast and their rainfall amounts are considerably higher than the others. It can be said that the Eskipazar station is more exposed to the arid and cold air currents of the Central Anatolia Region, while the Karabük station remains in the tectonic depression area lying on the axis of the Araç Stream and is more under the influence of hot and dry air currents. According to the Emberger climate classification, Karabük station data characterizes the Mediterranean type climate with dry and warm summers and cold winters. In this respect, it is neither as rainy and humid as the Black Sea coasts nor has a harsh continental climate like the Central Anatolia region of Turkey (Coşkun and Coşkun, 2017).

3.1.1 Mapping the Distribution of Precipitation

The mapping of the distribution of precipitation amounts was performed by combining the Schreiber formula and the mean center application of GIS. Apart from this method, precipitation mapping was performed with IDW. As a result of these two mappings, it was seen that there was a big difference between the maximum and minimum precipitation amounts. While there is a 76,5 mm precipitation difference in the field in the mapping made according to the Schreiber formula and mean center application, this difference is 17,07 mm according to the IDW method (Figure 3) (Doğru and Güngöroğlu, 2022). There is a difference of 1700 m between the lowest and highest elevations of the study area.

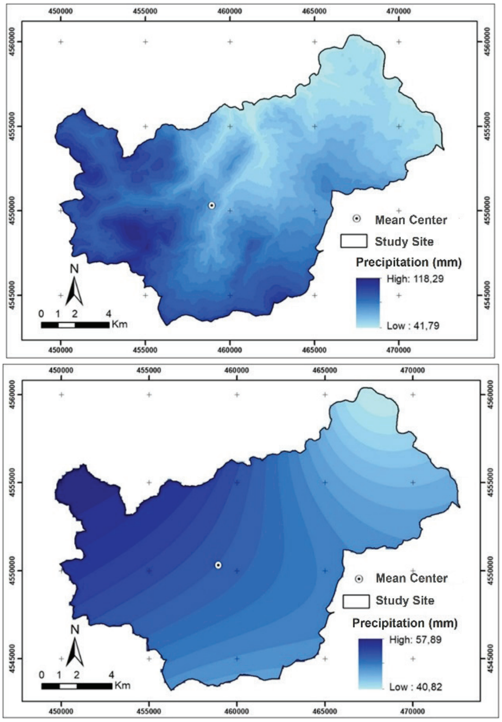
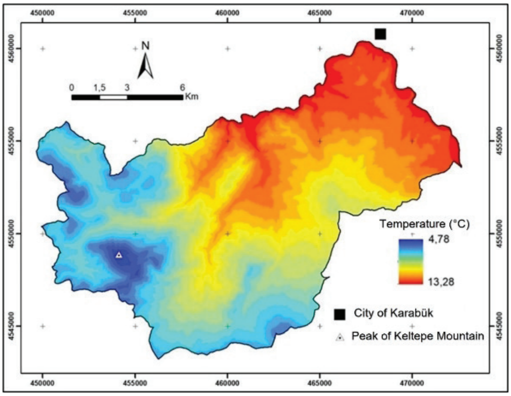


Figure 3. Distribution of precipitation, Schreiber formula and mean center (left), IDW (right)

3.1.2 Mapping Temperature Data

The temperature difference between the min and max elevations of the study site is 1,01 °C obtained by IDW. On the other hand, the temperature difference between the min and max elevations of the field is 8,5 °C obtained by the Lapse Rate and mean center application where the elevation is taken into account (Figure 4).



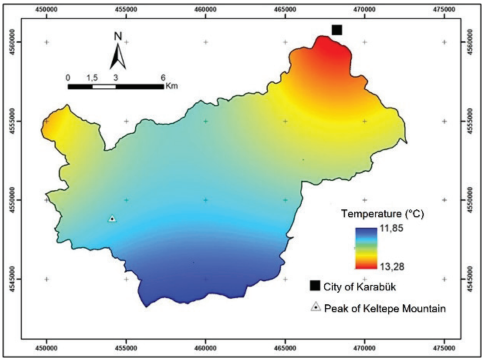


Figure 4. Distribution of temperature, Lapse Rate and mean center (left), IDW (right)

3.2 Physiographic Properties

3.2.1 Elevation

The elevation of study site are classified at both 100 m (Figure 5) and 400 m (Table 2) intervals. The width of the altitudinal ranges gradually decreases from 300 m to 1400 m, widens again from 1500 m and decreases towards the peak of Keltepe Mountain (Figure 6). According to the elevation classification with 400 m intervals, the elevation between 400-1600 m constitutes 82.62% of the entire study site (Table 2).

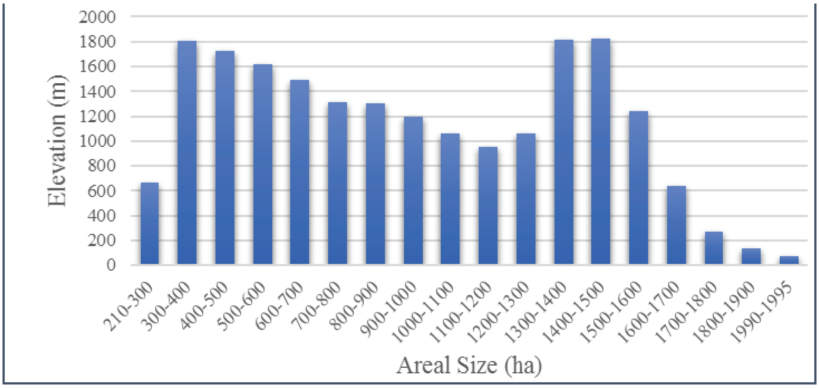


Figure 5. Areal sizes at 100 m elevational classes of the study site.

Table 2. Areal sizes at 400 m intervals of the study site.

Elevation classes (m)	Saha (ha)	Yüzde (%)
1600 -1995	1135,708	5,60
1200 -1600	5964,048	29,40
800 -1200	4535,648	22,36
400 - 800	6164,078	30,38
210 - 400	2488,248	12,26
Total (ha)	20287,73	100,00

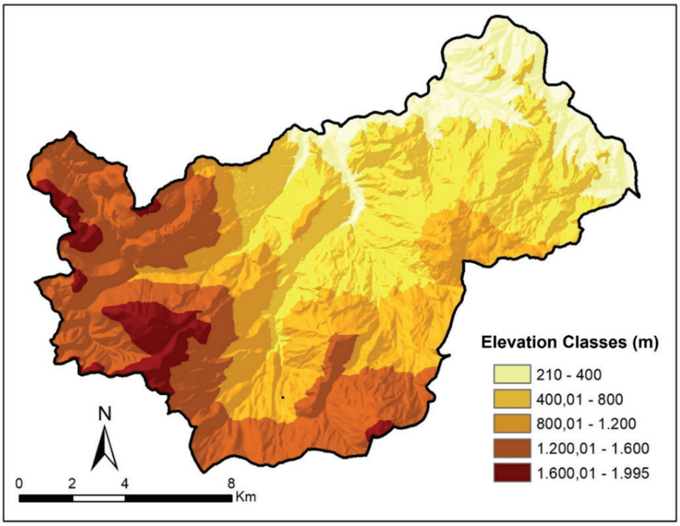


Figure 6. Map of elevation classified to 400 m.

3.2.2 Exposure

It has been observed that the north exposured areas constitute 40% of the total area with 8099.83 ha, followed by the east exposured areas with 5199.96 hectares, 26% of the study area (Figure 7). The areas facing west and south have a distribution of 31% in the study site with 6410.24 ha. The site covered by the flat areas is 514.91 ha and has a 3% coverage area.

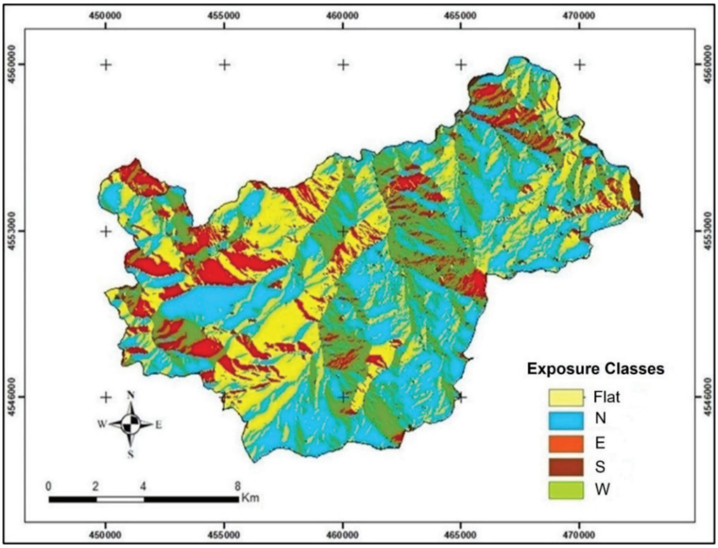


Figure 7. Map of exposure classes.

3.2.3 Slope

Very sloping areas in the field are 8113.96 ha, and it has been determined that they constitute 40% of the total area (Figure 8). The steeply sloping areas make up 22% of the field. Very steep inclined fields include 1% of the field. The site generally shows a significantly sloped land structure extending through narrow valleys.

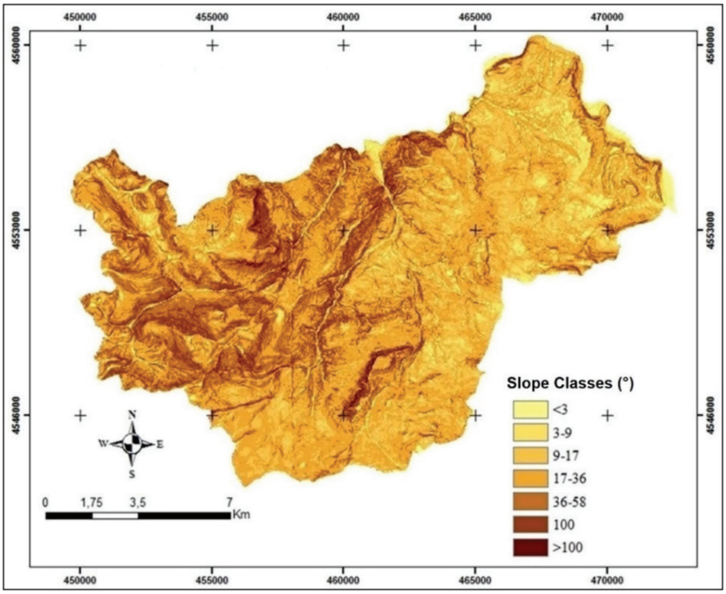


Figure 8. Map of slope classes

3.2.4 Landforms

Topographic position index (TPI) with a cell size of 200 m was created to create a landform map. The distribution of TPI values to raster cell amounts is given in the Figure. A four-class map of slope positions with 200 m intervals was created (Figure 9). It is understood from the TPI values of ± 100 that the roughness of the land, which occurs from 400-500 m, starts to increase gradually. It can be understood that narrow and deep valleys, and ridge formations begin to intensify, especially in the upper mountainous areas around the Keltepe peak. Although the field size of the slopes is the highest in the field, the field sizes of the ridges and valleys immediately follow it. It is seen that the flat areas have a very low field size compared to the others (Figure 10). This situation reveals that the field has a very rough terrain.

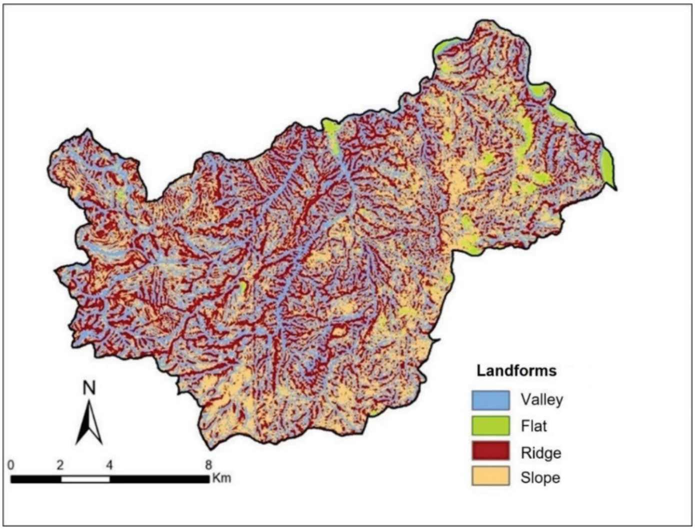


Figure 9. Landforms map.

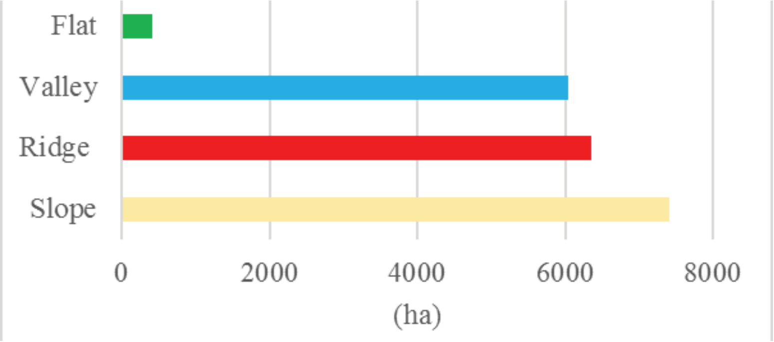


Figure 10. Distribution of areal sizes (ha) of landforms.

3.3 Bedrock and Soil

3.3.1 Bedrock

The most common bedrock type in the research area is the limestone formation covering 46% (Figure 11). This formation is explained by Upper Cretaceous and Paleocene aged limestones, pre-Jurassic metamorphics, and acidic intrusive rocks, and the present form of the Karabük-Safranbolu Tertiary Basin is a narrow basin formed at the end of the Upper Lutetian. It is stated in the literature that it has risen at least twice since the Upper Pliocene (Koçyiğit, 1987). The Akçapınar Formation, which is included in this formation, is a character sequence with white, yellowish gray-colored clayey limestone, dolomitic, and chert bands. In the second rank is a formation consisting of sandstone, shale, conglomerate, and limestone, and it was named Karabük - Safranbolu Tertiary Basin and its sediments by Koçyiğit (1987). Karabük formation is in third place. The lower parts of this formation are mainly composed of marls, and the marls are partly gypsum. Towards the upper sections, intercalations of sandstone are increasingly taking place. The uppermost parts are entirely composed of sandstone characters (Sinanoğlu, 2012).

3.3.2 Soil Types

Alluvial soils are located in the field as a narrow strip along the Filyos Stream. These soils are not horizonalized by continuous runoff and erosion. The A horizon develops only in mature alluvial soils. It has been reported that the colluvial soils in the study area have a clay content varying between 80-85% and this is montmorillonite and kaolin clay. The organic matter content of these soils is low, with a value between 1.5-2.5%. It was reported by Coşkun (2020) that an O horizon of more than 1 cm formed from the accumulation of needles in the Bornmullerian fir and scotch pine forests located in the Eğriova part of the study site, under which there is an A horizon that is very rich in organic matter. Furthermore, it has been reported that such formations include acid-reactive brown forest soils. Brown forest soils are common under oak, scotch pine and Anatolian black pine forests, which correspond to erosion plains in the study site. Rendzina soils consisting of A and C horizons are observed in Anatolian black pine forests that make pile roots on marl and soft limestones (Coşkun, 2020). Brown forest soils spreading in the study site are acidic in areas where washing is relatively high, and calcareous in areas where washing is less. It has been determined that acid brown forest soils are richer in organic matter than calcerous brown forest soils. Therefore, it has been reported that forest areas show more intensive development on acid brown soils (Dündar, 2019). Anatolian black pine trees are more preferentially spread on calcareous brown forest soils and acid brown forest soils. Bornmullerian fir, oriental beech and Scotch pine trees are preferently spreading on acid brown forest soil and rendzina (Table 3).

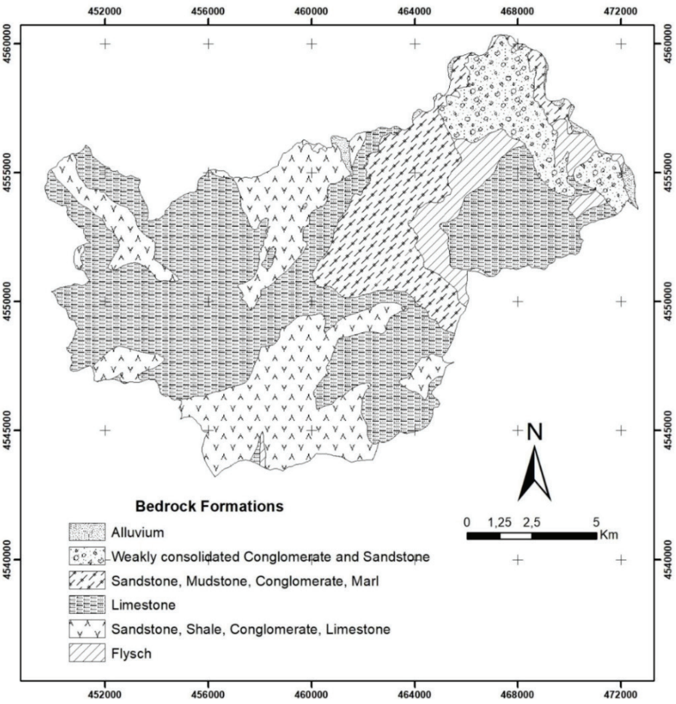


Figure 11. Main bedrock types of study site.

Table 3. Distribution of tree species by soil types.

Trees	Alluvial	Colluvial	Calcareous brown forest soil	Acid brown forest soil	Rendzina	Area (ha)
Black pine (Pinus nigra subsp. pallasiana)	99.38	114.23	2727.88	1598	343.61	4883.09
Bornmullerian fir (Abies bornmuelleriana)	-	26.86	-	3462.13	1092.52	4581.51
Oriental beech (Fagus orientalis)	-	0.33	-	430.71	13.86	444.9
Scotch pine (Pinus sylvestris)	-	17.38	-	991.29	187.24	1195.91
Calabrian pine (Pinus brutia)	266.98	216.38	907.83	-	-	1391.18
Common hornbeam (Carpinus betulus)	2.08	1.50	70.68	241.01	272.45	587.71
Juniper (Juniper exelca)	-	-	22.81	89.27	40.32	152.40
Sessile oak (Quercus petraea subsp. İberica)	28.15	40.70	310.12	127.15	213.78	719.9
Maple (Acer spp.)	-	-	-	4.01	31.73	35.74
Oriental plane (Platanus orientalis)	-	2.14	10.64	-	-	12.78
Hop hornbeam (Ostrya carpinifolia)	-	-	23.97	4,56	-	28.54
Total Area (ha)						14033.67

3.4 Stand Mixture of Tree Species

Anatolian black pine has the highest distributed in the study site with 4883.09 ha. It is followed by Bornmullerian fir with 4581.51 ha (Figure 12). These two tree species cover 67.44% of the total area of forests as stand dominant tree species (Table 4). These two tree species are followed by Calabrian pine with 9.91% and Scotch pine with 8.52%.

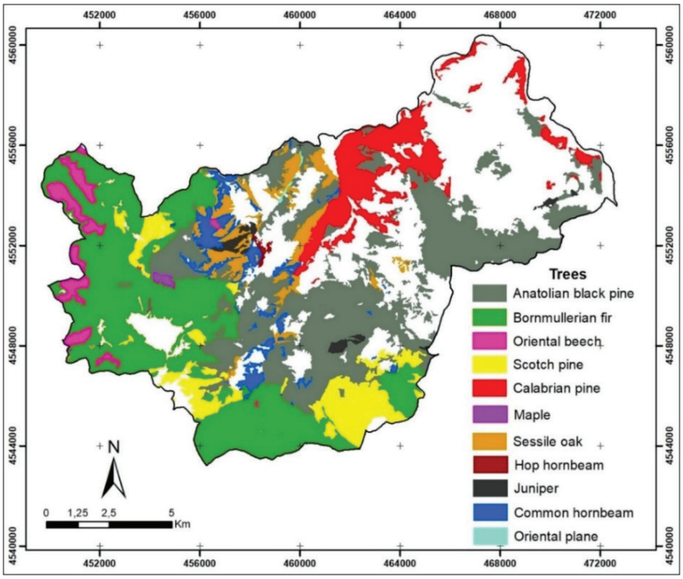


Figure 12. Distribution of forests in the study site according to dominant tree species.

Table 4. Areal distribution of stand establishing tree species.

Dominant Tree	Secondary Tree	Tertiary Tree	Area (ha)	%
Anatolian black pine	-	-	3524.32	25.11
	Bornmullerian fir	-	79.52	0.57
	Scotch pine	-	329.83	2.35
	Calabrian pine	-	82.50	0.59
	Common hornbeam	-	71.48	0.51
	Common hornbeam	Sessile oak	222.5	1.59
	Juniper	-	63.8	0.45
	Sessile oak	-	509.14	3.63
			4883.09	34.8
Bornmullerian fir	-	-	1221.46	8.7
	Anatolian black pine	-	314.37	2.24
	Oriental beech	-	1093.41	7.79
	Scotch pine	-	1850.12	13.18
	Common hornbeam	-	58.71	0.42
	Sessile oak	-	25.39	0.18
	Maple	-	18.05	0.13
			4581.51	32.65
Oriental beech	-	-	2.96	0.02
	Bornmullerian fir	-	441.94	3.15
			444.9	3.17
Scotch pine	-	-	481.36	3.43
	Anatolian black pine	-	145.7	1.04
	Bornmullerian fir	-	510.4	3.64
	Bornmullerian fir	Common hornbeam	16.49	0.12
	Common hornbeam	-	41.96	0.30
			1195.91	8.52
Calabrian pine	-	-	802.04	5.72
	Anatolian black pine	-	458.26	3.27
	Juniper	-	31.68	0.23
	Sessile oak	-	99.20	0.71
			1391.18	9.91
Common hornbeam	-	-	80.36	0.57
	Bornmullerian fir	-	24.89	0.18
	Oriental beech	-	53.89	0.38
	Sessile oak	-	428.58	3.05
			587.72	4.19
Juniper	-	-	74.67	0.53
	Sessile oak	-	77.73	0.55
			152.4	1.09
Sessile oak	-	-	462.40	3.29
	Anatolian black pine	-	190.70	1.36
	Common hornbeam	-	66.9	0.48
			719.89	5.13

Maple	Sessile oak	-	35,.4	0.25
Oriental plane	-	-	12.78	0.09
Hop hornbeam	Common hornbeam	-	28.54	0.2
			14033.66	100

Stand mixture forms of forest in the study site were mapped according to coniferous and deciduous tree species (Figure 13). Pure and mixed forests formed only by coniferous tree species have the highest distribution with 71.05% (Table 5). The rate of covering of forests consisting only of leaves is 8.35%, which is quite low compared to conifers.

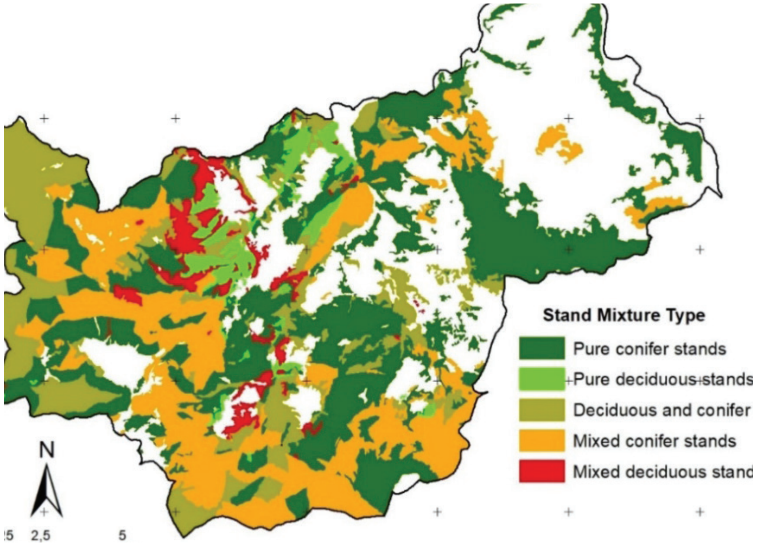


Figure 13. Mixture types of forest stands in the study site.

Table 5. Areal distribution of stand mixture types.

Mixture Type	Size (ha)	Percentage (%)
Pure coniferous	6000,41	42,76
Pure deciduous	558,51	3,98
Coniferous and deciduous mixed	2891,60	20,60
Mixed coniferous	3969,62	28,29
Mixed deciduous	613,54	4,37
Total	14033,68	100

3.5 Factors affecting on Tree Species Composition

Calabrian pine has the widest distribution with an average of 63.3% among other tree species up to 500 m altitude in the study site. This also shows that the Mediterranean climate is active up to this altitude. This tree is accompanied by Anatolian black pine with an average of 26.48% as the second tree species at these altitudes. Sessile oak, plane tree, hornbeam and juniper are respectively distributed in same altitudes. Anatolian black pine has an obvious dominance between 500-1200 m with an average of 63.03%. However, Calabrian pine accompanies Anatolian black pine at a very close rate between 500-600 m. In the study site, these two tree species are accompanied by sessile oak, hornbeam, juniper and Hop hornbeam. Bornmullerian fir has a very high dominance of 69.92% at altitudes of 1200-1990 m. But, it extends from 900 m to 1990 m. The eastern beech spreads between 1000 - 1800 m and the widest distribution area is between 1500 - 1700 m. This area is adjacent to the Yenice forests, where the effect of the oceanic climate of the Black Sea is directly recorded. The distribution area of Scotch pine in the study site is between 900 - 1900 m, and its widest spread at 1300 - 1600 m. Scotch pine is distributed in forests mixed with Bornmullerian fir at higher altitudes. Hornbeam is distributed between 210 – 1600 m, it has the highest distribution at 700 – 1100 m. Distribution of tree species in exposure classes is given in the Table 6. It has been determined that Anatolian black pine spreads in all exposition classes, especially in the west. Bornmullerian fir spreads in all exposition classes, but especially more in the northern slopes. Calabrian pine prefers south, west and plain areas. It is understood that the sessile oak spreads widely in the eastern and southern slopes. Percentage distributions of tree species in the study area by slope classes are shown in the Table 7. Although Anatolian black pine has the highest distribution in all slope classes, its widest distribution especially with 49.34% in areas with low slope. Bornmullerian fir has a distribution in all slope classes, similar to Anatolian black pine. But, its widest spread is formed by steeply sloping hills. It has been observed that scotch pine prefers the areas with medium slope classes. Calabrian pine, hornbeam and sessile oak cover steep and very steep areas in their distribution areas. Anatolian black pine and Bornmullerian fir are located in valley, ridge and slope type landforms without exception (Table 8). While Anatolian black pine has its highest distribution in valleys, Bornmullerian fir prefers slope land forms more. It is seen that the scotch pine prefers the slope land forms, while the oriental beech prefers the valleys. Calabrian pine prefers valleys and ridges more. The spread of sessile oak in valley and ridge landforms draws attention. The distribution of the areal sizes of the tree species according to the monthly average rainfall is given in the table 10. It is seen that Anatolian black pine has the highest distribution between precipitation amount of 57.09 – 87.89 mm, while Bornmullerian fir has the widest distribution between precipitation amount of 87.89 and 118.3 mm (Table 9). On the other hand, Anatolian black pine is distributed in all precipitation classes, while fir is located in the areas with monthly average precipitation amounts higher than 72 mm. Oriental beech, Scotch pine and maple accompany Bornmullerian fir in the same amount of precipitation. While the oriental beech has its widest distribution in the areas above 102 mm, for Scotch pine this is the areas above 87 mm. calabrian pine, a tree species belonging to a typical Mediterranean climate, has the widest distribution in the precipitation range of 41.79 to 57.09 mm. Hornbeam, juniper and sessile oak have a distribution between 41.79 and 103 mm, while hornbeam prefers slightly higher precipitation, and sessile oak prefers less precipitation. While Anatolian black pine spreads between 13.24 and 6.49 °C, its widest distribution is between 11.5 and 8 °C (Table 10). While the distribution areas of Bornmullerian fir, Scotch pine and maple forests vary between 11.5 and 4.48 °C, Bornmullerian fir has the largest distribution between 8,19 and 6,49 °C. On the other hand, the widest distribution of Scots Pine is between 9.88 and 6.49 °C. The temperature values of Scots pine are valid for oriental beech. Hornbeam, juniper and sessile oak range between 6.48 and 13.24 °C. However, hornbeam prefers a wide distribution in colder areas and sessile oak in warmer areas. The distribution of tree species on bedrock types is given in the Table 11. On the limestone, which covers 46% of the study site, there is the weight of Anatolian black pine and Bornmullerian fir forests. These two tree species cover 59.56% of the limestone areas. Other noteworthy tree species on limestone are oriental beech, Scots pine, hornbeam and sessile oak. Calabrian pine has the widest distribution in areas with sandstone, mudstone, conglomerate and marl content, which is named the Karabük formation. Other important distributions of Anatolian black pine, Bornmullerian fir, oriental beech, Scotch pine and sessile oak are on bedrock with sandstone, shale, conglomerate and limestone.

Exposure Classes	Anatolian black pine	Bornmullerian fir	Oriental beech	Scotch pine	Calabrian pine	Hornbeam	Juniper	Sessile oak	Maple	Oriental plane	Hophornbeam
Flat	34.05	28.12	5.56	9.45	13.11	1.62	1.36	4.44	1.09	1.20	.
North	36.05	38.62	3.43	8.19	8.32	2.62	0.21	1.83	0.40	0.03	0.28
East	31.39	29.37	2.58	6.65	9.07	8.36	2.75	9.32	0.04	0.15	0.31
South	32.87	31.29	3.76	8.66	8.28	3.65	1.61	9.39	0.45	0.04	0.00
West	38.73	24.89	2.82	12.03	15.99	2.06	0.12	3.22	0.03	0.11	0.01

Table 6. Percentage distribution of stand tree species by exposure classes

Table 7. Percentage distribution of stand tree species by slope classes

Slope Classes	Anatolian black pine	Bornmullerian fir	Oriental beech	Scotch pine	Calabrian pine	Hornbeam	Juniper	Sessile oak	Maple	Oriental plane	Hophornbeam
Flat	36.16	27.06	4.90	10.30	12.33	1.82	1.20	4.44	0.83	0.96	-
Less slope	49.34	22.33	3.20	11.92	7.37	2.40	0.51	2.56	0.09	0.23	0.03
Medium slope	35.58	31.16	2.08	18.41	8.06	2.65	0.44	1.36	0.13	0.10	0.03
Very slope	35.76	33.15	3.55	10.56	9.12	3.90	0.73	2.54	0.40	0.08	0.20
Steep slope	34.90	34.88	3.51	3.75	10.22	4.49	1.29	6.51	0.14	0.06	0.25
Steep	27.73	32.04	2.19	1.52	13.57	6.42	2.26	13.78	0.11	0.04	0.33
Very steep	34.40	10.71	1.16	1.06	11.86	10.36	4.71	25.40	0.07	-	0.27

Table 8. Percentage distribution of stand tree species by landforms

Landforms	Anatolian black pine	Bornmullerian fir	Oriental beech	Scotch pine	Calabrian pine	Hornbeam	Juniper	Sessile oak	Maple	Oriental plane	Hophornbeam
Valley	34.18	30.09	3.61	7.24	11.62	5.46	0.96	6.01	0.37	0.26	0.20
Flat	59.79	16.13	2.81	12.40	5.43	0.63	0.48	2.13	0.10	0.10	-
Ridge	36.11	31.02	3.24	6.90	10.91	3.80	1.45	6.32	0.04	0.01	0.21
Slope	33.64	36.89	2.71	11.25	7.39	3.47	0.83	3.22	0.37	0.02	0.20

Table 9. Percentage distribution of stand tree species according to monthly average rainfall

Rainfall (mm)	Anatolian black pine	Bornmullerian fir	Oriental beech	Scotch pine	Calabrian pine	Hornbeam	Juniper	Sessile oak	Maple	Oriental plane	Hophornbeam
41,79 - 57,09	28,21	.	.	.	62,32	0,51	0,44	7,89	.	0,63	.
57,09 - 72,39	58,68	.	.	.	23,49	4,45	1,79	10,76	.	0,20	0,63
72,39 - 87,89	61,85	14,74	0,09	4,18	0,01	9,08	1,63	7,24	0,90	.	0,29
87,89 - 102,99	12,40	60,85	5,87	16,54	.	2,42	0,67	1,20	0,06	.	.
102,99 - 118,3	0,84	72,89	13,18	12,87	.	.	.	.	0,22	.	.

Table 10. Percentage distribution of area sizes of stand tree species according to monthly average temperature

Temperature (°C)	Anatolian black pine	Bornmullerian fir	Oriental beech	Scotch pine	Calabrian pine	Hornbeam	Juniper	Sessile oak	Maple	Oriental plane	Hophornbeam
13,28-11,59	32,18	.	.	.	56,41	1,04	1,15	8,59	.	0,61	0,02
11,58-9,89	72,51	0,04	.	0,03	6,27	7,91	1,47	10,91	.	.	0,86
9,88-8,19	37,04	38,14	2,16	11,51	.	5,28	1,51	3,61	0,75	.	.
8,18-6,49	5,82	66,84	8,18	16,15	.	1,88	0,35	0,68	0,09	.	.
6,48-4,78	.	91,02	.	8,88	.	.	.	.	0,11	.	.

Table 11. The distribution of stand tree species on bedrock types

Tree	Bedrock Formation	ha	%
Anatolian black pine	Alluvium	0,32	0,00
	Weakly consolidated Conglomerate and Sandstone	131,40	0,94
	Sandstone, Mudstone, Conglomerate, Marl	467,40	3,33
	Limestone	2830,60	20,17
	Sandstone, Shale, Conglomerate, Limestone	1143,40	8,15
	Flysch	311,12	2,22
Bornmullerian fir	Limestone	2779,60	19,81
	Sandstone, Shale, Conglomerate, Limestone	1777,64	12,67
	Flysch	23,60	0,17
Oriental beech	Limestone	333,72	2,38
	Sandstone, Shale, Conglomerate, Limestone	111,88	0,80
Scotch pine	Limestone	632,00	4,50
	Sandstone, Shale, Conglomerate, Limestone	563,36	4,01
Calabrian pine	Alluvium	12,76	0,09
	Weakly consolidated Conglomerate and Sandstone	83,68	0,60
	Sandstone, Mudstone, Conglomerate, Marl	939,48	6,69
	Limestone	233,12	1,66
	Sandstone, Shale, Conglomerate, Limestone	36,04	0,26
	Flysch	84,48	0,60
Common hornbeam	Sandstone, Mudstone, Conglomerate, Marl	0,48	0,00
	Limestone	357,96	2,55
	Sandstone, Shale, Conglomerate, Limestone	228,96	1,63
	Flysch	0,32	0,00
Juniper	Limestone	138,48	0,99
	Sandstone, Shale, Conglomerate, Limestone	1,72	0,01
	Flysch	11,44	0,08
Sessile oak	Sandstone, Mudstone, Conglomerate, Marl	26,44	0,19
	Limestone	456,08	3,25
	Sandstone, Shale, Conglomerate, Limestone	238,52	1,70
	Flysch	0,48	0,00
Maple	Limestone	32,28	0,23
	Sandstone, Shale, Conglomerate, Limestone	3,60	0,03
Oriental plane	Sandstone, Shale, Conglomerate, Limestone	12,84	0,09
Hophornbeam	Limestone	7,76	0,06
	Sandstone, Shale, Conglomerate, Limestone	20,72	0,15
	Total	28,48	100

4. DISCUSSION

The eleven forest tree species establish forest stands. In the study site, from the lowest altitude to the highest altitude, Calabrian pine, Anatolian black pine and Bornmullerian fir forests follow each other in order in terms of their areal size and form a vertical forest zone. Other tree species accompany these tree species in different vertical zones. When the dominance of tree species in the study site is given depending on altitude: Calabrian pine at 210-400 m, Calabrian pine and Anatolian black pine between 500-600 m, Anatolian black pine between 600-1100 m, and

Bornmullerian fir from 1200 m up to 1990 m. These changes reveal that temperature and precipitation as a function of altitude significantly affect the distribution of tree species. Anatolian black pine and Bornmullerian Fir forests cover 67% of the area. The forests of these two tree species have distinctive distribution characteristics in different ecological factors of high mountain and mountainous regions. It has been revealed that temperature is quite effective on the distribution of tree species. Anatolian black pine and Bornmullerian fir forests spread especially in the areas with limestone bedrock. It is known that the precipitation increases and the temperature decreases every 100 m from the lower elevations to the upper elevations. The most important reason behind this is the increase in terrestrial radiation depending on altitude and its rapid cooling-warming period between night and day. In the upper elevations, low temperature and excess moisture also play an effective role on soil properties. Bases are washed out of the soil, the reaction becomes acid and, for example, podsolization can occur. In addition, biological activity in the soil slows down or may reach a complete standstill. This causes a continuous litter in the form of raw humus to accumulate on the soil. As the altitude affects the temperature and precipitation climate at a high level, the spreading of the forest plant belts with different ecological demands on the forested mountain slopes, on top of each other in steps, reveals the elevation-vegetation change areas called vertical forest zones. (Çepel, 1988). The vertical distribution limits of Anatolian black pine forests are different according to regions starting from the sea coast and exceeding 2000 m in inland areas of Turkey. The altitude limit of Anatolian black pine tree is determined by continentality. It is characterized by the increase in the temperature difference between summer and winter due to the decrease in relative humidity from the sea to the interior of the land, and the warming of the air in summer by a few degrees Celsius compared to the regions of the sea. It is reported that Anatolian black pine forests reaches its optimum condition between 1000-1400 m on north-facing slopes and between 1200-1600 m on south-facing slopes in terms of site conditions, except in regions with very high continentality (Atalay and Efe, 2010). In the study site, there is a very high distribution of Anatolian black pine forests between 600-1200 m. This low altitude range indicates that it prefers the slopes facing the Filyos basin, which have high humidity in summers and not high temperatures in winters. In addition, an approach can be made that soil and organic matter moisture provided by the flow from the upper region improves the conditions in these altitude range of Anatolian black pine forests during the dry months. It is known that Anatolian black pines, which are seen sporadically and in small groups in the coastal part of the Black Sea region, can reach up to 1500 m in the areas where there is not dense fog, and they are located in parts that receive direct solar radiation at higher altitudes. It is stated that the main tree species in the upper mountainous regions facing the coast in the Black Sea region is scotch pine, where there is less fog, and Bornmullerian fir forests dominate in the areas where the fog is intense (Kantarcı, 1980: Atalay and Efe, 2010). Looking at the situation in the study site, it is seen that Anatolian black pine can still establish stands up to 1600 m, while Scotch pine has a more intense distribution on the southern and western slopes between 1100-1900 m. While Bornmullerian fir and Scotch pine are located at the same altitude range, it is understood that Bornmullerian fir is distributed in all landforms, especially north exposed slopes. The average temperature of the altitude between 500-1400 m where Anatolian black pine spreads in the research area is approximately 9.5 °C. The temperature range of the distribution areas of Anatolian black pine in Turkey is found in the literature as 12 °C and 6 °C (Atalay and Efe, 2010). Bornmullerian fir spreads in the high mountain areas behind the coastal line of the Western Black Sea region (Avcı, 1998). The distribution of pure or mixed Bornmullerian fir forests with Scotch pine tree is high on the slopes of Keltepe Mountain above 1500 m, where the continental climate is dominant. Calabrian pine has a distribution between 208 m and 800 m in the study site. It is known that the widest distribution of Calabrian pine forests in the Soğanlıçay and Araç Çay basins of Karabük is between 400-600 m. Calabrian pine in Karabük forms mixed forests with Anatolian black pine at 700-800 m, and it is seen that the dominance of black pine begins after 800 m (Güngöroğlu, 2018). Calabrian pine is a typical forest ecosystem belonging to the Mediterranean climate in Turkey. It is reported that Calabrian pine is a species that has a high temperature demand, is sensitive to frost and avoids continental climates (Boydak et al., 2006). The annual average temperature in the natural distribution areas of Calabrian pine is given by Atalay et al. (1998) as 12-20 °C, and by Neyişçi (1987) as 10-25 °C. Calabrian pine has a dense distribution between 210-600 m and the average temperature of this altitidunal interval is 12.53 °C. When this temperature value is evaluated according to the studies mentioned above, the Calabrian pine distribution in the study site is in the lower steps of its optimum in Turkey. Karabük province has very high frost days in spring and autumn compared to Antalya province and the frost risk and snowfall effect increases towards the upper elevations of the basins (Güngöroğlu, 2018). In addition, it is known that the temperature inversion in the Araç Stream basin increases the effect of the cold weather in the winter quite intensely. Filyos stream is located in the north of the study site as a continuation of the Araç stream. Daily and annual temperature changes, fine soil washing and accumulation, air currents in ridges, slopes and valley depressions differ from flat lands and have different ecological characteristics. In addition, the soil depth in these landforms varies a lot depending on the bedrock, so the soils on the ridge and near the ridge slopes are rich in skeleton, shallow and poor in nutrients and dry. Therefore, there is an important relationship between the productivity of forest ecosystems and their distance from the upper edge of the slope (Çepel, 1988). In Bornmullerian fir forests of the region, mostly covered with fog, the amount of organic matter and total nitrogen falls from top to bottom in the soil layer and rises with the altitude. The nutrition of Uludağ Fir was positively affected by the increasing of precipitation and fog due to altitude (Kantarcı, 1980). Likewise, pit lands in the form of valley gutters are filled with fine soil material from the slopes, slope leachate or runoff water. In such areas, the air is more humid and stagnant, the soil is also deep for root development and rich in fine materials and nutrients. It has been revealed in this study that oriental beech forests prefer such areas in the study site.

5. CONCLUSION

In this study, mainly ecological factors affecting the distribution of tree species mixture were examined. Tree species were obtained from stand type mixtures. Forest stand types constitute the most homogeneous units in forest management. These forest patches emerge as a function of ecological factors affecting the growing site. Providing spatial data of ecological factors affecting these patches makes important contributions to what kind of forest management is done. In forest management, which depends on many ecological, economic and social factors, the decisions about the future of the forest and the selection of appropriate applications for these decisions are a basic management principle. As a result of a management type that does not take into account the factors affecting the growth and development of a forest, it is inevitable that the productivity of that forest will be lost. The decreasing of productivity also means degredation of ecosystem quality. Loss of productivity also means degradation of ecosystem quality in the form of loss of biodiversity and primary productivity, reduced nutrient cycling, etc. It is obvious that climate change will affect the development of forests in the future. On the other hand, it is certain that the demand for forest ecosystem services will increase due to the increasing population. Considering that ecological factors have different changes in the short and long term, the necessity of managing forests according to the ecological conditions of the site is increasing. For this purpose, another important step of this study is to spatially know the similar growing areas that ecological factors affect in different scales such as locality and region.

REFERENCES

Acharya, B.K., Basundhara, C., Lalitha, V. 2011. Distribution pattern of trees along an elevation gradient of Eastern Himalaya, India. Acta Oecologica, 37: 329-336.

Atalay, İ., Sezer, L. İ., Çukur, H., 1988. Kızılçam (Pinus brutia Ten.) Ormanlarının Ekolojik Özellikleri ve Tohum Nakli Açısından Bölgelere Ayrılması. Orman Ağaçları ve Tohumları Islah Araştırma Müdürlüğü Yayını. No:4, Ankara.

Atalay, İ., Efe R. 2010. Structural and Distributional Evaluation of Forest Ecosystem in Turkey. Journal Environment Biology, 31: 61-70.

Avcı, M. 1988. Ilgaz Dağları ve Çevresinin Bitki Coğrafyası II: Bitki Örtüsünün Coğrafi Dağılışı. Coğrafya Dergisi, 6: 275-344.

Bergh J, Freeman M, Sigurdsson BD, Kelloma¨ki S, Laitinen K, Niinisto S, et al. 2003. Modelling the short-term effects of climate change on the productivity of selected tree species in Nordic countries. Forest Ecology and Managemen,t 183: 327–340.

Botkin, D.B., Janak, J.F., Wallis, J.R. 1972. Some ecological consequences of a computer model of forest growth. Journal of Ecology, 60: 849–872.

Boydak, M., Dirik, H. Çalıkoğlu, M. 2006. Kızılçamın (Pinus brutia Ten.) Biyolojisi ve Silvikültürü. OGEM-VAK yayınları, Ankara, 364 pp.

Bugmann, H. 2001. A review of forest gap models. Climatic Change, 51: 259–305.

Candel-Pérez, D., Linares, J.C., Viñegla, B., Lucas-Borja, M.E. 2012. Assessing climate–Growth Relationships Under Contrasting Stands of co-occurring Iberian Pines Along an Altitudinal Gradient. Forest Ecology and Management, 274: 48–57.

Çelik, H., Özkan, K. 2015. Antalya Ovacık Dağı Yöresi'nde kızılçam (Pinus brutia Ten.)'ın gelişimi ile yetişme ortamı özellikleri arasındaki ilişkiler, SDÜ Fen Bilimleri Enstitüsü Dergisi, 19 (2): 190-197.

Çepel, N. 1988. Orman Ekolojisi. İstanbul Üniversitesi Orman Fakültesi Yayınları, İ.Ü. Yayın No.3518, O.F. Yayın No. 399. 3. Baskı. Gençlik Matbaası, İstanbul, 536 P.

Coşkun, S. 2020. Karabük Çevresinin Vejetasyon Ekolojisi ve Sınıflandırılması. İKSAD, 302 pp.

Coşkun and Coşkun, 2017). An Analysis on the Distribution of Maquis-Shrubland: Karabuk-Safranbolu Basin. International Journal of Sciences, 6 (06): 63-70.

Demircan, M., Sensoy, S., Ekici, M. 2013. İklim normalleri ve 1981-2010 sıcaklık normallerinin coğrafi bilgi sistemleri ile topografya kullanarak yüksek çözünürlüklü grid veri setinin üretilmesi 6th Atmospheric Science Symposium.

De Reu, J., Bourgeois, J., Bats, M., Zwertvaegher, A., Gelorini, V., De Smedt, P., ..., Van Meirvenne, M. 2013. Application of thetopographic position index to heterogeneous landscapes, Geomorphology, 186: 39-49.

Doğru and Güngöroğlu, 2022. Farklı Meteorolojik İstasyonlara Ait Yağış Değerlerinin Haritalanmasında Etkenliğin Arttırılmasına Dair Bir Uygulama. Turkish Journal of Geographic Information Systems (In Press).

Dorman, M., Svoray, T., Perevolotsky, A. 2013. Homogenization in Forest Performance Across an Environmental Gradient – The Interplay Between Rainfall and Topographic aspect. Forest Ecology and Management, 310: 256–266.

Duncker, P. S., Barreiro, S. M., Hengeveld, G. M., Lind, T., Mason, W. L., Ambrozy, S., Spiecker, H. 2012. Classification of forest management approaches: a new conceptual framework and its applicability to European forestry. Ecology and Society, 17 (4): 51.

Dündar, Ö. 2019. Karabük- Safranbolu Havzası'nda güncel ve paleosol toprakların belirlenmesi", Yüksek Lisans Tezi, Karabük Üniversitesi Sosyal Bilimler Enstitüsü, Karabük, 1-132.

Fujimori, T. 2001. Ecological and silvicultural strategies for sustainable forest management. Elsevier, Amsterdam, The Netherlands.

Garten, C.T., Post, W.M., Hanson, P.J., Cooper, L.W. 1999. Forest soil carbon inventories and dynamics along an elevation gradient in the southern Appalachian Mountains. Biogeochemistry, 45: 115-145.

Griffiths, R.P., Madritch, M.D., Swanson, A.K. 2009. The effects of topography on forest soil characteristics in the Oregon Cascade Mountains (USA): Implications for the effects of climate change on soil properties", Forest Ecology and Management, 257: 1–7.

Güngöroğlu, C. 2018. Batı Karadeniz Bölgesi kızılçam ormanlarının bazı ekolojik özelliklerinin belirlenmesi (Karabük örneği)", Karabük Üniversitesi Bilimsel Araştırma Projesi, KBÜ-BAP-15/1-DS-020, Karabük.

Günlü, A., Yılmaz, M., Altun, L., Ercanlı, İlker., Küçük, M. 2006. Artvin Genya Dağı bölgesinde saf doğu ladini (Picea Orientalis (L) Link.) meşcerelerinin verimliliği ile bazı edafik ve fizyografik faktörler arasındaki ilişkiler", Süleyman Demirel Üniversitesi Orman Fakültesi Dergisi, Seri: A (1): 1-10.

Hahm, J.W., Riebe, C.S., Lukens, C,E., Araki, S. 2014. Bedrock composition regulates mountain ecosystems and landscape evolution. PNAS, 111 (9): 3338–3343.

Huang, Y., Liu, D., An, S. 2015. Effects of slope aspect on soil nitrogen and microbial properties in the Chinese Loess region. Catena 125: 135–145.

Kantarcı, M.D. 1980. Aladağ kütlesinin (Bolu) kuzey yamacında Uludağ Göknarı ibrelerindeki mineral madde miktarlarının yükselti-iklim kuşaklarına göre değişimi. Journal of the Faculty of Forestry Istanbul University, Seri A, 30 (2): 135-152.

Kantarcı, M.D., 1985. Akdeniz Bölgesinde Yetişme Ortamı Bölgesel Sınıflandırmasının Yorumu. İstanbul Üniversitesi Orman Fakültesi Dergisi, 35: 59-82.

Karataş, R., Özkan, K. 2017. Toros sediri (Cedrus libani A. Rich.) ağaçlandırmalarının gelişimi ile yetişme ortamı özellikleri arasındaki ilişkiler, Ormancılık Araştırma Dergisi, 4 (1): 12-21.

Karatepe, Y., Özçelik, R., Gürlevik, N., Yavuz, H., Kırış, R. 2014. Batı Akdeniz'de farklı yetişme ortamı bölgelerindeki kızılçam (Pinus brutia Ten.) ormanlarının vejetasyon yapısının ekolojik değerlendirilmesi. SDÜ Orman Fakültesi Dergisi, 15: 1-8.

Koçyiğit, A. 1987. Karabük-Safranbolu Tersiyer Havzası kuzey kenarının stratigrafisi ve niteliği. Türkiye Jeoloji Kurumu Bülteni, 30: 61-69.

Landsberg J.J., Waring, R.H., Coops, N.C. 2003. Performance of the forest productivity model 3-PG applied to a wide range of forest types. Forest Ecology and Management, 172: 199–214.

Mendez-Toribio, M., Meave, J. A., Zermeno-Hernandez, I., Ibarra-Manriquez, G., 2016. Effects of slope aspect and topographic position on environmental variables, disturbance regime and tree community attributes in a seasonal tropical dry forest. Journal of Vegetation Science, 27: 1094–1103.

Neyişçi, T. 1987. Kızılçamın Ekolojisi. Kızılçam El Kitabı Dizisi-2, Ormancılık Araştırma Enstitüsü Yayınları, Muhtelif Yayınlar Dizisi, 52,:23-56, Ankara.

Otto, H.J. 1994. Waldökologie. Verlag Eugen Ulmer, Stutgart, 391 p.

Pretzsch, H., Grote, R., Reineking, B., Rötzer, T., Seifert, S., 2008. Models for forest ecosystem management: a European perspective. Annals of Botany, 101 (8): 1065–1087.

Pretzsch, H., Forrester, D.I., Rötzer, T. 2015. Representation of species mixing in forest growth models. A review and perspective. Ecological Modelling, 313: 276–292.

Pyatt, G., Ray, D., . Fletcher, J. 2001. An Ecological Site Classification for Forestry in Great Britain. Forestry Commission Bulletin, 124, Edinburgh.

Shifley, S., He, H.S., Lischke, H., …Yang, J. 2017. The past and future of modeling forest dynamics: from growth and yield curves to forest landscape models. Landscape Ecology, 32:1307–1325.

Siles, J.A., Cajthaml, T., Minerbi, S., Margesin, R. 2016. Effect of altitude and season on microbial activity, abundance and community structure in Alpine forest soils. FEMS Microbiology Ecology, 92, fiw008.

Sinanoğlu, D. 2012. Safranbolu Havzası (Karabük) Eosen Yaşlı Çökellerin Foraminifer Biyostratigrafisi, Yüksek Lisans Tezi, Fırat Üniversitesi Fen Bilimleri Enstitüsü, Elazığ.

Skovsgaard, J.P., Vanclay, J.K. 2008. Forest site productivity: a review of the evolution of dendrometric concepts for even-aged stands. Forestry, 81 (1): 13-31.

Chapter 4

THE RELATIONSHIP BETWEEN LIGHT AND NITRATE IN VEGETABLE PLANTS AND IMPACTS OF LED LIGHT USAGE ON NITRATE ACCUMULATION

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INTRODUCTION

People met their nutritional needs by using different agricultural techniques according to the periods in which they lived. However, as the world population increases, the demand for food has increased. Depending on the development of technology and the increase in the demand for food, modern agriculture has been started, the amount of product obtained from the unit area has increased and the total crop yield has increased. However, plants are exposed to various abiotic and biotic stresses such as drought, salinity, heavy metals, nutrient deficiency or toxicity, light, temperature, UV light stress, pesticides, pest and disease damages, which have an inhibitory effect on the photosynthetic process of plants (Soares et al., 2018; Sharma et al., 2019; Ceritoglu et al., 2020.; Sabagh et al., 2020; Saddhe et al., 2021). Stress in plants restricts photosynthesis by decreasing stomatal conductance, leading to oxidative stress and reducing Rubisco activity (Zhang et al. 2014; Kohli et al. 2017). Moreover, environmental stresses adversely influence the photosystems (PS I and PS II), electron transport mechanism, and biosynthesis of chlorophyll (Dobson et al., 2021; Mathur et al., 2021). Out of environmental stresses, light has a pivotal role in physiological and metabolic processes in plants (Burkholder, 1936; Mekala ve ark., 2015; Sharma ve ark., 2020). Additionally, various researchers pointed out that there is a strong correlation between light and nitrate accumulation in plant tissues (Steingröver et al., 1982; Cardenas-Navarro et al., 1999; Anjana and Iqbal, 2007). This study is to aim to contribute the understand nitrate accumulation-light relationship in plants.

1. Structure of Light and Role in the Plant Metabolism

Light usually refers to the visible portion of solar radiation or some form of energy that acts on the eye. While the propagation of light is in the form of electromagnetic waves, the speed of these wave movements is $3x10^8$ m/s. Electromagnetic waves from both natural (solar) and artificial sources travel in a sinusoidal curved trajectory in the direction of propagation. The distance between two close peaks of this curve is expressed as wavelength. Electromagnetic waves emitted from natural and artificial sources have different wavelengths (Dholakia, 2008).

All living organisms in the world benefit from the rays produced by the sun through various mechanisms. Plants benefit by converting the physical energy of the sun into chemical food energy in organic matter as a result of photosynthesis. The deficiency or excess of light intensity hurts the metabolic functions of the plant. If the light is less than needed, a series of metabolic changes follow the decrease in the number of carbohydrates in plants. In the absence of light, while shade plants expand their leaf areas, they send fewer photosynthesis products and slow down root development.

With the slowing of root development, the utilization of nutrients by plants is also adversely affected (Willey, 2016; Yavari et al., 2021).

Plants are living things that need light to survive. It adjusts plant growth and development according to the light period and light quality. All of the events that are affected by the light and create the shape of the plant are called ‘photomorphogenesis’. Photomorphogenesis is an expression of development in the active state of light. In the light environment, chlorophyll is formed in the seedlings, stem elongation is suppressed, stem expansion is ensured, the development of lateral roots is accelerated, leaf growth is encouraged (Padem and Özdamar, 2016). The wavelengths of red-blue light have the greatest influence on photosynthetic biosynthesis and photomorphogenesis. Because chlorophyll a and b in leaf cells effectively absorb both red and blue light for photosynthesis. Red and blue lights have different effects on plant growth. The effects of light quality on growth and secondary metabolite content of Ipomoea aquatica Forsk plant grown in a closed plant production system were investigated. It has been determined that red light is effective in increasing plant biomass, while blue light is important in chlorophyll biosynthesis and stomatal opening (Kitayama et al., 2019). Again, small wart-like tumors can be seen in tomato plants grown in closed plant production systems. These formations can develop mainly on the leaf surface, sometimes on the petioles and stems. Light quality plays an important role in this physiological disorder. Ultraviolet (UV) radiation, especially UVB (280-320 nm), is known to inhibit tumor-like growth. In addition to UV-B, far-red, blue and green light also has an inhibitory effect against swelling (Eguchi et al., 2016).

2. Nitrogen Uptake and Nitrate (NO_3^-) Accumulation in Plants

In agricultural production, high yield and quality are the two most important parameters. In order to grow high-quality and efficient products, first of all, the water and basic nutrients needed by the plant must be met. If the nutrient is not found in the soil at a sufficient level, it is called fertilization to bring it to the soil in various forms and techniques and to ensure that it is taken by the plants. The most common and most used fertilizer in production is undoubtedly nitrogenous fertilizers (Korkmaz et al., 2008). Plants take nitrogen in the form of ammonium (NH4+) and nitrate (NO3-). A large part of the taken nitrogen is metabolized in the leaves under normal ecological conditions and converted to protein (Sulak and Aydın, 2005). Excessive application of nitrogen fertilizer or inappropriate ecological conditions limits the conversion of nitrogen taken by plants to proteins and causes nitrate accumulation in the plant (Maynard et al., 1976; Wang and Li, 2004).

Nitrate (NO3-) is the end product of the biochemical oxidation of organic nitrogen (Mikuska and Vecera, 2003). Nitrates are naturally found in soil, water and nutrients (McClelland et al., 2007). It is an essential nutrient source for plants and is taken from the soil as nitrogen. There are two places in the plant where nitrate is found. These; It is the metabolic part in the cytoplasm and the storage part in the vacuole. In the metabolic zone, nitrate is converted to proteins, where the nitrate concentration is relatively low compared to the storage part. The nitrate in the storage area cannot be used easily by the plant and accumulated nitrate is located here. Nitrate accumulation in vacuoles decreases with increasing light intensity. The nitrate concentration in vegetables depends on the amount of nitrate taken up by plants from the soil and endogenous nitrate reductase enzyme activity. In plants, NO3- is reduced to nitrite by the nitrate reductase enzyme. When the activity of this enzyme is inhibited for any reason, nitrate accumulation increases (Özdestan and Üren, 2010). Nitrate accumulates in the leaves, stems and roots of plants grown in soils with a deficiency or excess of boron. The reason for this is that nitrate reduction and amino acid synthesis are inhibited. Nitrate accumulates mostly in leaves and mesophyll. The nitrate content of fruit and seed is generally low. Low light intensity, low soil moisture, high temperature and increasing potassium nitrate fertilizers increase nitrate accumulation in greenhouse products.

Nitrate and nitrite are found in nature at significant levels in water, soil and plant tissues, and 70% of the nitrate source taken into the human body is vegetables and 10% is fruit and its derivatives. Nitrate taken by plants is used as the basic building block for protein synthesis. However, nitrate accumulation in the plant is encouraged as a result of the inability to decompose the nitrate taken due to the effect of various factors (drought, cold, Fe, Mn, Mo deficiency, decrease in the number of sunny days, etc.). The accumulation of nitrate and its amount are especially important in vegetables that are directly consumed by humans. Nitrate concentration can reach high levels, especially in some vegetables such as lettuce and spinach whose leaves are eaten. Nitrate can turn into harmful substances that can cause cancer in humans and animals (Wynn et al., 2007). Although nitrate does not have a direct toxic effect, the main danger arises from the reduction of nitrate to nitrite. Especially the high level of nitrate contained in leafy vegetables can turn into nitrites, which are ten times more toxic than itself, during product processing and consumption, under inappropriate storage conditions, as a result of bacterial metabolism. For example, while the nitrite amount in fresh spinach is negligible, the nitrate concentrations in the stems and leaves of the preserved spinach can be high (Brown and Smith 1967).

Nitrate accumulation in vegetables depends on genetic structure, relative humidity, the water content of the soil, temperature, lighting, etc. In addition to the factors, nitrogen dose and form, amount of other nutrients, herbicide use, etc. as maintenance processes. affected by many factors such as In general, vegetables with the highest nitrate accumulation belong to the Brassicaceae, Chenopodiaceae, and Amaranthaceae families, and beetroot, lettuce, broccoli, spinach, radish, and celery species (Santamaria, 2006; Prasad and Chetty, 2008)). Although the acceptable limit of nitrate level for vegetables does not vary much between countries, the European Community Food Scientific Committee has determined the daily acceptable nitrate intake as 0-3.65 mg/kg body weight. According to this value, 100 g of fresh vegetables containing 2000 mg of NO3/kg in fresh weight corresponds to the daily nitrate intake of a person weighing 60 kg. The amount of nitrate taken daily with vegetables varies between 300-940 mg/g. This makes vegetables the most important nitrate source (Santamaria, 2006). In the evaluations made considering animal health, nitrate content of plant material up to 1000 ppm is used safely, while it carries a risk for animal health between 1000-2000 ppm. Because nitrate has acute and chronic effects in animals. It causes excessive nitrite formation in the rumen in animals fed with feed containing excessive nitrate. Nitrite, which does not convert to ammonia, binds hemoglobin in the blood and converts it to methemoglobin. Methemoglobin, on the other hand, prevents the transport of oxygen in the blood and causes nitrate poisoning in animals (Sulak and Aydın, 2005). In case of excessive use of nitrogen fertilizers, the amount of nitrate in the leaf reaches a level that threatens human health, especially in vegetables whose leaves are eaten (Eysinga, 1984). It is known that the nitrate content of dark green leafy vegetables (arugula, parsley, spinach) is higher than rooted, bulbous and tuberous vegetables. The amount of nitrate in various parts of the plant varies. The amount of nitrate is high in petiole and stem, moderate in leaves and roots, and very low in fruits and flowers. There are two places in the plant where nitrate is found. These; It is the metabolic part in the cytoplasm and the storage part in the vacuole. Nitrate accumulation in vacuoles decreases with increasing light intensity. Since sunlight is required for nitrate use in sprouts, nitrate concentration in the afternoon was lower than in the morning (Blom-Zandstra, 1989).

İnal and Güneş (1995), in their study on the effect of increasing nitrogen doses on nitrate content in sugar beet; applied N to the soil at doses of 0, 5, 20, 50, 100, 200, 500 mg kg-1. In leaf samples taken in the middle of the growth period, 6675 mg kg-1 nitrate was obtained at 500 mg N kg-1 application dose, while 2500 mg kg-1 nitrate was determined in leaf samples taken during the harvest period. The interest in micro-elements, which should be mandatory in soils and plants along with their macro elements, has become an issue that needs more attention in recent years and is gaining importance (Yazıcı and Korkmaz, 2020). This is since microelement applications are not made or that it causes serious yield losses due to the wrong time and amount of applications (Kılıç and Korkmaz, 2012).

Boon-Van der et al. (1990) changed the NH4-N/NO3-N ratio and the total nitrogen concentration to reduce the nitrate concentration of the lettuce plant in their experiments conducted in the NFT system for five years (summer and winter months). According to the research findings, nitrate concentration in plants grown in low light conditions in winter is significantly higher than in plants grown in summer. The nitrate accumulation in the lettuce was reduced by 20% replacement of NO3-N with NH4-N in the nutrient solution. Increasing the amount of ammonium in the nutrient solution a few weeks before the harvest did not affect the fresh weight of the plants, but decreased the nitrate concentration. Temporarily omission of all nitrogen produced the lowest nitrate concentrations, while also causing a sharp decrease in fresh weight. When the amount of NO3-N in the nutrient solution was reduced from 10 mmol/L to 2.5 mmol/L in winter, nitrate concentration and growth were not affected. In summer and spring, nitrate concentration decreased, but growth decreased. An increase in temperature in the nutrient solution, equivalent to a decrease in the temperature of the greenhouse air, in order to reduce energy consumption, although yielded better growth, led to increased nitrate accumulation, especially in the absence of ammonium in the nutrient solution.

Studies have shown that the nitrate content of vegetables produced in winter is higher than in summer. While the amount of nitrate in spinach was 2580 mg/kg in autumn and winter, it was determined as 1622 mg/kg in spring (Santamaria et al., 1999). Since sunlight is required for nitrate use in sprouts, nitrate concentration in the afternoon was lower than in the morning. Therefore, the nitrate content of plants harvested earlier in the day was higher than that harvested at the end of the day. It has been concluded that nitrate amounts can be reduced with an appropriate harvesting program in vegetables.

Nitrate must first be reduced to ammonia in order to enter organic structures as a plant nutrient and to fulfill its basic functions in the plant. The importance of reducing and assimilating nitrate to ammonia for plant life is equivalent to the reduction and assimilation of carbon dioxide (Arslan and Güleryüz, 2005). Nitrate Reductase (NR) catalyzes the reduction of nitrate to nitrite. Nitrite Reductase (NiR) is responsible for the reduction of nitrate to ammonia. One of the factors stimulating nitrate reductase activity in plant tissues is light (Marschner, 1995).

On the activity of nitrate reductase; While light intensity, temperature, nitrate level, some other ions and phytohormones affect, molybdenum deficiency in plants reduces nitrate reductase activity. Not feeding the plants with nitrate also reduces the nitrate reductase enzyme (Li and Gresshoff, 1990). Guerrero et al. (1981), depending on the increase in ATP synthesis in the tissues of plant leaves, protein and nitrate reductase synthesis increases. There is a positive relationship between light intensity and nitrate reduction in green leaves. While the reduction of nitrate in the leaf varies at different times of the day, the reduction in the roots does not show fluctuations in the leaf (Turan and Horuz, 2012).

3. Effect of LED Light on nitrate Accumulation in Plants

LED light applications in plant development Light is energy packets that move in waves and are composed of units called photon particles. As the wavelength of light changes, its color also changes. For example, long wavelengths generate red light, while short wavelength rays generate ultraviolet rays. Plants have different sensitivity to light of various wavelengths than humans. Only part of the light that can be seen by the human eye, that is, light with a wavelength between 400 and 700 nm, is used for photosynthesis and as an energy source. plants; They perform their vital activities by using light energy for the formation of leaves, flowers, shoots, branches and fruits. They need light for photosynthesis, the formation of chlorophyll, and the synthesis of organic and inorganic substances. The light energy needed for plants is provided either from sunlight or artificial light sources. The purpose of using artificial light sources in plant production is to support sunlight and/or to encourage the response of plants to sunlight (Atakli and Şahin, 2019). The most well-known artificial light sources are LED lights, which provide maximum light intensity at different wavelengths. They have been widely used in plant studies with their very long lifespan and long periods of unchanged light intensity. Since LED lights also do not generate infrared (IR) rays, they do not cause an increase in temperature on the objects to which they are applied (Hubbezoglu et al., 2008).

In studies on the factors affecting nitrate and nitrite contents of vegetables, it has been determined that vegetables produced in winter accumulate more nitrate than in summer months (Santamaria et al. 1999). It is known that this difference in nitrate accumulation is due to the decrease in temperature, light and day length. It has been determined that there is a direct relationship between the decrease in light intensity and the increase in the use of nitrogen fertilizers and nitrate accumulation in vegetables. The nitrate amount can be adjusted by adjusting the light intensity of artificial lighting used instead of sunlight in indoor plant production systems. Based on the studies, it can be said that the nitrate content is low with the application of high light intensities to leafy vegetables such as lettuce, spinach and arugula, and the light level acts inversely with nitrate accumulation (Cantliffe, 1972a). Increasing light conditions cause an increase in nitrate reductase activity, and a negative relationship emerges between photosynthetic activity and nitrate accumulation. Pavlou et al. (2007), according to the results of his study, the lowest nitrate content accumulated in plant tissues was observed in September and October, when the days are the longest.

Light is one of the most important environmental factors affecting plant growth and development. For this reason, it is necessary to choose the most suitable light source in indoor plant production systems. Besides light intensity, light quality or light spectrum is also important for the growth and development of plants. In sunlight and conventional lighting, plants absorb red and blue wavelengths of light, while they do not use and reflect some of the purple, green and yellow light. However, in LED lighting, the blue, red and long-wave red (far-red) light that plants need for photosynthesis is given directly (Atakli and Şahin, 2019).

One of the main factors determining the nitrate content of plants is light. The nitrate contents in plants are affected by the light intensity, the photoperiod, and the light duration during the photoperiod. Studies have shown that nitrate accumulation increases in conditions with low light intensity such as the winter season, while nitrate content decreases at high light intensities (Cantliffe, 1972b). Day length (photoperiod) is also effective on nitrate accumulation like light intensity. Nitrate contents also change at different times of the day. At high light intensity, the nitrate contents of spinach and lettuce are lower in the afternoon than in the morning (Cantliffe, 1972a).

Blom-Zandstra and Lampe (1985) studied the effect of different light intensities on nitrate accumulation in plant juice extracted from lettuce leaves, with concentrations of other compounds. After growing lettuce plants under constant environmental conditions for 52 days, they were transported to areas with different light intensities and harvested periodically. In the solution extracted from the plant sap, as a result of the quantitative analysis of the components, a decrease in the nitrate concentration; Inorganic acids (malate) and sugars (glucose) increased with increasing light intensity. The reduction in nitrate concentration determined in the plant sap was compensated by an increase in an organic acid to maintain electroneutrality and by increases in organic acids and sugars to maintain osmolality. This result proved that nitrate serves as an osmoticum to compensate for the carbohydrate deficiency caused by the lack of optimum photosynthesis under low light conditions.

Barczak and Majcherczak (1995) investigated the quality of vegetables grown in different natural conditions in terms of nitrate content. Nitrogen, nitrate, potassium and sodium contents in vegetables were higher in the early stages of vegetation (April and May for lettuce and radish, June for carrots). Gaudreau et al. (1995) cultivated lettuce plants at 3 light levels (0, 50 and 100 µmol/m2/s) with supplemental lighting. In greenhouse trials, photoperiods were set as 16h, 20h, 24h and 24/16h and compared with natural light. The use of supplemental light significantly reduced the nitrate concentration in the leaves during the winter. While total nitrate reductase activity was higher at one level increase in light (compared to constant light) in all studied plants, different light treatments created significant differences in fresh weight. Fluctuations in nitrate reductase activity were observed over a 24-hour cycle. Enzyme activity is lowest between 11:00 in the morning and 1:00 p.m. nitrate concentration and nitrate reductase activity in outer leaves were found at the highest level. Studies have shown that nitrate accumulation increases in conditions with low light intensity such as the winter season, while nitrate content decreases at high light intensities (Cantliffe, 1972a). Day length (photoperiod) is also effective on nitrate accumulation like light intensity. Nitrate contents also change at different times of the day. At high light intensity, the nitrate contents of spinach and lettuce are lower in the afternoon than in the morning (Cantliffe, 1972b).

CONCLUSION

Light has a pivotal role in physiological and metabolic processes in plants. The nitrate concentration in vegetables depends on the amount of nitrate taken up by plants from the soil and endogenous nitrate reductase enzyme activity. In plants, NO3- is reduced to nitrite by the nitrate reductase enzyme. When the activity of this enzyme is inhibited for any reason, nitrate accumulation increases. There is a strong correlation between light and nitrate accumulation in plant tissues. Many types of research pointed out that low light intensity such as short-day conditions inhibits nitrate reductase activity and triggers nitrate accumulation. However, LED light usage might be a sustainable and applicable solution for the mitigation of nitrate accumulation in vegetable crops under greenhouse conditions.

REFERENCES

Anjana, S. U., Iqbal, M. (2007). Nitrate accumulation in plants, factors affecting the process, and human health implications. A review. Agronomy for Sustainable Development, 27, 45-57. https://doi.org/10.1051/agro:2006021

Arslan, H., Güleryüz, G. (2005). A study on nitrate reductase activity (NRA) of geophytes from Mediterranean environment. Flora-Morphology, Distribution, Functional Ecology of Plants, 200 (5), 434-443. https://doi.org/10.1016/j.flora.2005.02.003

Atakli, S. B., Şahin, S. (2019). Development of lettuce plant in spring and autumn period, effects of led lightning on the quantity of mineral substrates and leaf nitrate. Asian Journal of Soil Science and Plant Nutrition, 5 (3), 1-9. 10.9734/ajsspn/2019/v5i330065

Barczak, B., Majcherczak, E. (1995). Vegetables quality estimation with special consideration related to nitrate contents. Zeszyty Noukowe Academii Techniczno Rolniczej Bydgosczy, 36, 71-85.

Blom-Zandstra, M. (1989). Nitrate accumulation in vegetables and its relationship to quality. Annals of Applied Biology, 115 (3), 553-561. https://doi.org/10.1111/j.1744-7348.1989.tb06577.x

Blom-Zandstra, M., Lampe, J. E. M. (1985). The role of nitrate in the osmoregulation of lettuce (Lactuca sativa L.) grown at different light ıntensities. Journal of Experimental Botany, 36 (7), 1043-1052.

Boon, J. V. D., Steenhuizen, J. W., Steingrover, E. G. (1990). Growth and nitrate concentration of lettuce as affected by total nitrogen and chloride concentration, NH4/N03 ratio and temperature of the recirculating nutrient solution. Journal of Horticultural Science, 65 (3), 309-321. https://doi.org/10.1080/00221589.1990.11516060

Burkholder, P. R. (1936). The role of light in the life of plants. I. Light and physiological processes. Botanical Review, 2 (1), 1-52.

Cantliffe, D. J. (1972a). Nitrate accumulation in spinach grown under different light intensities. Journal of the American Society for Horticultural Science, 97, 152-154.

Cantliffe, D. J. (1972b). Nitrate accumulation in vegetable crops as affected by photoperiod and light duration. Journal of the American Society for Horticultural Science, 97, 414-418.

Cardenas-Navarro, R., Adamowicz, S., Robin, P. (1999). Nitrate accumulation in plants: A role for water. Journal of Experimental Botany, 50 (334), 616-624. https://doi.org/10.1093/jxb/50.334.613

Ceritoglu, M., Erman, M., Yıldız, F. (2020). Effect of salinity on germination and some agro-morphological traits in chickpea seedlings. ISPEC Journal of Agricultural Sciences, 4 (1), 82-96. DOI: 10.46291/ISPECJASvol4iss1pp82-96

Dholakia, K. (2008). Against the spread of the light. Nature, 451, 413. https://doi.org/10.1038/451413a

Dobson, Z., Ahad, S., Vanlandingham, J., Toporik, H., Vaughn, N., Vaughn, M., Williams, D., Reppert, M., Fromme, P., Mazor, Y. (2021). The structure of photosystem I from a high-light-tolerant cyanobacteria. eLife, 10, e67518.

Eguchi, T., Hernandez, R., Kubota, C. (2016). Far-red and blue light synergistically mitigate ıntumescence ınjury of tomato plants grown under ultraviolet-deficit light environment. HortScience, 51 (6), 712-719. https://doi.org/10.21273/HORTSCI.51.6.712

Eysinga, R. V. (1984). Nitrate and glasshouse vegetables. Fertilizer Research, 5, 149-156. https://doi.org/10.1007/BF01052712

Gaudreau, L., Charbonneau, J., Vezina, L. P., Gosselin, A. (1995). Effects of photoperiod and photosynthet1c photon flux on nitrate content and nitrate reductase activity in greenhouse-grown lettuce. Journal of Plant Nutrition, 18 (3), 437-453. https://doi.org/10.1080/01904169509364914

Guerrero, M. G., Vega, L. M., Losada, M. (1981). The assimilatory nitrate reducing system and its regulation. Annual Review of Plant Physiology, 32, 169-204.

Hubbezoglu, I., Dogan, A., Dogan, O. M., Bolayır, G., Bek, B. (2008). Effects of light curing modes and resin composites on temperature rise under human dentin: an in vitro study. Dental Materials Journal, 27, 581-589.

İnal, A., Güneş, A. (1995). Effects of nitrogenous fertilization on yield and nitrate accumulation in sugar beet. Tarım Bilimleri Dergisi, 1 (1), 27-30. https://doi.org/10.1501/Tarimbil_0000000601

Kılıç, R., Korkmaz, K. (2012). Kimyasal gübrelerin tarım topraklarında artık etkileri. Biyoloji Bilimleri Araştırma Dergisi, 5 (2), 87-90.

Kitayama, M., Nguyen, D. T. P., Lu, N., Takagaki, M. (2019). Effect of light quality on physiological disorder, growth, and secondary metabolite content of water spinach (Ipomoea aquatica Forsk) cultivated in a closed-type plant production system. Horticultural Science and Technology, April 2019, 206-218

Kohli, S. K., Handa, N., Sharma, A., Kumar, V., Kaur, P., Bhardwaj, R. (2017). Synergistic effect of 24-epibrassinolide and salicylic acid on photosynthetic efficiency and gene expression in Brassica juncea L. under Pb stress. Turkish Journal of Biology, 41 (6), 943-953.

Korkmaz, K., Ibrikci, H., Ryan, J., Buyuk, G., Guzel, N., Karnez, E., Yagbasanlar, T. (2008). Optimizing nitrojen fertilizer-use recommendations for winter wheat in a mediterranean-type environment using tissue nitrate testing. Communications in Soil Science and Plant Analysis, 39, 1352-1366.

Li, Z. Z., Gresshoff, P. M. (1990). Development and biochemical regulation of 'constitutive' nitrate reductase activity in leaves of nodulating soybean. Journal of Experimental Botany, 41, 1231-1238.

Marschner, H. 1995. Mineral Nutrition of Higher Plants (2nd edn.). Academic Press, London.

Mathur, S., Sunoj, V. S. J., Elsheery, N. I., Reddy, V. R., Jajoo, A., Cao, K. F. (2021). Regulation of photosystem ıı heterogeneity and photochemistry in two cultivars of C4 crop sugarcane under chilling stress. Frontiers in Plant Science, 12, 627012.

Maynard, D. N., Baker, A. V., Minotti, P. L., Peck, N. H. (1976). Nitrate accumulation in vegetables. Advances in Agronomy, 28, 71-118.

McClelland, J. W., Stieglitz, M., Pan, F., Holmes, R. M., Peterson, B. J. (2007). Recent changes in nitrate and dissolved organic carbon export from the upper Kuparuk River, North Slope, Alaska. Journal of Geophysical Research: Biogeosciences, 112, 1-13. https://doi.org/10.1029/2006JG000371

Mekala, N. R., Suorsa, M., Rantala, M., Aro, E. M., Tikkanen, M. (2015). Plants actively avoid state transitions upon changes in light ıntensity: Role of light-harvesting complex II protein dephosphorylation in high light. Plant Physiology, 168 (2), 721-734. https://doi.org/10.1104/pp.15.00488

Mikuska, P., Vecera, Z. (2003). Simultaneous determination of nitrite and nitrate in water by chemiluminescent flow-injection analysis. Analytica Chimica Acta, 495 (1-2), 225-232.

Özdestan, Ö., Üren, A. (2010). Development of a cost-effective method for nitrate and nitrite determination in leafy plants and nitrate and nitrite contents of some green leafy vegetables grown in the Aegean Region of Turkey. Journal of Agricultural and Food Chemistry, 58 (9), 5235-5240. https://doi.org/10.1021/jf904558c

Padem, H., Özdamar, H. (2016). Sebze büyüme ve gelişiminde fotoreseptörler. Derim, 19 (2), 2-8.

Pavlou, G., Ehaliotis, C. D., Kavvadias, V. A. (2007). Effect of organic and inorganic fertilizers applied during successive crop seasons on growth and nitrate accumulation in lettuce. Scientia Horticulturae, 111 (4), 319-325. https://doi.org/10.1016/j.scienta.2006.11.003

Prasad, S., Chetty, A. A. (2008). Nitrate-N determination in leafy vegetables: Study of the effects of cooking and freezing. Food Chemistry, 106 (2), 772-780.

Sabagh, A.E.L, Hossain, A., Islam, M.S., Iqbal, M.A., Fahad, S., Ratnasekera, D., Azeem, F., Wasaya, A., Sytar, O., Kumar, N., Llanes, A., Erman, M., Ceritoglu, M., Arslan, A., Arslan, D., Hussain, S., Mubeen, M., Ikram, M., Meena, R.S., Gharib, H., Waraich, E., Nasim, W., Liu, L., Saneoka, H., 2020. Consequences and mitigation strategies of heat stress for sustainability of soybean (Glycine max L. Merr.) production under the changing climate. In: A. Hossain (Ed.) Plant Stress Physiology (1st Edn.). IntechOpen, London, pp. 1-22. DOI: 10.5772/intechopen.92098

Saddhe, A. A., Manuka, R., Penna, S. (2020). Plant sugars: Homeostasis and transport under abiotic stress in plants. Physiologia Plantarum, 171 (4), 739-755.

Santamaria, P. (2006). Nitrate in vegetables: Toxicity, content, intake and EC regulation. Journal of the Science of Food and Agriculture, 85 (1), 10-17. https://doi.org/10.1002/jsfa.2351

Santamaria, P., Elia, A., Serio, F., Todaro, E. (1999). A survey of nitrate and oxalate content in fresh vegetables. Journal of the Science of Food and Agriculture, 79, 1882-1888. http://dx.doi.org/10.1002/(SICI)1097-0010(199910)79:13<1882::AID-JSFA450>3.0.CO;2-D

Sharma, A., Kumar, V., Shahzad, B., Ramakrishnan, M., Sidhu, G. P. S., Bali, A. S., Handa, N., Kapoor, D., Yadav, P., Khanna, K., Bakshi, P., Rehman, A., Kohli, S. K., Khan, E. A., Parihar, R. D., Yuan, H., Thukral, A. K., Bhardwaj, R., Zheng, B. (2020). Photosynthetic response of plants under different abiotic stresses: A review. Journal of Plant Growth Regulation, 39, 509-531. https://doi.org/10.1007/s00344-019-10018-x

Sharma, A., Soares, C., Sousa, B., Martins, M., Kumar, V., Shahzad, B., Sidhu, G. P. S., Bali, A. S., Asgher, M., Bhardwaj, R., Thukral, A. K., Fidaldo, F., Zheng, B. (2019). Nitric oxide-mediated regulation of oxidative stress in plants under metal stress: A review on molecular and biochemical aspects. Physiologia Plantarum, 168 (2), 318-344.

Soares, C., Branco-Neves, S., de Sousa, A., Azenha, M., Cunha, A., Pereira, R., Fidalgo, F. (2018). SiO2 nanomaterial as a tool to improve Hordeum vulgare L. tolerance to nano-NiO stress. Science of the Total Environment, 622, 517-525.

Steingröver, E., Oosterhuis, R., Wieringa, F. (1982). Effect of Light Treatment and Nutrition on Nitrate Accumulation in Spinach (Spinacia oleraceae L.). Zeitschrift für Pflanzenphysiologie, 107 (2), 97-102. https://doi.org/10.1016/S0044-328X(82)80095-0

Sulak, M., Aydın, İ. (2005). Yem bitkilerinde nitrat birikmesi. OMÜ Ziraat Fakültesi Dergisi, 20 (2), 106-109.

Turan, M., Horuz, A. (2012). Bitki beslemenin temel ilkeleri. In: Karaman, M. R. (edn) Bitki Besleme (1st edn.). Dumat-Ofset Matbaacılık, Ankara, pp. 123-346.

Wang, Z., Li, S. (2004). Effects of nitrogen and phosphorus fertilization on plant growth and nitrate accumulation in vegetables. Journal of Plant Nutrition, 27 (3), 539-556. https://doi.org/10.1081/PLN-120028877

Willey, N. (2016). Environmental Plant Physiology (1st edn). Garland Science, New York. https://doi.org/10.1201/9781317206231

Wynn, P. M., Hodson, A. j., Heatın, T. H. E., Chenery, S. R. (2007). Nitrate production beneath a High Arctic glacier, Svalbard. Chemical Geology, 244 (1-2), 88-102. https://doi.org/10.1016/j.chemgeo.2007.06.008

Yavari, N., Tripathi, R., Wu, B. S., Macpherson, S., Singh, J., Lefsrud, M. (2021). The effect of light quality on plant physiology, photosynthetic, and stress response in Arabidopsis thaliana leaves. Plos One, 16 (3), e0247380. https://doi.org/10.1371/journal.pone.0247380

Yazıcı, D., Korkmaz, K. (2020). Karabuğday bitkisinde bor alınımı ve toksitesi üzerine potasyum uygulamalarının etkisi. Akademik Ziraat Dergisi, 9 (1), 151-162. https://doi.org/10.29278/azd.723988

Zhang, X., Zhang, X., Gao, B., Li, Z., Xia, H., Li, H., Li, J. (2014). Effect of cadmium on growth, photosynthesis, mineral nutrition and metal accumulation of an energy crop, king grass (Pennisetum americanum × P. purpureum). Biomass Bioenergy, 67, 179-187.

Chapter 5

RESUPINATUS NIGER (BASIDIOMYCOTA: AGARICALES): A RARE FUNGUS FROM TURKEY

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INTRODUCTION

The genus Resupinatus Nees ex Gray is in the family Tricholomataceae R. Heim ex Pouzar (Kirk et al., 2008) and is represented by only about fifty species (excluding synonyms) worldwide (www.indexfungorum.org). The species of the genus has characteristic features which include small-sized and dark-colored carpophores, hyaline, inamyloid, globose or subglobose to elliptical or cylindrical spores, presence or absence of metuloid cystidia, a gelatinized trama of the gills, pileipellis hyphae with amorphous-globular incrustation and sometimes with fine tapering spines each tipped with a droplet (Singer, 1986; Thorn and Barron, 1986; Watling and Gregory, 1989; Consiglio et al., 2018). A lamellate hymenophore is also a distinct feature of the genus (Singer, 1986). However, merulioid, poroid and cyphelloid species have been reported recently (Thorn et al., 2005; McDonald, 2015; McDonald and Thorn, 2019). Most species are saprotrophic and found on dead, rotten or decomposing hardwood branches (McDonald, 2015; Consiglio et al., 2018).

Over the years, species of the Resupinateae Singer have been classified under different genera and families. Singer (1948) named the tribe Resupinateae within the family Pleurotaceae Kühner, which included the two genera Resupinatus and Hohenbuehelia Schulzer. Later, Thorn et al. (2000) determined that Hohenbuehelia and Resupinatus formed distinct monophyletic groups, which are transferred to the families Pleurotaceae and Tricholomataceae, respectively. Additional phylogenetic studies also supported the molecular distinction on the two genera (Moncalvo et al., 2002; Thorn et al., 2005; Koziak et al., 2007; Consiglio et al., 2018). Despite similar morphological appearances, species of Hohenbuehelia and Resupinatus can be differentiated based on the size and color of basidiomata and the presence or absence of metuloids. The presence of metuloid cystidia indicates that the species belongs to Hohenbuehelia since it is absent in many species of Resupinatus (Singer, 1951, 1975). Moreover, Hohenbuehelia has a nematophagous conidial anamorph which is absent in Resupinatus (Thorn and Barron, 1986). The species of Resupinatus have tapering spines, sometimes tipped with a small droplet, on cuticular and assimilative hyphae that is not possessed by Hohenbuehelia (Singer, 1986; Thorn and Barron, 1986; Thorn et al., 2005).

In the past, the taxonomical position and correct nomenclature of macrofungi has been controversial based on morphological descriptions alone. With the availability of genetic information, great progress has been made in the last few decades in revealing the taxonomic status of a taxon and understanding its relationship between several taxa. A combinatorial usage of molecular and morphological tools is the most promising way of identifying a fungal species which show great biological diversity. For this purpose, nuclear gene regions, such as nuclear ribosomal RNA internal transcribed spacer (nrITS) and nuclear ribosomal DNA large subunit (nrLSU) sequences, have been extensively used for effective discrimination and correct identification of several fungal lineages (Moncalvo et al., 2000, 2002; Schoch et al., 2012).

In Turkey, only three species of the genus, Resupinatus applicatus (Batsch) Gray, Resupinatus trichotis (Pers.) Singer and Resupinatus taxi (Lév.) Thorn have been reported as new records and some of those have been provided with morphological features only (Sümer, 1982; Taşkın, 2000; Kaşık et al., 2003; Allı et al., 2017; Altuntaş et al., 2017; Uzun et al., 2015, 2017, 2018; Tırpan et al., 2018). More studies from different geographic regions are needed to identify members of this genus for a better understanding of their ecological preferences and host specificities. Here we describe two specimens of Resupinatus niger from Aegean costal region of Turkey based on morphological characters and phylogenetic analyses of the nrITS and nrLSU gene sequences. We also provide a detailed phylogenetic analysis of the species from Resupinatus to better resolve the controversy of species distinction in this genus.

MATERIAL AND METHODS

Morphological studies

Resupinatus specimens were collected from Kuşadası (Aydın Province) in southwestern Turkey in 2018. The fungi were photographed in their natural habitat and ecological data were noted. The macro-morphological descriptions were determined based on photographs of fresh basidiocarps and field notes. Microscopic characteristics were recorded using a Leica DM500 (Leica Microsystems, Wetzlar, Germany) light microscope at 40×, 100×, 400×, and 1000× magnifications. Microscopic structures were observed from the dried specimens rehydrated in 3% KOH and stained in Congo Red. Measurements include: L_m and W_m indicate the mean length and width of basidiospores, Q shows the length/width ratios, and Q_m mean the average of basidiospores measured. All examined materials are deposited at the fungarium of Isparta University of Applied Sciences, Isparta, Turkey.

Molecular studies and phylogenetic analysis

Genomic DNA was extracted from fresh specimens using ZR Fungal/Bacterial DNA MiniPrep kit (Zymo research, Irvine, California) according to the manufacturer's protocol. The primer pairs ITS1F/ITS4 (White et al., 1990) and LR0R/LR5 (Vilgalys and Hester, 1990) were used to amplify nrITS and nrLSU gene regions, respectively. Polymerase chain reactions were prepared in a total volume of 25 µl, including 1 µL of DNA template, 1 μL of each primer (at 10 μM final concentration), 12.5 μL of OneTaq Quick-Load 2× Master Mix (New England Biolabs, Ipswich, Massachusetts) and 9.5 μL double-distilled water. The gene amplification conditions included initial denaturation for 5 min at 95°C, followed by 35 cycles of 1 min at 94°C, 45 s at 54°C, and 1 min at 72°C, and a final extension at 72°C for 10 min. Positive PCR products were further sequenced from both ends (Source Bioscience, Berlin, Germany). Sequence chromatograms were checked and edited using in BioEdit 7.0.5 (Hall, 1999).

Sequences for phylogenetic analysis were retrieved from GenBank (Table 1). Phylogenetic tree was inferred from Maximum Likelihood (ML) and Bayesian Inference (BI) methods using a concatenated dataset. The ML analysis was performed using RAxML v8.2.10 (Stamatakis, 2014) and GTRGAMMA substitution model with 1.000 bootstrap replicates and default settings. The BI analysis was performed using MrBayes 3.2.2 (Ronquist et al., 2012) by Markov chain Monte Carlo (MCMC) algorithm. Six simultaneous Markov chains were run for 1.000.000 generations, sampling every 100^{th} generation.

RESULTS

Molecular phylogeny

The combined nrITS + nrLSU dataset is used for phylogenetic analysis which included sequences from 103 specimens representing 53 taxa (Table 1). The dataset had an aligned length of 1744 characters, of which 1267 were constant, 129 were variable, and 348 were parsimony-informative. The phylogeny showed that all newly generated sequences of Resupinatus niger from Turkey clustered in the genus Resupinatus and formed a distinct clade with the Resupinatus collections from Italy, Russia, USA and China with high bootstrap support (MLB = 99%, BPP= 1.0, Fig. 1). Resupinatus niger is in sister position to R. conspersus and R. europaeus in which the former is basal within the /niger (Fig. 1). Resupinatus alboniger which is morphologically the most similar species to R. niger (Thorn and Barron, 1986) seems that it is genetically distant to R. niger since it is separately grouped in a well-supported clade. The outgroup species is selected as Hohenbuehelia thornii and formed a basal clade for the Resupinatus phylogeny. Our results are in accordance with Consiglio et al. (2018) and support the fact that Resupinatus and Hohenbuehelia are monophyletic.

Table 1: A list of taxa, specimens and GenBank accession numbers of sequences used in the phylogenetic analysis of Resupinatus. Collections identified in this study are shown in bold.

Species	Voucher	Accession no.		Region
		nrITS	nrLSU	
R. aff. trichotis	FP2014-08-23	-	MK278558	Hungary
R. alboniger	CD5-E2-ITS4_I03.ab1	MN752401	-	USA
R. alboniger	TENN F-61436	KP026236	-	USA
R. alboniger	TENN F-60492	KP026234	-	USA
R. alboniger	TENN F-60318	KP026235	-	USA
R. alboniger	FLAS-F-60754	MH211679	-	USA
R. applicatus	PB335	AY571059	AY571022	France
R. applicatus	MHHNU8394	MK388160	-	China
R. applicatus	AMB 18075 Scandurra Holotype	KU355368	KU355411	Italy
R. applicatus	PDD:95777	HQ533025	-	New Zealand
R. cinerascens	PERTH 8476942	-	MK278551	Australia
R. conspersus	C61852	-	AY571024	Ecuador
R. europaeus	GC 09259 Neotype	KU355366	-	Italy
R. europaeus	GC 09253	KU355365	-	Italy
R. europaeus	CL 050908-04	KU355362	-	Italy
R. griseopallidus	AMB 18277	MH137823	-	Denmark
R. griseopallidus	Blasco	MG553642	-	Spain
R. hausknechtii	WU:7659 Holotype	KU355370	KU355412	Austria
R. kavinae	AVM 3128	MG553643	MG553650	Italy
R. niger	OK-TR1687	OL693686	OL693691	Turkey
R. niger	OK-TR1688	OL693687	OL693692	Turkey
R. niger	MCVE 10781 Holotype	KU355331	KU355395	Italy
R. niger	Gelsomini 20130111_01	KU355371	KU355413	Italy
R. niger	Roux 3740	KU355372	KU355414	Italy
R. niger	CFMR:RLG 10761	KY679146	KY679146	USA
R. niger	NAMA 2017-452	MH979266	-	USA
R. niger	HMJAU2887	GQ142025	-	China
R. odoratus	TBGT17789	MT452498	-	India
R. poriiformis	CBS 327.91	AY571062	AY571025	Canada
R. poriiformis	RLG1156sp	-	AF261372	USA
R. porosus	CFMR:PR-5832 Paratype	NR_119556	-	USA
R. rouxii	ACAD 7603	KU355369	-	USA
R. rouxii	Z+ZT 971	MH168326	MH190787	Switzerland
Resupinatus sp.	TENN F-63042	KP026232		USA
Resupinatus sp.	TENN F-63042	KP026231	-	USA
Resupinatus sp.	Thorn 870601/19 ALV5614 Holotype	KU355376	KU355415	Italy

Resupinatus sp.	VT1520	-	AF042599	Russia
Resupinatus sp.	TENN-F-060976	MW727693	MW727693	New Zealand
Resupinatus sp.	TENN-F-061027	MW727692	MW727692	New Zealand
Resupinatus sp.	HMJAU7036	GQ142021	GQ142045	China
R. striatulus	Roux 305	KU355373	-	France
R. striatulus	Wilhelm 5316	MH137831	MH169342	France
R. striatulus	KR-M-053702	MW035051	-	Germany
R. subapplicatus	MEL:2380813	MT856383	-	Australia
R. taxi	TENN:074428	MH558280	-	USA
R. trichotis	GC 03069	KU355377	-	Italy
R. trichotis	GC 07089 Epitype	KU355378	KU355416	Italy
R. trichotis	Striegel 299	KU355381	-	Italy
R. trichotis	TENN F-62209	KP026228	-	USA
R. trichotis	KY608090	KY608090	KY608090	Luxembourg
R. vetlinianus	LE(BIN) 2335	KP026237	KP026215	Russia
R. vetlinianus	LE 287742	KP212104	-	Russia
R. vinosolividus	ICMP:16568	MZ325958		New Zealand
Hohenbuehelia thornii	GC 98149	KU355342	KU355400	Italy

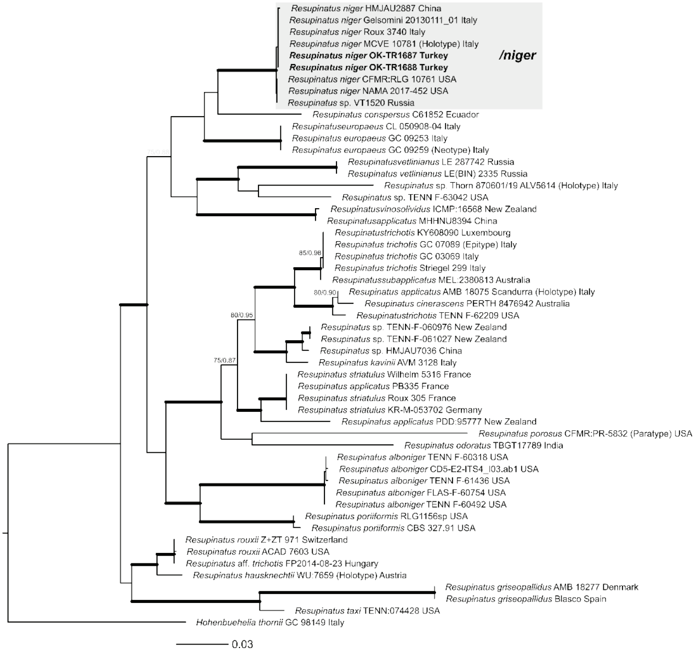

Figure 1. Maximum likelihood (ML) phylogenetic tree of Resupinatus based on concatenated nrITS and nrLSU sequence data. The tree is rooted with Hohenbuehelia thornii (GC 98149). ML bootstrap support values/Bayesian posterior probability greater than 75%/0.85 given above/below the branches. Branches of significant support (MLB ≥ 90% and BPP ≥ 0.95) are thickened. The scale bar represents the expected number of nucleotide substitutions per site. Newly generated sequences in this study are shown in bold.

Taxonomy

Resupinatus niger (Schwein.: Fr.) Murrill, N. Amer. Fl. (New York) 9(4): 242 (1915).

Basionym: Agaricus niger Schwein., Schr. Naturf. Ges. Leipzig 1: 90 (1822).

Synonym: Pleurotus niger (Schwein.: Fr.) Sacc., Syll. Fung. (Abellini) 5: 380 (1887); Hohenbuehelia nigra (Schwein.: Fr.) Singer, Lilloa 22: 256 (1951) [1949]; Hohenbuehelia nigra var. pileocystidiata Fazio & Albertó, in Alertó, Fazio & Wright, Mycologia 90 (1): 143 (1998); Hohenbuehelia latialis Angeli & Contu, Micol. Veg. Medit. 22 (2): 120 (2008).

Basidiomata small to medium, sessile, conchate, dorsally attached to the substrate, gelatinous. Pileus 3–15 mm diam., when young dome-shaped to circular, then convex to plano-convex, surface light to dark gray-brown to blackish, almost black in mature basidiocarps, completely blackened when dry, margin almost glabrous and crenulate with a wavy edge. Lamellae blackish to dark gray, moderately close to distant, thick, lamellae margin light brown or blackish. Stipe rudimentary to absent. Context grayish, gelatinous.

Basidiospores (6.2–)6.5–8.0(–8.8) × (4.0–)4.5–5.4(–5.6) µm, $L_m \times W_m = 7.2 \times 5.0$ µm, Q = 1.4–1.7, $Q_m = 1.6$, ellipsoid to elongate ellipsoid, smooth, guttulate, hyaline, thin-walled. Basidia 35–55 × 5.0–8.0 µm, clavate, with sterigmata up to 6 µm long, 4-spored, hyaline and thin-walled. Cheilocystidia (25.0–)27.5–39.0(–42.0) × (12.0–)12.5–15.0(–16.0) µm, metuloid, narrowly fusiform to clavate, without crystalline granules, brownish, very thick-walled. Pleurocystidia (70.0–)75.5–98.0(–110.0) × (10.0–)11.5–14.0(–16.0) µm, metuloid, narrowly fusiform to fusiform, with crystals throughout, especially at the apex, brownish, darker at the base, very thick-walled. Pileipellis a cutis of 2-6 wide hyphae, with light brown pigment, slightly thick-walled, clamped. Pileocystidia (40.0–)42.5–62.0(–75.0) × (12.0–)14.5–17.0(–18.0) µm, metuloid, cylindraceous to clavate, with almost small encrusted crystals towards the apex, brownish, darker at the base, very thicked-walled. Clamp connections present in all tissues.

Habitat and phenology: Gregarious or caespitose, on dead branches or very rotten wood of Quercus sp., present at elev. 5 m, mostly in late October, in calcareous sandy areas along the coastal zone.

Collections examined: TURKEY, Aydın Province, Kuşadası district, around Davutlar village, on well decayed wood of Quercus sp., alt. 5 m, 30 October 2018, O. Kaygusuz, OKA-TR1687; GenBank: OL693686 (nrITS), OL693691 (nrLSU); ibid., on well decayed wood of Quercus sp., alt. 6 m, 30 October 2018, O. Kaygusuz, OKA-TR1688; GenBank: OL693687 (nrITS), OL693692 (nrLSU).

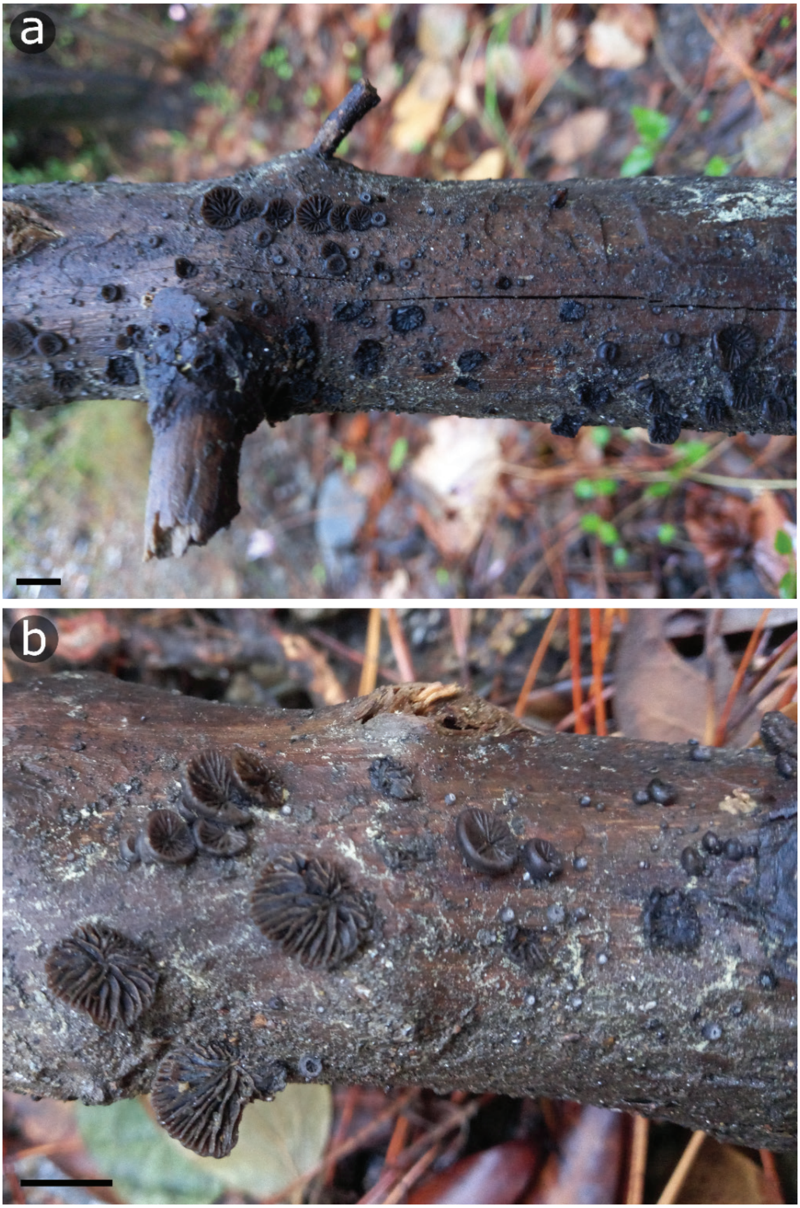

Figure 2. Basidiocarps of Resupinatus niger (a. col. OK-TR1687, b. col. OK-TR1688). Scale bars: 10 mm.

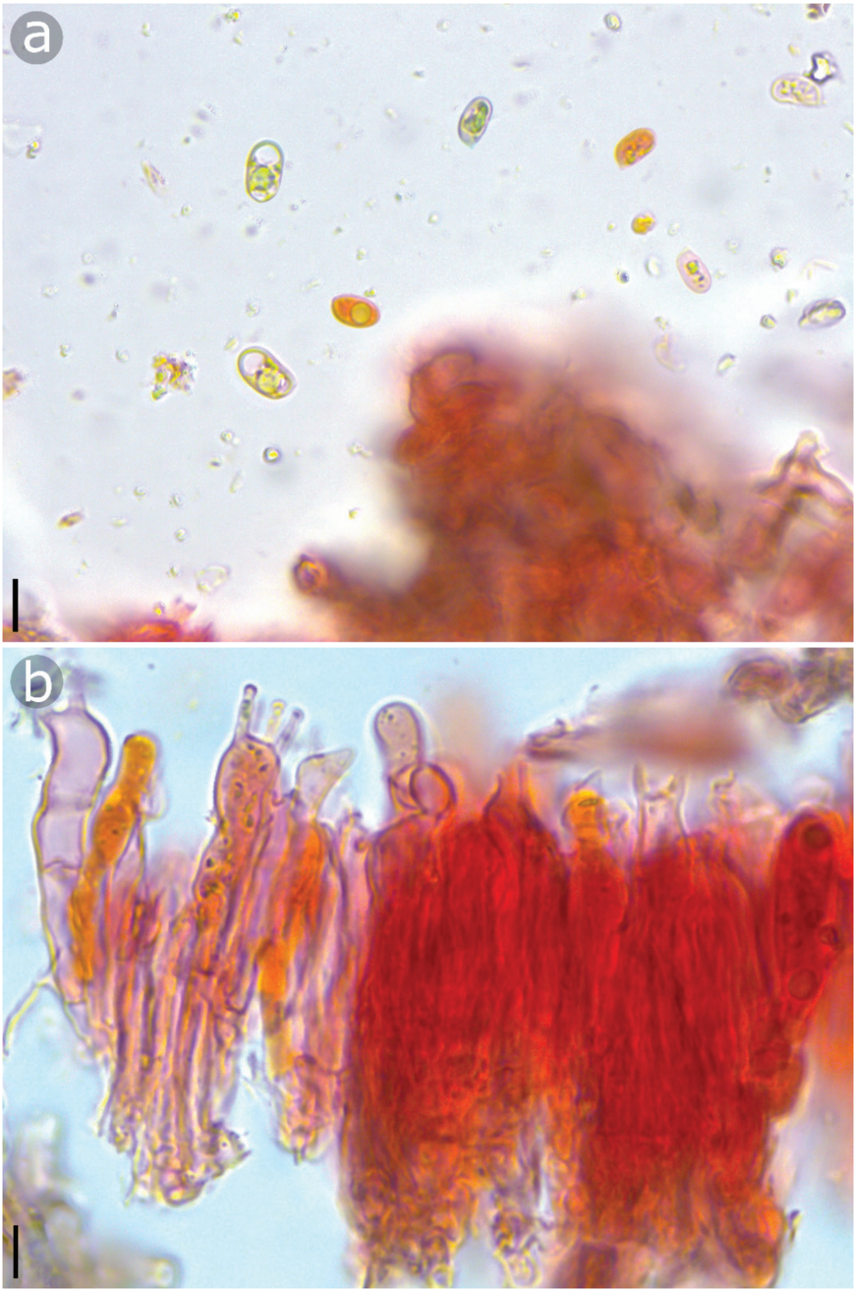

Figure 3. Microscopic features of Resupinatus niger. a. Basidiospores. b. Basidia and basidioles. Scale bars: 10 µm.

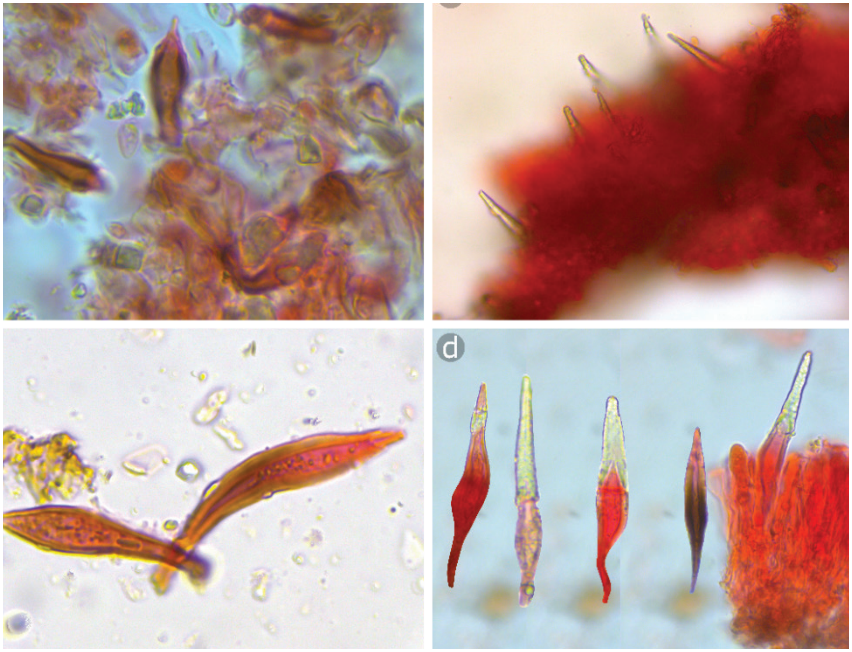

Figure 4. Microscopic features of Resupinatus niger. a-b: Cheilocystidia. c-d: Pleurocystidia. Scale bars: 10 µm.

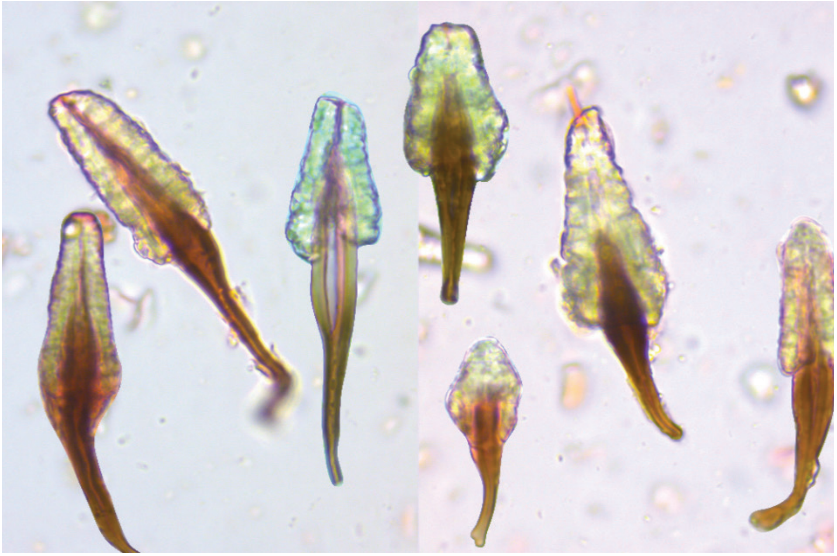

Figure 5. Microscopic features of Resupinatus niger. Pileocystidia. Scale bar: 10 µm.

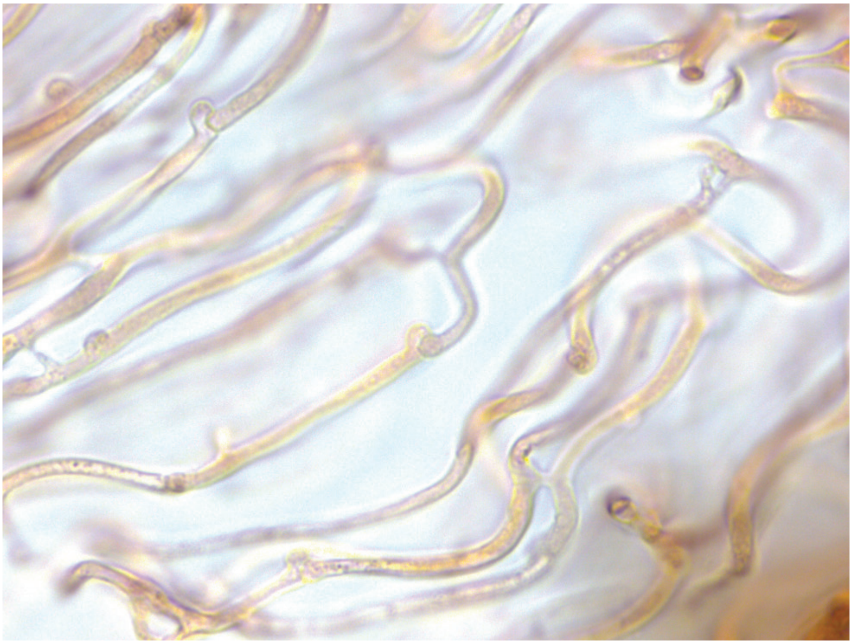

Figure 6. Microscopic features of Resupinatus niger. Pileipellis. Scale bar: 5 µm.

DISCUSSION

The genus Resupinatus is a striking example in which names to its species have been misapplied and its taxonomy has been less understood. The taxon named Resupinatus niger is one if those whose name has been changed many times and it has been placed in several different genera. It was originally described as Agaricus niger Schwein by Schweinitz (1822). Later, Saccardo (1887) reported it as Pleurotus niger (Schwein.) Sacc, Kuntze (1898) as Dendrosarcus niger (Schwein.) Kuntze, Patouillard (1900) as Calathinus niger (Schwein.) Pat. It was described by Murrill (1915) as Resupinatus niger (Schwein.) Murrill. Singer (1951) transferred it to Hohenbuehelia and named it as Hohenbuehelia nigra (Schwein.) Singer. His nomenclature was accepted until a recent work by Consiglio et al. (2018) which indicated that it should be regarded as a member of Resupinatus. Their phylogenetic analysis based on a combined dataset of three nuclear gene regions clearly showed that Hohenbuehelia and Resupinatus are two distinct clades, the latter of which includes R. niger. Accordingly, R. niger is the current name accepted.

Resupinatus niger has a world-wide distribution but it is a rare fungus species. It is so far known from Europe, including Italy, France, Norway; from the Northern Hemisphere, including Canada and USA; from Costa Rica and China (Albertó et al., 1998; Liu and Bau, 2012; Consiglio and Setti, 2018; Consiglio et al., 2018) It is mostly found on hardwood branches, on dead or rotten hardwood of deciduous trees such as Quercus, Ulmus or Alnus (Singer, 1986; Thorn and Barron, 1986; Thorn et al., 2005; Consiglio et al., 2018). Not surprisingly, our collections were also found on dead or rotten branches of Quercus showing a selective deciduous substrate selection of this fungus species even in different geographic locations.

Resupinatus niger has distinctive features which are black pileus, trilayered metuloid cystidia and elliptical to allantoid basidiospores different from the typical globose to subglobose spores of the type specimen of the genus, R. applicatus. Resupinatus niger resembles R. alboniger in having similar types of spores and nearly black fruiting bodies (Thorn and Barron, 1986). However, R. alboniger lacks metuloid cystidia which is present in R. niger. Based on habitat preferences, it could be hard to differentiate them since R. niger and R. alboniger can be both found on deciduous trees (Thorn, 1986; Watling and Gregory, 1989; Courtecuisse, 1993). Interestingly, R. alboniger collections were also found on coniferous trees (Abies and Pinus) from Greece (Gonou-Zagou et al., 2011) which may indicate that R. niger and R. alboniger may have variable substrate preferences. Hohenbuehelia subbarbata (Berk. & M.A. Curtis) Singer is also a similar species to R. niger in having black pileus, metuloid cystidia and elliptical spores but it has much smaller spores when compared to R. niger (Albertó et al., 1998). Resupinatus niger also shows similarities with R. conspersus (Pers.) Thorn, Moncalvo & Redhead but they exhibit different habitat and substrate preferences. Resupinatus conspersus mostly grows high up in trees, especially seen on coniferous trees (Abies) (Breitenbach and Kranzlin, 1986; McDonald, 2015). Based on our phylogenetic tree, it is evident that R. niger and R. conspersus are more genetically related in this genus. Resupinatus europaeus Consiglio & Setti is another species that is more closely related with the R. niger collections. However, they are morphologically distinct in such that R. europaeus has more greyish or greyish-white pileus with blackish tints.

The genus Resupinatus is found to be monophyletic in Agaricales (Hibbett et al., 1997; Moncalvo et al., 2000, 2002; Matheny et al., 2007) but the phylogeny within the genus has not been well-resolved. Understanding close relatives of the Resupinatus and resolving its controversial taxonomic position has been difficult with less taxon identified at the molecular level. The recent work by Consiglio et al. (2018) solved delimitation of the two genera Resupinatus and Hohenbuehelia with the help of morphological and molecular evidence. Our work provides a rare member of Resupinatus from Turkey, a continent that connects Asia and Europe. A region in this location with high biological diversity is a good target to investigate for a better understanding of the evolutionary taxonomy of the genus. Thus, sampling from different continents of the world should be done and molecular data should be generated for more species of Resupinatus in order to improve our knowledge on their taxonomy and phylogeny.

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REFERENCES

Albertó, E., Fazio, A., Wright, J. E. (1998). Reevaluation of Hohenbuehelia nigra and species with close affinities. Mycologia, 90, 142.

Allı, H., Çöl, B., Şen, I. (2017). Macrofungi biodiversity of Kütahya Turkey province. Biyolojik Çeşitlilik ve Koruma, 10, 133.

Altuntaş, D., Akata, I., Allı, H. (2017). Macrofungi of Kazdağı National Park Turkey and its close environs. Biyolojik Çeşitlilik ve Koruma, 10, 17.

Breitenbach, J., Kranzlin, F. (1986). Fungi of Switzerland, Vol. 2. Lucerne: Verlag Mykologia.

Consiglio, G., Setti, L. (2018). The Genera Hohenbuehelia and Resupinatus in Europe. Monografie di Pagine di Micologia, Associazione Micologica Bresadola, Vol. 3, 448 pp.

Consiglio, G., Setti, L., Thorn, R. G. (2018). New species of Hohenbuehelia, with comments on the Hohenbuehelia atrocoerulea – Nematoctonus robustus species complex. Persoonia, 41, 202.

Courtecuisse, R. (1993). Macromycetes interessants, rares ou nouveaux. VII. Taxons nouveaus pour Ia France et autres recoltes remarquables. Documents mycologiques, 23, 1.

Gonou-Zagou, Z., Triantafyllou, M., Floudas, D., Delivorias, P. (2011). The genus Resupinatus Nees ex Gray in Greece. Nova Hedwigia, 92, 513.

Hall, T. A. (1999). BioEdit: a user-friendly biological sequence alignment editor and analysis program for Windows 95/98/NT. Nucleic Acids Symposium Series, 41, 95.

Hibbett, D. S., Pine, E. M., Langer, E., Langer, G., Donoghue, M. J. (1997). Evolution of gilled mushrooms and puffballs inferred from ribosomal DNA sequences. Proceedings of the National Academy of Sciences USA, 94, 12002.

Kaşık, G., Doğan, H. H., Öztürk, C., Aktaş, S. (2003). New records of Tricholomataceae and Cortinariaceae for Turkish macrofungi flora from Alanya (Antalya) district. Ot Sistematik Botanik Dergisi, 10, 143.

Kirk, P. M., Cannon, P. F., Minter, D. W., Stalpers, J. A. (2008). Dictionary of the Fungi 10th Ed. Cary: CAB International, Oxford University Press.

Kuntze, O. (1898). Revisio Generum Plantarum 3. Felix Leipzig, 2, 464.

Koziak, A. T. E., Cheng, K. C., Thorn, R. G. (2007). Phylogenetic analyses of Nematoctonus and Hohenbuehelia (Pleurotaceae). Canadian Journal of Botany, 85, 762.

Liu, Y., Bau, T. (2012). Molecular phylogeny of several pleurotoid fungi collected in China. Acta Edulis Fungi, 19, 21.

Matheny, P. B., Curtis, J. M, Hoffstetter, V., Aime, M. C., Moncalvo, J. M., Ge, Z. W., Yang, Z. L., Slot, J. C., Ammirati, J. F., Baroni, T. J., Bougher, N.

L., Hughes, K. W., Lodge, D. J., Kerrigan, R. W., Seidl, M. T., Aaneni, D. K., DeNitis, M., Daniele, G. M., Desjardin, D. E., Kropp, B. R., Norvell, L. L., Parker, A., Vellinga, E. C., Vilgalys, R., Hibbett D. S. (2007). Major clades of Agaricales: a multilocus phylogenetic overview. Mycologia, 98, 982.

McDonald, J. (2015). Morphological and Molecular Systematics of Resupinatus (Basidiomycota). PhD thesis, The University of Western Ontario, Canada, 319 pp.

McDonald, J. V., Thorn, R. G. (2019). Resupinatus urceoloides sp. nov. Index Fungorum, 425, 1.

Moncalvo, J. M., Lutzoni, F. M., Rehner, S. A., Johnson, J., Vilgalys, R. (2000). Phylogenetic relationships of agaric fungi based on nuclear large subunit ribosomal DNA sequences. Systematic Biology, 49, 278.

Moncalvo, J. M., Vilgalys, R., Redhead, S. A., Johnson, J. E., James, T. Y., Aime, M. C., Hofstetter, V., Verduin, S. J. W., Larsson, E., Baroni, T. J., Thorn, R. G., Jacobsson, S., Clémençon, H., Miller OK, Jr., (2002). One hundred and seventeen clades of euagarics. Molecular Phylogenetic Evolution, 23, 357.

Murrill, W. A. (1915). Agaricales, Agaricaceae, Agariceae. North American Flora, 9, 240.

Ovrebo, C. L. (1997). The agaric flora (Agaricales) of La Selva Biological Station, Costa Rica. Revista de Biologia Tropical, 44, 39.

Patouillard, N. (1900). Essai taxonomique sur les familles et les genres des Hyménomycètes. Imprimerie et lithographie L. Declume.

Ronquist, F., Teslenko, M., van der Mark, P., Ayres, D. L., Darling, A., Höhna, S., Larget, B., Liu, L., Suchard, M. A., Huelsenbeck, J. P. (2012). MrBayes 3.2: Efficient Bayesian phylogenetic inference and model choice across a large model space. Systematic Biology, 61, 589.

Saccardo, P. A. (1887). Sylloge fungorum omnium hucusque cognitorum: Sylloge Hymenomycetum. Agaricineae (Vol. 1). Typis Seminarii.

Schoch, C. L., Seifert, K. A., Huhndorf, S., Robert, V., Spouge, J. L., Levesque, C. A., Chen, W., Bolchacova, E., Voigt, K., Crous, P. W., Miller, A. N., Wingfield, M. J., Aime, M. C., An, K. D., Bai, F. Y., Barreto, R. W., Begerow, D., Bergeron, M. J., Blackwell, M., Boekhout, T., Bogale, M., Boonyuen, N., Burgaz, A. R., Buyck, B., Cai, L., Cai, Q., Cardinali, G., Chaverri, P., Coppins, B. J., Crespo, A., Cubas, P., Cummings, C., Damm, U., de Beer, Z. W., de Hoog, G. S., Del-Prado, R., Dentinger, B., Dieguez-Uribeondo, J., Divakar, P. K., Douglas, B., Duenas, M., Duong, T. A., Eberhardt, U., Edwards, J. E., Elshahed, M. S., Fliegerova, K., Furtado, M., Garcia, M. A., Ge, Z. W., Griffith, G. W., Griffiths, K., Groenewald, J. Z., Groenewald, M., Grube, M., Gryzenhout, M., Guo, L. D., Hagen, F., Hambleton, S., Hamelin, R. C., Hansen, K., Harrold, P., Heller, G., Herrera, C., Hirayama, K., Hirooka, Y., Ho, H. M., Hoffmann, K., Hofstetter, V., Hognabba, F., Hollingsworth, P. M., Hong, S. B., Hosaka, K., Houbraken, J., Hughes, K., Huhtinen, S., Hyde, K. D., James, T. Y., Johnson, E. M., Johnson, J. E., Johnson, P. R., Jones, E. B. G., Kelly, L. J., Kirk, P. M., Knapp, D. G., Kolialg, U., Kovacs, G. M., Kurtzman, C. P., Landvik, S., Leavitt, S. D., Liggenstoffer, A. S., Liimatainen, K., Lombard, L., Luangsaard, J. J., Lumbsch, H. T., Maganti, H., Maharachchikumbura, S. S. N., Martin, M. P., May, T. W., McTaggart, A. R., Methven, A. S., Meyer, W., Moncalvo, J. M., Mongkolsamrit, S., Nagy, L. G., Nilsson, R. H., Niskanen, T., Nyilasi, I., Odaka, G., Okane, I., Olariaga, I., Otte, J., Papp, T., Park, D., Petkovits, T., Pino-Bodas, R., Quaedvlieg, W., Raja, H. A., Redecker, D., Rintoul, T. L., Ruibal, C., Sarmiento-Ramirez, J. M., Schmitt, I., Shussler, A., Shearer, C., Sotome, K., Stefani, F. O. P., Stenroos, S., Stielow, B., Stockinger, H., Suetrong, S., Suh, S. O., Sung, G. H., Suzuki, M., Tanaka, K., Tedersoo, L., Telleria, M. T., Tretter, E., Untereiner, W. A., Urbina, H., Vagvolgyi, C., Vialle, A., Vu, T. D., Walther, G., Wang, Q. M., Wang, Y., Weir, B. S., Weiss, M., White, M. M., Xu, J., Yahr, R., Yang, Z. L., Yurkov, A., Zamora, J. C., Zhang, N., Zhuang, Y., Schindel, D. (2012). Nuclear ribosomal internal transcribed spacer (ITS) region as a universal DNA barcode marker for Fungi. Proceedings of the National Academy of Sciences, 109, 6241.

Schweinitz, L. D. von (1822). Synopsis fungorum Carolinae superioris. Schriften der Naturforschenden Gesellschaft in Leipzig, 1, 20-131.

Singer, R. (1948). Diagnoses fungorum novorum Agaricalium. Sydowia, 2, 26.

Singer, R. (1951). The Agaricales in modern taxonomy. Lilloa, 22, 1.

Singer, R. (1975). The Agaricales in modern taxonomy. 3rd ed. Vaduz: J. Cramer.

Singer, R. (1986). The Agaricales in modern taxonomy 4th Ed. Koeltz Scientific Books, Koenigstein, 981 pp.

Stamatakis, A. (2014). RAxML version 8: A tool for phylogenetic analysis and post-analysis of large phylogenies. Bioinformatics, 30, 1312.

Sümer, S. (1982). Wood–decaying fungi in the western Black Sea region of Turkey, especially in and around Bolu province. İstanbul Üniversitesi Orman Fakültesi Yayınları, İstanbul.

Taşkın, H. (2000). Studies on fungi causing rots in the wooden material of historical and plateaul houses in Bolu province, Turkey. PhD thesis. Marmara Üniversitesi Fen Bilimleri Enstitüsü, İstanbul.

Thorn, R. G. (1986). The ‘Pleurotus silvanus’ complex. Mycotaxon, 25, 27.

Thorn, R. G., Barron, G. L. (1986). Nematoctonus and the tribe Resupinateae in Ontario, Canada. Mycotaxon, 25, 321.

Thorn, R. G., Moncalvo, J. M., Reddy, C. A., Vilgalys, R. (2000). Phylogenetic analyses and the distribution of nematophagy support a monophyletic

Pleurotaceae within the polyphyletic pleurotoid-lentinoid fungi. Mycologia, 92, 241.

Thorn, R. G., Moncalvo, J. M., Redhead, S. A., Lodge, D. J., Martín, M. P. (2005). A new poroid species of Resupinatus from Puerto Rico, with a reassessment of the cyphelloid genus Stigmatolemma. Mycologia, 97, 1140.

Tırpan, E., Çöl, B., Şen, İ., Allı, H. (2018). Macrofungi of Datça Peninsula (Turkey). Biological Diversity and Conservation, 11, 90.

Uzun, Y., Kaya, A., Karacan, İ. H., Kayai Ö. F., Yakar, S. (2015). Macromycetes determined in Islahiye (Gaziantep/Turkey) district. Biological Diversity and Conservation, 8, 209.

Uzun, Y., Acar, İ., Akçay, M. E., Kaya, A. (2017). Contributions to the macrofungi of Bingöl, Turkey. Turkish Journal of Botany, 41, 516.

Uzun, Y., Karacan, İ. H., Yakar, S., Kaya, A. (2018). New additions to Turkish Tricholomataceae. Anatolian Journal of Botany, 2, 65.

Vilgalys, R., Hester, M. (1990). Rapid genetic identification and mapping of enzymatically amplified ribosomal DNA from several Cryptococcus species. Journal of Bacteriology, 172, 4238.

Watling, R., Gregory, N. M. (1989). British Fungus Flora. 6. Crepidotaceae, Pleurotaceae and other pleurotoid agarics. Royal Botanic Garden, Edinburgh.

White, T. J., Bruns, T., Lee, S., Taylor, J. (1990). Amplification and direct sequencing of fungal ribosomal RNA genes for phylogenetics. In: Innis, M. A., Gelfand, D. H., Sninsky, J. J., White, T. J. (eds.). PCR Protocols: A Guide to Methods and Applications. Academic Press, New York, pp. 315-322.

Chapter 6

OXIDATIVE STRESS AND DEFENCE SYSTEMS IN PLANTS

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INTRODUCTION

Redox processes, which include the transmission of electrons between a donor and an acceptor, widespread in living organisms and are in charge for generating ROS (Decros et al., 2019). As a consequence of a balance between ROS creation and antioxidant enzyme function homeostasis in redox, in-plant cells are developed whereby the active defence system in plants maintains an appropriate equilibrium between ROS formation and removal (Paciolla et al., 2016). Therefore, the baseline level of ROS, which is kept beyond cytotoxic suppression or below the cytotoxic dosage, is obligatory for redox signalling in cells or ROS; it is preserved through balancing ROS making plus ROS scavenging (Mittler,2017; Hasanuzzaman et al., 2019a). Thus, redox biology is a term to raise ROS, scientists have employed signalling molecules to support and control typical plant physiological activities (Reczek & Chandel, 2015; Mittler, 2017). Redox signals are defined for matching small scale ROS, which operates as indications for starting signal cascades that affect normal plant functioning with an excellent range of ROS, which induces oxidative cellular loss (Decros et al., 2019).

Consequently, ROS production and scavenger mechanisms are tightly coupled over period and distance, interacting with cellular components that are susceptible to oxidation and reduction to create and accurately change final signaling actions in a cell-specific and environment (Panieri and Santoro, 2015). On the other hand, it results from more than ROS, resulting in oxidative stress in various abiotic stress scenarios (Hasanuzzaman et al., 2012). Cell dysfunction is caused by oxidative stress. And death in the end by the production of lipid peroxidation, the destruction of proteins and nucleic acids, and the alteration of carbohydrate metabolism (Hasanuzzaman et al., 2019a; Al-Mahmud, 2019).

1. ROS (REACTIVE OXYGEN SPECIES)

Due to global warming and the abiotic stress conditions that comes with it, including lack of rain, salinity, toxic substances, waterlogging, extreme heat, oxygen deprivation, and so on, significantly affect plant growth and advancement, directly influencing crop productivity and agricultural productivity sustainable development overall. Plant cells make derivatives and oxygen radicals during numerous abiotic stress-related events, known as ROS (reactive oxygen species). Furthermore, ROS generation has a role in higher plants, which transfer cellular-signalling data in reaction to altering circumstances. The disruption of the equilibrium between ROS generation with antioxidant defence mechanisms, resulting in excessive ROS build up and oxidative stress in plants, is among the most severe consequences of abiotic stress. Generally, both nonenzymatic antioxidant and enzymatic defence mechanisms achieve a balance between detoxification and ROS formation under severe environmental conditions (Hasanuzzaman et al., 2020a).

Many negative consequences cause oxidative stress caused by an abundance of ROS, mainly free - radical (superionic anion, O2 -; hydroperoxyl radicals, HO2; alkoxy radicals, R.O.; and hydroxyl radicals, O.H.) and non-molecule radicals (hydrogen peroxide, H2O2, and mono oxygen, 1O2) (Mehla et al., 2017; Hasanuzzaman et al., 2019a). Electron transfer reactions or high energy initiation reactions to atmospheric oxygen (O_2) lead to the forms mentioned above of reactive or reductive molecular oxygen (Choudhury et al., 2017). Chloroplasts, mitochondria, peroxisomes, apoplasts, and plasma membranes are the primary sites of cellular ROS generation (Singh et al., 2019). ROS are naturally formed in plants as part of regular cellular metabolism. However, due to their highly reactive nature, under stress, an excess of ROS causes severe damage to vital biological components such as lipids, DNA, carbohydrates, proteins, also other macromolecules (Raja et al., 2017).

1.1. Types of ROS scavenging mechanisms:

Antioxidant defense systems, both nonenzymatic and enzymatic, function together to kill free radicals synergistically and interactively. The critical enzymatic systems include CAT (catalase), SOD (superoxide dismutase), glutathione peroxidase (GPX) and ascorbate peroxidase (APX) (Apel & Hirt, 2004). In rice, the bulk of these ROS-removal genes show tissue/organ-specific expression patterns. Their involvement in ROS homeostasis and gene expression regulation, on the other hand, is uncertain. SOD, for example, may convert O.H. to $H_2O_{2,}$ and the H_2O_2 produced is subsequently transformed into freshwater and dioxygen via CAT and peroxidase (Gechev et al., 2006; Mittler, 2017). Antioxidants with glutathione, ascorbic acid (ASA), and flavonoids have a low molecular mass, primarily moderate nonenzymatic processes by removing hydroxyl radicals with singlet oxygen (Gechev et al., 2006). However, when the amount of ROS in the cell exceeds the range of the scavenger mechanisms, the cell enters an oxidative condition, which causes oxidative alteration and cellular damage, which could also cause death.

On the other hand, while ROS levels have decreased, they can even be utilized as signaling pathways in processes such as stem cell preservation, cell division and specialization, organogenesis, including biotic and abiotic responses, and others (Zeng et al., 2017). As a result, for plant health, ROS levels must be kept within a reasonable range. Changes in ROS levels that are part of the plant's proper functioning should, of course, never exceed the cytostatic-cytotoxic threshold. For instance, by inducing CAT OsCATB development with cell protection against ROS oxidative damage, ABA inhibits H2O2 buildup under drought circumstances (Ye et al., 2011).

Ethylene increases RBOHH; a part of the nicotinamide adenine dinucleotide oxidase (NADPH) gene family are expressed. The deletion of RBOHH by CRISPR/Cas9 reduces ROS accumulation while inactivating aerenchyma formation in rice seedlings, which is essential for the rice to acclimatize to floods and other oxygen-deficient conditions. (Yamauchi et al., 2017).

1.2. ROS Chemistry

In its original form in the atmosphere, O2 is a freestanding molecule with two unpaired spindle electrons of the same spinning number, reducing its reactivity. However, the extra energy from various metabolic activities, electron carriers chains (ETC), UV-B, and ionizing radiation assists 3O2 in overcoming spin limitation and becoming ROS (Mailloux, 2016).

In-plant cells, reactive oxygen species can occur in various compartments, including peroxisomes, chloroplasts, plasma membranes and mitochondria (Dmitrieva et al., 2020). The chlorophyll (CHL) pigments in the chloroplast absorb quanta of light and get captivated in its triplet state. This triplet CHL will not be effectively reduced if it is not satisfied; reaction occurs, resulting in $^3O_2$ to excited $^1O_2$ (Dmitrieva et al., 2020). Despite its brief existence (3.1–3.9 μs), when the diffusion range is short (190 nm), $^1O_2$ Directing signaling cascades in the plasma membrane, tonoplast, or even the cytoplasm after diffusing from outside chloroplast to enter the cell structure (Fischer et al., 2013). However, ^{3}O2, Etc as well as adenosine diphosphate could provide electrons. (NADPH) producing oxidase O_2•−, with a mid around 1–1000 μs (Hasanuzzaman et al., 2019a). Moreover, O_2•− reacts with H+ producing HO_2•−, and that's higher reactivity, stability, and permeability via biological membranes. It may also be made the same way H_2O_2 concluded the transformation of O2•−/HO_2•− through SOD isoforms, heme-containing class III peroxidases (POX) activity and NADPH oxidases (Berwal & Ram, 2018). H_2O_2 actions Chemically, it is classified as a mild acid that disperses quickly and remains stable, with a lifespan of < 1 s, can penetrate the plasma membrane through aquaporin (Mhamdi et al., 2012). The Fenton reaction, hydroperoxide action, and inner-sphere electron allocation can help form additional substantial ROS—•OH during daylight. Particular proteins also produce superoxides like superoxide reductases, cytochrome P450s, heme oxygenases, and sure photosystem proteins II (PSII). • O.H. (Demidchik, 2015). • H.O. has a calculated half-life of around one nanosecond (ns) and a low reaching effect (<1 nm) (Hasanuzzaman et al., 2020a).

ROS are included in both free radicals and nonradicals. Midst the free-radicals, O_2•–, • O.H., RO•, nonradicals, peroxyl radical (ROO•), H_2O_2, $^1O_2$, and ozone (O3) remain prevalent (Maurya, 2020; Hasanuzzaman et al., 2020a). Nonradical ROS observed in plants includes hypochlorous acid (HOCl), hydroperoxides (ROOH), with exciting carbonyls (R.O. *) (Kapoor et al., 2015). Oxygen radical intermediates (ROI) are reactive oxygen atoms generated by partial reduction of O_2. As a result, ROS encompasses all forms of ROI and also O_3 and $^1O_2$. Furthermore, several acids such as hypoiodous acid (HOI), HOCl (HOBr), hypoiodous acid (HOI), hypobromous acid as well as radicals such as semiquinone (SQ•−), carbonate radical (CO_3•−) and ROS (Demidchik, 2015; Waszczak et al., 2018). Also, ROS, O_2•− It primarily functions as a reducing agent, resulting in solid oxidants. Furthermore, O_2•− When it comes into contact with nitric oxide (NO), it produces reactive nitrogen species RNSs, reacting radical carbonyl species RCSs and sulfur species RSS. Thus, these chemicals contribute to oxidative stress by "shaping" the intracellular and external redox signal (Suzuki et al., 2012).

1.3. Revisiting ROS Signalling in Plant Defence

ROS is generated due to disruption of various metabolic functions and physiological disturbances under abiotic stress. These processes NADPH are a sort of energy required, and if this power is exhausted, they cannot prevent ROS toxicity (Choudhury et al., 2017). After the twentieth and beginning of the twenty-first centuries, ROS (especially H_2O_2) functions in plant responses to stress. It acknowledged H_2O_2 as a signalling molecule that promotes acclimatization and tolerates various biotic and abiotic obstacles (Neill et al., 2002). Stress may divert electrons from the photosynthetic mechanisms to prevent antenna overload, and subsequent damage by the chloroplast produces oxygen species that are reactive oxygen species, on the other hand, protect mitochondria (Choudhury et al., 2017).

ROS generation in signalling would be aided by cell wall peroxidase H_2O_2 using the Ca^{2+} the pathway sequence is the Mitogen-activated protein kinase (MAPK) pathway. Furthermore, phytohormones, particularly ethylene (E.T.) as well as abscisic acid (ABA), are implicated in stress response via interaction with ROS and improve stress tolerance, implying that ROS has two functions during stressful situations (Kar, 2011). ROS also can influence metabolic fluxes under abiotic stress settings. They are in charge of plant adaptability in the same way oxidation-reduction reactions govern stress-dependent enzymes and protein's transcription and translation. Finally, it shields plant cells from harm (Choudhury et al., 2017; Mittler, 2017). Aside from other biological and metabolic reactions to diverse abiotic stressors, H_2O_2 modifies the NO plus Ca^{2+} signaling passageways, and Plant developments may be controlled (Janicka et al., 2019). Since endogenous H_2O_2 is tasked with creating resistance to biotic stresses, the external submission of H_2O_2 is gaining popularity and has shown to be quite effective to a considerable extent (Hasanuzzaman et al., 2017; Sohag et al., 2020). Change ROS generation and contribute to sending signals cellular antioxidant levels might be affected (Hancock & Whiteman, 2016).

2. OXIDATIVE STRESS UNDER ABIOTIC STRESS

During the hot season, in most parts of the world, plants are subjected to excessive light. Besides, various abiotic stresses induced by human activities and severe climate changes cause oxidative stress through the over-generation of ROS. Although it is commonly known that peroxisomes, mitochondria, chloroplasts, and extracellular matrix are all sources of chloroplasts, cellular ROS and apoplasts are the primary sites for producing reactive oxygen species (Singh et al., 2019). The majority of abiotic pressures diminish carbon dioxide availability and delay carbon fixation, thus leading to the progressive loss of molecular oxygen, increasing the reactive oxygen percentage, and impairs the performance of chloroplasts, which disturbs photosynthesis (Gill & Tuteja, 2010). However, species of plants, genotypes, the stress level of tolerance, and length of stress exposure all vary dramatically with ROS formation (Hasanuzzaman et al., 2020a).

1.1. Salinity

Saline conditions are a critical yield-limiting condition that poses a severe danger to agriculture across the world. It causes an oxidative burst due to uncontrolled ROS build up (Pareek et al., 2020). Ion toxicity, nutritional deficiency, osmotic stress and genotoxicity are the effects of salinity on plants and lead to overproduction of ROS and oxidative stress. For example, Munns & Tester, (2008) discovered a 2.5, a 3-fold rise in H2O2 generation, as well as 2, 3-fold H2O2 creation increase rise in the responsive material content of thiobarbituric acid (TBARS), compared to the control below 100 plus 200 mM NaCl pressure, that correspondingly, indicating the condition. The oxidative stress differs between plant tissues under salt stress. In addition, root tissues suffer from oxidative stress induced by salinity, preceded by developed and younger leaves. Salt-induced • O.H. Arabidopsis thaliana roots have been shown to produce in whole plants. The end outcome of this work is K^+ defeat concluded •OH motivated K^+ efflux stations, also heads to Programmed cell death (PCD) through K^+-Endonucleases and proteases that are reliant on cell death. As a result, excessive O.H. synthesis can cause severe strain and plant cell damage (Demidchik, 2014). Many reports indicate that increased accumulation of O_2•–, H_2O_2, Electrolyte leakage (E.L.), and malondialdehyde (MDA) content results in oxidative stress in under salinity (Ahmad et al., 2019).

2.2. Drought

Water deficits constitute a significant danger to crop production and food stability in several world regions, owing to insufficient or unpredictable rainfall and loss of groundwater supplies (Hussain et al., 2019). Drought causes increased ROS production by stomatal closures, reduced entry of carbon dioxide, impaired photosynthesis rate, an unbalance in light gathering and use, and changes in photochemical reactions in chloroplasts (Blokhina et al., 2003). Furthermore, Nicotinamide adenine dinucleotide phosphate was lowered ($NADP^{+).}$ During drought stress, regeneration resulted in a more significant decrease of electron transport chains (ETC) and increased E.L., eventually leading to higher ROS production and oxidative stress (Hasanuzzaman et al., 2018a). During drought and heat stress, ROS and reactive oxygen and nitrogen species (RNS), A wide range of plant species create superoxide radicals, hydrogen peroxide, and nitric oxide, which are removed by antioxidant defense enzymes (Barroso et al., 2020). In many plant spices, an increase in E.L., MDA, of O_2•−, H_2O_2 under drought conditions was reported (Abideen et al., 2020).

2.3. Metalloids Toxicity

Metal contamination is a big issue in the environment. Toxic metal concentrations represent a severe danger to human health and agricultural production, producing a slew of plant physiological responses. The creation of ROS that inhibits most cellular functions at various metabolism levels is crucial for heavy metal stress in plants (Sytar et al., 2013). Reactive oxygen species, for example, hydrogen peroxide (H_2O_2), the hydroxyl radical (OH•), the superoxide radical (O_2•-), singlet oxygen ($^1O_2$), has the potential to impair metabolism and cellular function. They can break down proteins, nucleic acids, and enzymes and disassemble cellular parts and structures (Panda et al., 2016; Hasanuzzaman et al., 2020b). In addition, hazardous metal ions significantly influence cellular protein homeostasis by interacting with nascent and non-native protein folding and aggregation, lowering cell survival. (Hasan et al., 2017).

Toxicity increases lipid peroxidation, L.E., lipoxygenases LOX H_2O_2 and O_2•– levels (Hasanuzzaman et al., 2019b; Al Mahmud, 2018).

2.4. High Temperature

Heat stress can abbreviate the growth period of crops and hasten senescence and death of cells, resulting in considerable production losses. The harm is caused by a reduction of electron-transport across the photosystems and an imbalance between the light and shadow phases of photosynthesis, and this can lead to the formation of ROS O_2-, H_2O_2, and O.H. (Tonhati et al., 2020). In addition, high-temperature pressure causes the PSII reaction centre to become blocked. As a result, electron movement reduces (Fv/Fm) quantum efficiency and photochemistry PSII that increase, increasing the content of O_2•− in cucumber tobacco and sorghum, (Djanaguiraman et al., 2018). Furthermore, in reaction to high-temperature treatments, NO, a free radical gaseous molecule, accumulates in various plant species. For example, in the extreme heat signalling of A. thaliana seedling, NO functions downstream of H2O2 (Parankusam et al., 2017).

2.5. Low Temperature

Cold temperatures are usually characterized as low but not cold conditions (0–15 C), standard in nature throughout the growing season of warm-climate crops. Low temperatures impede crop growth, resulting in significant yield reduction. The principal effect of low-temperature strain is the abnormal build-up of reactive oxygen species, primarily $H_2O_{2,}$ as broken electron transport system in superoxide anion radicals (O_2•–), chloroplasts, and hydroxyl radicals (• O.H.) are shaped (Repetto et al., 2012). Increasing the contents of MDA and E.L. in rice seedlings, MDA and H_2O_2 content S. Lycopersicum, H_2O_2 accumulation in Ammopiptanthus mongolicus, SOD and APX activities of maize, Liu et al., (2020), is reported by cold stress.

2.6. Flooding

Flood and waterlogging caused hypoxic or anoxic conditions, which resulted in the production of toxic chemicals that disrupt plant metabolism, culminating in ROS overproduction and oxidative loss (Loreti et al., 2016). Water lodging causes higher accumulation of MDA increases in sorghum (Zhang et al., 2019) that H_2O_2 and MDA increased in Sesamum indicum, Deschampsia Antarctica, and S. Lycopersicum (Anee et al., 2019).

2. ANTIOXIDATIVE DEFANCE SYSTEMS

2.2. Antioxidant in Plants under Salinity

Plants' responses to salt stress are reduced by regulation of antioxidant machinery; the antioxidant enzymes' activity varies depending on salinity, exposure length, and plant development stage (Guler & Pehlivan, 2016). Several plant species, for example, mulberry (Harinasut et al., 2003), C. arietinum (Kukreja et al., 2005), and esculent of Lycopersicon (Gapinska et al., 2008), have shown a considerable increase in SOD movement when exposed to saline. For example, Vighi et al., (2017) find that salt-resistant rice cultivar (BRS Bojuru) had a different reaction than the salt-sensitive rice cultivar (BRS Pampa), and it was proposed that the OsGR2, OsAPX3, OsSOD3-Cu / Zn, OsGR3 genes were the different key indicators among genes and susceptible genotypes of rice. Eyidogan & Oz (2007) revealed that 3 of SOD activity bands in C. arietinum under salt stress (Cu/ZnSOD and

MnSOD, FeSO). Also, during salt stress, activities of MnSOD, Cu/ZnSOD isozymes rose considerably. Glycyrrhiza uralensis Fisch was subjected to salt and drought stress tests (Pan et al., 2006). Other studies such as (Zeeshan et al., 2020) evaluated two varieties of barley (salt-tolerant cv. CM72), and wheat (salt-tolerant cv. Suntop and -sensitive Sunmate) determined that greater antioxidant deeds of wheat (salt-tolerant cv. Suntop and -sensitive Sunmate) (APX, GR, SOD, peroxidase; POD, and CAT). This was closely related to high salt tolerance, and this shows that antioxidant activities have a clear role in reducing salt-induced oxidative damage. When just salt stress was given, they detected significantly enhanced SOD synthesis and an extra MnSOD isoenzyme. Mn-SOD overexpression increased salt tolerance in transgenic Arabidopsis and L. esculentum plants (Wang et al., 2007). Similarly, Alzahrani et al., (2019) discovered a rise in GR, ASA, SOD, and CAT. altitudes in faba bean genotypes when H_2O_2 levels climbed beyond 90% below salinity pressure suggest controlling the antioxidant response under salt stress and dilution. Under salt stress, Eyidogan and Oz (2007) reported a substantial increase in CAT activity in C. arietinum plant leaves. Overexpression of the Escherichia coli CAT produced by the katE gene in rice conferred salt tolerance to transgenic plants (Nagamiya et al., 2007). Similarly, (Kukreja et al., 2005) discovered an increase in CAT activity in C. arietinum roots following salt stress. Under the strain of salt, the modulation of antioxidant activities through the use of chemical or natural protective materials underlined the significance of antioxidant tools and machinery in relieving stressors, including such salinity (Numan et al., 2018). Alsahli et al., (2019) for instance, examined untreated (control) and salt-stressed wheat plants using salicylic acid (S.A.) treatment. They discovered that increasing SOD, CAT, and APX activity by twofold reduced H_2O_2 thrice. Similarly, combining humic acid and jasmonic acid (J.A.) boosted APX motion, causing sorghum salt acceptance (Ali et al., 2020). Although polyamines were used externally to alter antioxidant responses in acidic oranges under salt stress conditions (Tanou et al., 2014). Under salt stress, APX activity was reported to increase in A. doliolum (Srivastava et al., 2005). In research on wheat grown at 100 mM, NaCl stress increased antioxidant levels (SOD, Monodehydroascorbate reductase, APX, CAT, Dehydroascorbate reductase; Glutathione reductase; G.R., MDHAR, DHAR activities, and the production of ASA as well as GSH), with a drop of 2.5 times H_2O_2 and 1.7 times O_2•- (Ahanger et al., 2019). Overexpression of APX in tobacco plant chloroplasts was also demonstrated to improve plant resistance to salt and water deficits (Badawi et al., 2004). Salt tolerance was improved in transgenic Arabidopsis plants with constitutively active OsAPXa or OsAPXb. Under various NaCl concentrations, overproduction of OsAPXb improved and sustained APX activity in transgenic plants to a larger extent than overproduction of OsAPXa (Lu et al., 2007).

Furthermore, when silicon (Si) supplementation was added to mung bean, it boosted antioxidant activity while decreasing ROS, MDA, and E.L. levels (Ahmad et al., 2019). Under salt stress, GPOX activity has increased Vigna radiating leaves and roots tissues (Panda, 2001) and O. sativa (Yamane et al., 2009). Eyidogan and Oz (2007) discovered enhanced G.R. activity in C. arietinum L. cv leaf tissue during salt stress Kukreja et al., (2005) discovered enhanced G.R. activity in C. arietinum roots after salt stress. Srivastava et al., (2005) discovered that when A. doliolum was exposed to Cu2, its G.R. activity dropped but rose when subjected to salt. (Chung et al., 2020) found that the Si-induced antioxidant enzyme genes GmCAT1 (3-fold), GmCAT2 (4-fold), and GmAPX1 (8-fold) were upregulated in soybeans after 6 hours of stress, leading to salt stress resistance. MDAR overexpression increased salt and osmotic stress in transgenic tobacco (Eltayeb et al., 2007). DHAR overexpression increased Arabidopsis salt tolerance (Ushimaru et al., 2006). Gapinska et al., (2008) discovered enhanced Glutathione S-transferase (GST) activity in L. esculentum under salt stress. Comparable transcriptional inflexion of antioxidant enzyme transcript levels (MnSOD, cAPX, CAT, and GR) lowered 0.4-fold H2O2 and 3.9-fold NO in strawberry plants pre-treated using hydrogen sulfide (H2S) during NaCl stress in an aqueous environment (Christou et al., 2013). According to Santander et al., (2020) arbuscular mycorrhiza raises the concentrations of SOD, CAT, and APX activities in cucumber at 40 and 80 mM NaCl. During normal circumstances, transgenic G. hirsutum seedlings had 30-60% greater GPX activity because, under salt stress, it's no different from W.T. seedlings (Light et al., 2005). Stress with 150 mM NaCl significantly boosted GPX activity in L. esculentum Mill. cv "Perkoz" roots, thus according (Gapinska et al., 2008). Furthermore, Moringa oleifera leaf extract (6%) decreases salt stress by regulating wheat antioxidants (Rady et al., 2019). Lastly, the fungicide econazole (15 mg L^{-1}) modulates the activities of POX, PPO (Polyphenol oxidase), SOD, and CAT to lessen the deleterious salt effect in sesame (Heydari et al., 2019).

2.3. Antioxidant in Plants under Drought

Some of the key negative impacts that utterly decimate a plant under drought stress are accelerated leaf senescence, chlorophyll degradation, decreased photosynthesis and canopy growth, and poor water and nutrient usage efficiency (Liang et al., 2018). Furthermore, hyperaccumulation of ROS (reactive oxygen species) in drought-stressed plants causes oxidative damage to cell membranes, critical enzymes, proteins, and nucleic acids (Liang et al., 2018).

In one experiment, drought-tolerant (M35-1) and drought-sensitive (SPV-839) sorghum cultivars were exposed to 150 mM NaCl for 72 hours, and M35-1 demonstrated effective H2O2 scavenging mechanisms with considerably higher GST and CAT levels. Jogeswar et al., (2006) defines formalized when exposed to PEG stress, transgenic tobacco plants overexpressing Prosopis juliflora GST (PjGSTU1) outlived control plants by 15%. (George et al., 2010). In drought-prone V. radiate seedlings, Nahar et al., (2017) discovered a reduction in the ratio of Ascorbic acid / Dehydroascorbate (ASA / DHA) and Lowered glutathione / Oxidized glutathione (GSH / GSSG) with enhanced activities of GPX, APX, GR, and GST compared to controls, This aided in the resistance to drought-induced oxidative damage While Zea mays cv. Xida 889 and Xida 319 were subjected to drought (50% F.C., 15 days), GSH level rose by 17 and 28%, respectively, in Xida 319 and Xida 889, compared to control (Hussain et al., 2019). When treated to water stress, three cultivars of P. vulgaris (Zlatev et al., 2006) and P. asperata (Yang et al., 2008) showed a significant increase in APX activity. Sharma & Dubey (2005) discovered that slightly drought-stressed seedlings have more chloroplastic-APX activity than control plants. Nevertheless, as the severity of the drought rose, so did this activity. According to Koussevitzky et al. (2008) cytosolic APX1 is necessary for plant defence against heat and drought. (Yang et al., 2009) linked increased APX activity to transgenic rice plants overexpressing OsMT1a's drought tolerance. Akram et al., (2018) reported raised CAT and POD activities as well as increased total phenolic content in both cultivars of B. napus (cv. Dunkeld and Cyclone) when comparing their performances in water-stressed conditions (60 per cent F.C., 21 d) Sharma & Dubey (2005) discovered that the activity of enzymes involved in (ASH) regeneration, such as MDHAR, DHAR, and G.R., were more significant in drought-stressed rice seedlings. DHAR improved tobacco tolerance to drought and ozone stress (Eltayeb et al., 2006). Research on two Sorghum cultivars (M-81E (tolerant) and Roma (sensitive)) enhanced drought tolerance (Guo et al., 2018). Drought stress raised H2O2 levels by 28.9 per cent and 54.9 per cent in M-81E and Roma, respectively, when SOD activity rose 1.6 and 1.1 times and APX activity increased 1.7 and 0.9 times between. Nevertheless, CAT activity was reduced, whereas GPX activity was boosted under drought stress (irrigation stopped ten days after planting, 11 days) in Triticum aestivum cv. Sakha-94 (Hassan et al., 2020). Drought stress elevated activities of sod in three P. Vulgaris cultivars (Zlatev et al., 2006), Alternanthera philoxeroides (Wang et al., 2008), and Oryza sativa varieties (Sharma & Dubey, 2005). According to Chang-Quan and Rui-Chang (2008), water stress enhanced total leaf SOD and chloroplast SOD activity in Trifolium repens L., who observed a much more significant rise in SOD activity during water stress. Furthermore, (Rady et al., 2020) demonstrated that under drought stress (60 per cent F.C., 20 d), a rise in H_2O_2 (26.2 per cent) and O_2•- (51 per cent) generation increased SOD, CAT, and APX activities by 110 per cent, 66 per cent, and 77 per cent, respectively, as well as a significant increase in ASA, GSH, and alpha-tocopherol content. (Yang et al., 2008) demonstrated the cumulative influence of drought and poor lighting on Picea asperata Mast. They develop seedlings using two irrigation regimes: well-watered and drought and with and without light. It was discovered that depletion significantly increased SOD operation in high light relative to low light. (Antoniou et al., 2017) suggested that pre-treatment with melatonin and drought-stress of M. sativa plants increased CAT activity and decreased H2O2 content compared to control. According to (Simova Stoilova et al., 2010), drought enhanced CAT behaviour in wheat, although it was more pronounced in vulnerable cultivars. Another study, Sharma & Dubey (2005) revealed a decrease in CAT behaviour in rice seedlings under drought stress. Maximum light levels boosted CAT activity in P. asperata during drought stress (Yang et al., 2008). Similarly, to increase performance in M. sativa plants subjected to extreme dehydration stress, nitric oxide aspirin and hydrogen sulfide (NOSH-aspirin) regulate CAT and SOD activity, as well as cAPX Cu / ZnSOD and FeSOD transcripts (Antoniou et al., 2020). Pan et al., (2006) discovered that combining salt and drought stress on Glycyrrhiza uralensis seedlings reduces CAT activity. Transgenic rice plants overexpressing OsMT1a displayed increased CAT activity and, as a result, improved drought tolerance (Yang et al., 2009).

2.4. Antioxidant in Plants under Toxic Metals

Enhanced SOD activity is also being observed subsequent Cd treatments in Hordeum vulgare (Guo, et al., 2004) A. thaliana, (Simonovicova et al., 2004), Triticum aestivum (Khan et al., 2007), O. sativa (Hsu & Kao, 2004), Anabaena d (Li et al., 2009). During photooxidative stress, protoplasts overexpressing Mn-SOD exhibited modest oxidative stress, increased H2O2 concentration, and a significant increase in SOD and G.R. activity (Melchiorre et al., 2009). Compared to control plants, transgenic Arabidopsis plants have much amplified Mn-SOD activity and Cu/Zn-SOD, POD, Fe-SOD, and CAT activity (Wang et al., 2004). Transgenic tobacco plants overexpressing Cu/Zn-SOD (Badawi et al., 2004). Moreover, the transgenic Festuca plants with familiar themes of Cu/ZnSOD and APX showed enhanced tolerance to MV, H2O2, Cu, Cd, and other heavy metals (Lee et al., 2007). In a study of the function of Fe-SODs in early chloroplast formation in Arabidopsis thaliana Myouga et al., (2008) it was shown that Arabidopsis possesses three kinds of FeSODs, only two of them, FSD2 and FSD3, are required for early chloroplast growth. By mixing it with it, GST helps minimize metals/metalloid toxicity among the important antioxidants (Kumar & Trivedi, 2018). Furthermore, GSH functions as a cell antecedent to phytochelatin (P.C.), which binds minerals and increases the shuttling of metallic ions and other biotic exogenous chemicals, which speeds up their passage inside the cell vacuole (Hasanuzzaman et al., 2012).

Slow transit of cytosolic metals/metalloid ions into vacuoles lowers cellular toxicity (Al Mahmud et al., 2019). Moreover, GST and GSH are involved in accumulating some flavonoids (anthocyanins), which act as metal binders and can be produced in the vacuole via the same process (Landi et al., 2015). GST activity was shown to be increased in the the roots of O. sativa and Phragmites australis plants (Iannelli et al., 2002). Hasanuzzaman et al., (2019b) observed a significant increase in GSH and GSSG levels in O. Sativa seedling during nickel stress (0.25 and 0.5 mM NiSO4.7H2O), which raised GSH, while GSSG reduced when external Si (0.05 mM Na2SiO3) was applied, suggesting the involvement of Si in GSH regulation. Furthermore, the stress-induced increase in SOD, GPX, APX, MDHAR, DHAR, and G.R. activities, further enhanced by Si supplement, assisted minimize Ni toxicity. The varied response of CAT behaviour to metal stress has indeed been described. Its activity reduced in Glycine max (Balestrasse et al., 2001), Phragmites australis (Iannelli et al., 2002), Capsicum annuum (Leon et al., 2002) during Cd stress, but it rose in O. sativa (Hsu & Kao, 2004), B. juncea (Mobin & Khan, 2007). According to Hsu & Kao (2007), pre-treatment of rice plants with H2O2 under quasi shock conditions increased CAT activities and rescued rice seedlings against subsequent Cd stress. Under NaCl and Cu^{2+} stress, Srivastava et al., (2005) found a reduction in CAT activity in A. doliolum. CATA3 transcript levels were elevated in H. annuus leaf discs incubated with 300 and 500 mM CdCl2 under light conditions, although this transcript was not stimulated by Cd in elongated plants, according to the study (Azpilicueta et al., 2007). Cd also produced more serious DNA damage inside the root of transgenic CAT-deficient tobacco lines (CAT 1AS) than those in the roots of wild tobacco varieties (Gichner et al., 2004). Transgenic plants showed around twice as much CAT activity as wild-type plants, associated with improved resistance to Cd stress (Guan et al., 2009). Contrarily, under cadmium stress (50 M $CdCl_2$, 100 d), SOD, CAT, POX, and G.R. activities were upregulated with higher H2O2 content (53.45 per cent and 69.83 per cent, respectively) in two Mentha arvensis genotypes (cultivar Kosi and Kusha), indicating the activation of an antioxidant defence system to confer tolerance to cadmium toxicity (Zaid et al., 2020). According to the researchers, pre-treatment of O. Sativa seedlings with H2O2 under non-heat shock conditions boosted APX activity and protected rice seedlings against future Cd stress (Hsu & Kao, 2007). Pekker et al., (2002) examined cAPX expression in de-rooted bean plant leaves in response to iron overload and observed that cAPX expression (mRNA and protein) was quickly increased. When root tips were stressed with Al for 72 hours, (Simonovicova et al., 2004) discovered an increase in APX activity of H.

Vulgare L. cv. Alfor. Al Mahmoud et al., (2018) measured the contents of ASA, DHA, GSH, and GSSG in B. juncea seedlings exposed to (0.5 and 1.0 mM CdCl2, 3 d) cadmium toxicity and discovered that the ASA content, as well as the activities of CAT, MDHAR, DHAR, and G.R., were reduced in a dose-dependent manner, which was reversed by citric acid treatment (CA, 0.5 and 1.0 mM). Under stress, GPX activity rises in C. annuum cultivars while decreasing in roots and generating no major change in Cd-exposed P. sativum seedlings (Leon et al., 2002). Furthermore, cadmium treatment boosted GSH content, SOD, APX, and GPX activities while decreasing oxidative stress (Al Mahmud et al., 2018). GPOX activity varies substantially depending on plant type and stress levels. It increased in Cd-exposed plants such as T. aestivum (Milone et al., 2003) and C. demersum (Aravind & Prasad, 2003). Radotic et al., (2000) discovered an initial rise in GPOX activities in spruce needles subjected to Cd stress, proceeded by a reduction following consecutive Cd treatments. Lead (Pb) stress (1.0 mM Pb $(NO_3)_2$) reduced ASA material as well as CAT, MDHAR, GR, and GPX actions with increased H2O2 content by 41% and 95%, respectively, in wheat plants, which was reversibly altered by 1.0 mM GSH diets supplemented, demonstrating the role of GSH in activating the antioxidant defense system (Hasanuzzaman et al., 2018b). The role of MDAR or DHAR in ASH regrowth has been investigated in transgenic tobacco plants constitutively active A. thaliana cytosolic DHAR (DHAR-OX) or MDAR under Al stress Monodehydroascorbate reductase-Overexpressor (MDAR-OX) (MDAR-OX). In contradiction to WT, Dehydroascorbate reductase-Overexpressor (DHAR-OX) transgenic plants had higher levels of ASH with or without Al, but MDAR-OX transgenic plants only had higher levels of ASH when Al was absent. DHAR-OX plants with considerably higher ASH and APX resisted Al stress better than MDAR-OX plants. Plants that overexpress DHAR showed resilience to Al stress by having high ASH levels (Yin et al., 2010). Exogenous spermidine, but on the other hand, was able to restore the contents of ASA and GSH, as well as the ratios of ASA/DHA and GSH/GSSG, as well as the activity of APX, DHAR, GR, and CAT, resulting in decreased aluminium (Al; AlCl3 0.5 mM, 48 and 72 h) oxididative stress-induced in V. radiate seedlings (Nahar et al., 2017). Sharma & Dubey (2005) revealed that drought-stressed rice seedlings had enhanced ASH regeneration enzymes such as MDHAR, DHAR, and G.R.

REFERENCES

Abideen, Z., Koyro, H. W., Huchzermeyer, B., Ansari, R., Zulfiqar, F., & Gul, B. J. P. B. (2020). Ameliorating effects of biochar on photosynthetic efficiency and antioxidant defence of Phragmites karka under drought stress. Plant Biology, 22(2), 259-266.

Ahanger, M. A., Qin, C., Begum, N., Maodong, Q., Dong, X. X., El-Esawi, M., ... & Zhang, L. (2019). Nitrogen availability prevents oxidative effects of salinity on wheat growth and photosynthesis by up-regulating the antioxidants and osmolytes metabolism, and secondary metabolite accumulation. BMC plant biology, 19(1), 1-12.

Ahmad, P., Ahanger, M. A., Alam, P., Alyemeni, M. N., Wijaya, L., Ali, S., & Ashraf, M. (2019). Silicon (Si) supplementation alleviates NaCl toxicity in mung bean [Vigna radiata (L.) Wilczek] through the modifications of physio-biochemical attributes and key antioxidant enzymes. Journal of Plant Growth Regulation, 38(1), 70-82.

Akram, N. A., Iqbal, M., Muhammad, A., Ashraf, M., Al-Qurainy, F., & Shafiq, S. (2018). Aminolevulinic acid and nitric oxide regulate oxidative defense and secondary metabolisms in canola (Brassica napus L.) under drought stress. Protoplasma, 255(1), 163-174.

Al Mahmud, J., Bhuyan, M. B., Anee, T. I., Nahar, K., Fujita, M., & Hasanuzzaman, M. (2019). Reactive oxygen species metabolism and antioxidant defense in plants under metal/metalloid stress. In Plant abiotic stress tolerance (pp. 221-257). Springer, Cham.

Al Mahmud, J., Hasanuzzaman, M., Nahar, K., Bhuyan, M. B., & Fujita, M. (2018). Insights into citric acid-induced cadmium tolerance and phytoremediation in Brassica juncea L.: Coordinated functions of metal chelation, antioxidant defense and glyoxalase systems. Ecotoxicology and environmental safety, 147, 990-1001.

Ali, A. Y. A., Ibrahim, M. E. H., Zhou, G., Nimir, N. E. A., Jiao, X., Zhu, G., ... & Yue, W. (2020). Exogenous jasmonic acid and humic acid increased salinity tolerance of sorghum. Agronomy Journal, 112(2), 871-884.

Alsahli, A., Mohamed, A. K., Alaraidh, I., Al-Ghamdi, A., Al-Watban, A., El-Zaidy, M., & Alzahrani, S. M. (2019). Salicylic acid alleviates salinity stress through the modulation of biochemical attributes and some key antioxidants in wheat seedlings. Pak. J. Bot, 51(5), 1551-1559.

Alzahrani, S. M., Alaraidh, I. A., Migdadi, H., Alghamdi, S., Khan, M. A., & Ahmad, P. (2019). Physiological, biochemical, and antioxidant properties of two genotypes of Vicia faba grown under salinity stress. Pak. J. Bot, 51(3), 786-798.

Anee, T. I., Nahar, K., Rahman, A., Mahmud, J. A., Bhuiyan, T. F., Alam, M. U., ... & Hasanuzzaman, M. (2019). Oxidative damage and antioxidant defense in Sesamum indicum after different waterlogging durations. Plants, 8(7), 196.

Antoniou, C., Chatzimichail, G., Xenofontos, R., Pavlou, J. J., Panagiotou, E., Christou, A., & Fotopoulos, V. (2017). Melatonin systemically ameliorates drought stress-induced damage in M edicago sativa plants by modulating nitro-oxidative homeostasis and proline metabolism. Journal of Pineal Research, 62(4), e12401.

Antoniou, C., Xenofontos, R., Chatzimichail, G., Christou, A., Kashfi, K., & Fotopoulos, V. (2020). Exploring the potential of nitric oxide and hydrogen sulfide (NOSH)-releasing synthetic compounds as novel priming agents against drought stress in Medicago sativa plants. Biomolecules, 10(1), 120.

Apel, K., & Hirt, H. (2004). Reactive oxygen species: metabolism, oxidative stress, and signal transduction. Annu. Rev. Plant Biol., 55, 373-399.

Aravind, P., & Prasad, M. N. V. (2003). Zinc alleviates cadmium-induced oxidative stress in Ceratophyllum demersum L.: a free floating freshwater macrophyte. Plant Physiology and Biochemistry, 41(4), 391-397.

Azpilicueta, C. E., Benavides, M. P., Tomaro, M. L., & Gallego, S. M. (2007). Mechanism of CATA3 induction by cadmium in sunflower leaves. Plant Physiology and Biochemistry, 45(8), 589-595.

Badawi, G. H., Yamauchi, Y., Shimada, E., Sasaki, R., Kawano, N., Tanaka, K., & Tanaka, K. (2004). Enhanced tolerance to salt stress and water deficit by overexpressing superoxide dismutase in tobacco (Nicotiana tabacum) chloroplasts. Plant Science, 166(4), 919-928.

Balestrasse, K. B., Gardey, L., Gallego, S. M., & Tomaro, M. L. (2001). Response of antioxidant defence system in soybean nodules and roots subjected to cadmium stress. Functional Plant Biology, 28(6), 497-504.

Berwal, M., & Ram, C. (2018). Superoxide dismutase: A stable biochemical marker for abiotic stress tolerance in higher plants. Abiotic and Biotic Stress in Plants, 1-10.

Blokhina, O., Virolainen, E., & Fagerstedt, K. V. (2003). Antioxidants, oxidative damage and oxygen deprivation stress: a review. Annals of botany, 91(2), 179-194.

Chaki, M., Begara-Morales, J. C., & Barroso, J. B. (2020). Oxidative stress in plants.

Chang-Quan, W., & Rui-Chang, L. (2008). Enhancement of superoxide dismutase activity in the leaves of white clover (Trifolium repens L.) in response to polyethylene glycol-induced water stress. Acta Physiologiae Plantarum, 30(6), 841-847.

Choudhury, F. K., Rivero, R. M., Blumwald, E., & Mittler, R. (2017). Reactive oxygen species, abiotic stress and stress combination. The Plant Journal, 90(5), 856-867.

Christou, A., Manganaris, G. A., Papadopoulos, I., & Fotopoulos, V. (2013). Hydrogen sulfide induces systemic tolerance to salinity and non-ionic osmotic stress in strawberry plants through modification of reactive species biosynthesis and transcriptional regulation of multiple defence pathways. Journal of experimental botany, 64(7), 1953-1966.

Chung, Y. S., Kim, K. S., Hamayun, M., & Kim, Y. (2020). Silicon confers soybean resistance to salinity stress through regulation of reactive oxygen and reactive nitrogen species. Frontiers in plant science, 10, 1725.

Decros, G., Baldet, P., Beauvoit, B., Stevens, R., Flandin, A., Colombié, S., ... & Pétriacq, P. (2019). Get the balance right: ROS homeostasis and redox signalling in fruit. Frontiers in plant science, 10, 1091.

Demidchik, V. (2014). Mechanisms and physiological roles of K+ efflux from root cells. Journal of plant physiology, 171(9), 696-707.

Demidchik, V. (2015). Mechanisms of oxidative stress in plants: from classical chemistry to cell biology. Environmental and experimental botany, 109, 212-228.

Djanaguiraman, M., Perumal, R., Jagadish, S. V. K., Ciampitti, I. A., Welti, R., & Prasad, P. V. V. (2018). Sensitivity of sorghum pollen and pistil to high-temperature stress. Plant, cell & environment, 41(5), 1065-1082.

Dmitrieva, V. A., Tyutereva, E. V., & Voitsekhovskaja, O. V. (2020). Singlet oxygen in plants: Generation, detection, and signaling roles. International journal of molecular sciences, 21(9), 3237.

Eltayeb, A. E., Kawano, N., Badawi, G. H., Kaminaka, H., Sanekata, T., Shibahara, T., ... & Tanaka, K. (2007). Overexpression of monodehydroascorbate reductase in transgenic tobacco confers enhanced tolerance to ozone, salt and polyethylene glycol stresses. Planta, 225(5), 1255-1264.

Eltayeb, A. E., Kawano, N., Badawi, G. H., Kaminaka, H., Sanekata, T., Morishima, I., ... & Tanaka, K. (2006). Enhanced tolerance to ozone and drought stresses in transgenic tobacco overexpressing dehydroascorbate reductase in cytosol. Physiologia Plantarum, 127(1), 57-65.

Eyidogan, F., & Öz, M. T. (2007). Effect of salinity on antioxidant responses of chickpea seedlings. Acta Physiologiae Plantarum, 29(5), 485-493.

Fischer, B. B., Hideg, E., & Krieger-Liszkay, A. (2013). Production, detection, and signaling of singlet oxygen in photosynthetic organisms. Antioxidants & redox signaling, 18(16), 2145-2162.

Gapińska, M., Skłodowska, M., & Gabara, B. (2008). Effect of short-and long-term salinity on the activities of antioxidative enzymes and lipid peroxidation in tomato roots. Acta Physiologiae Plantarum, 30(1), 11.

Gechev, T. S., Van Breusegem, F., Stone, J. M., Denev, I., & Laloi, C. (2006). Reactive oxygen species as signals that modulate plant stress responses and programmed cell death. Bioessays, 28(11), 1091-1101.

George, S., Venkataraman, G., & Parida, A. (2010). A chloroplast-localized and auxin-induced glutathione S-transferase from phreatophyte Prosopis juliflora confer drought tolerance on tobacco. Journal of plant physiology, 167(4), 311-318.

Gichner, T., Patková, Z., Száková, J., & Demnerová, K. (2004). Cadmium induces DNA damage in tobacco roots, but no DNA damage, somatic mutations or homologous recombination in tobacco leaves. Mutation Research/ Genetic Toxicology and Environmental Mutagenesis, 559(1-2), 49-57.

Gill, S. S., & Tuteja, N. (2010). Reactive oxygen species and antioxidant machinery in abiotic stress tolerance in crop plants. Plant physiology and biochemistry, 48(12), 909-930.

Guan, Z., Chai, T., Zhang, Y., Xu, J., & Wei, W. (2009). Enhancement of Cd tolerance in transgenic tobacco plants overexpressing a Cd-induced catalase cDNA. Chemosphere, 76(5), 623-630.

Guler, N. S., & Pehlivan, N. (2016). Exogenous low-dose hydrogen peroxide enhances drought tolerance of soybean (Glycine max L.) through inducing antioxidant system. Acta Biologica Hungarica, 67(2), 169-183.

Guo, T., Zhang, G., Zhou, M., Wu, F., & Chen, J. (2004). Effects of aluminum and cadmium toxicity on growth and antioxidant enzyme activities of two barley genotypes with different Al resistance. Plant and soil, 258(1), 241-248.

Guo, Y. Y., Tian, S. S., Liu, S. S., Wang, W. Q., & Sui, N. (2018). Energy dissipation and antioxidant enzyme system protect photosystem II of sweet sorghum under drought stress. Photosynthetica, 56(3), 861-872.

Hancock, J. T., & Whiteman, M. (2016). Hydrogen sulfide signaling: interactions with nitric oxide and reactive oxygen species. Annals of the New York Academy of Sciences, 1365(1), 5-14.

Harinasut, P., Poonsopa, D., Roengmongkol, K., & Charoensataporn, R. (2003). Salinity effects on antioxidant enzymes in mulberry cultivar. Science Asia, 29(2), 109-113.

Hasan, M., Cheng, Y., Kanwar, M. K., Chu, X. Y., Ahammed, G. J., & Qi, Z. Y. (2017). Responses of plant proteins to heavy metal stress—a review. Frontiers in plant science, 8, 1492.

Hassan, N., Ebeed, H., & Aljaarany, A. (2020). Exogenous application of spermine and putrescine mitigate adversities of drought stress in wheat by protecting membranes and chloroplast ultra-structure. Physiology and Molecular Biology of Plants, 26(2), 233-245.

Hasanuzzaman, M., Alam, M. M., Nahar, K., Mohsin, S. M., Bhuyan, M. B., Parvin, K., ... & Fujita, M. (2019b). Silicon-induced antioxidant defense and methylglyoxal detoxification works coordinately in alleviating nickel toxicity in Oryza sativa L. Ecotoxicology, 28(3), 261-276.

Hasanuzzaman, M., Bhuyan, M. H. M., Anee, T. I., Parvin, K., Nahar, K., Mahmud, J. A., & Fujita, M. (2019a). Regulation of ascorbate-glutathione pathway in mitigating oxidative damage in plants under abiotic stress. Antioxidants, 8(9), 384.

Hasanuzzaman, M., Bhuyan, M. H. M., Zulfiqar, F., Raza, A., Mohsin, S. M., Mahmud, J. A., ... & Fotopoulos, V. (2020a). Reactive oxygen species and antioxidant defense in plants under abiotic stress: Revisiting the crucial role of a universal defense regulator. Antioxidants, 9(8), 681.

Hasanuzzaman, M., Hossain, M. A., da Silva, J. A. T., & Fujita, M. (2012). Plant response and tolerance to abiotic oxidative stress: antioxidant defense is a key factor. In Crop stress and its management: perspectives and strategies (pp. 261-315). Springer, Dordrecht.

Hasanuzzaman, M., Nahar, K., Gill, S. S., Alharby, H. F., Razafindrabe, B. H., & Fujita, M. (2017). Hydrogen peroxide pretreatment mitigates cadmium-induced oxidative stress in Brassica napus L.: an intrinsic study on antioxidant defense and glyoxalase systems. Frontiers in plant science, 8, 115.

Hasanuzzaman, M., Nahar, K., Khan, M. I. R., Al Mahmud, J., Alam, M. M., & Fujita, M. (2020b). Regulation of reactive oxygen species metabolism and glyoxalase systems by exogenous osmolytes confers thermotolerance in Brassica napus. Gesunde Pflanzen, 72(1), 3-16.

Hasanuzzaman, M., Nahar, K., Rahman, A., Inafuku, M., Oku, H., & Fujita, M. (2018a). Exogenous nitric oxide donor and arginine provide protection against short-term drought stress in wheat seedlings. Physiology and Molecular Biology of Plants, 24(6), 993-1004.

Hasanuzzaman, M., Nahar, K., Rahman, A., Mahmud, J. A., Alharby, H. F., & Fujita, M. (2018b). Exogenous glutathione attenuates lead-induced oxidative stress in wheat by improving antioxidant defense and physiological mechanisms. Journal of Plant Interactions, 13(1), 203-212.

Heydari, H., Rezayian, M., Niknam, V., & Ebrahimzadeh, H. (2019). Role of Penconazole in salt stress amelioration in Sesamum indicum L. Soil Science and Plant Nutrition, 65(3), 243-250.

Hsu, Y. T., & Kao, C. H. (2004). Cadmium toxicity is reduced by nitric oxide in rice leaves. Plant Growth Regulation, 42(3), 227-238.

Hsu, Y. T., & Kao, C. H. (2007). Heat shock-mediated H 2 O 2 accumulation and protection against Cd toxicity in rice seedlings. Plant and soil, 300(1), 137-147.

Hussain, H. A., Men, S., Hussain, S., Chen, Y., Ali, S., Zhang, S., ... & Wang, L. (2019). Interactive effects of drought and heat stresses on morpho-physiological attributes, yield, nutrient uptake and oxidative status in maize hybrids. Scientific reports, 9(1), 1-12.

Iannelli, M. A., Pietrini, F., Fiore, L., Petrilli, L., & Massacci, A. (2002). Antioxidant response to cadmium in Phragmites australis plants. Plant Physiology and Biochemistry, 40(11), 977-982.

Janicka, M., Reda, M., Napieraj, N., & Kabała, K. (2019). Plant abiotic stress: Function of nitric oxide and hydrogen peroxide. In Nitric Oxide and Hydrogen Peroxide Signaling in Higher Plants (pp. 201-219). Springer, Cham.

Jogeswar, G., Pallela, R., Jakka, N. M., Reddy, P. S., Rao, J. V., Sreenivasulu, N., & Kishor, P. K. (2006). Antioxidative response in different sorghum species under short-term salinity stress. Acta Physiologiae Plantarum, 28(5), 465-475.

Kapoor, D., Sharma, R., Handa, N., Kaur, H., Rattan, A., Yadav, P., ... & Bhardwaj, R. (2015). Redox homeostasis in plants under abiotic stress: role of electron carriers, energy metabolism mediators and proteinaceous thiols. Frontiers in Environmental Science, 3, 13.

Kar, R. K. (2011). Plant responses to water stress: role of reactive oxygen species. Plant signaling & behavior, 6(11), 1741-1745.

Khan, N. A., Samiullah, Singh, S., & Nazar, R. (2007). Activities of antioxidative enzymes, sulphur assimilation, photosynthetic activity and growth of wheat (Triticum aestivum) cultivars differing in yield potential under cadmium stress. Journal of Agronomy and Crop Science, 193(6), 435-444.

Koussevitzky, S., Suzuki, N., Huntington, S., Armijo, L., Sha, W., Cortes, D., ... & Mittler, R. (2008). Ascorbate peroxidase 1 plays a key role in the response of Arabidopsis thaliana to stress combination. Journal of Biological Chemistry, 283(49), 34197-34203.

Kukreja, S., Nandwal, A. S., Kumar, N., Sharma, S. K., Unvi, V., & Sharma, P. K. (2005). Plant water status, H 2 O 2 scavenging enzymes, ethylene evolution and membrane integrity of Cicer arietinum roots as affected by salinity. Biologia plantarum, 49(2), 305-308.

Kumar, S., & Trivedi, P. K. (2018). Glutathione S-transferases: role in combating abiotic stresses including arsenic detoxification in plants. Frontiers in Plant Science, 9, 751.

Landi, M., Tattini, M., & Gould, K. S. (2015). Multiple functional roles of anthocyanins in plant-environment interactions. Environmental and Experimental Botany, 119, 4-17.

Lee, S. H., Ahsan, N., Lee, K. W., Kim, D. H., Lee, D. G., Kwak, S. S., ... & Lee, B. H. (2007). Simultaneous overexpression of both CuZn superoxide dismutase and ascorbate peroxidase in transgenic tall fescue plants confers increased tolerance to a wide range of abiotic stresses. Journal of plant physiology, 164(12), 1626-1638.

León, A. M., Palma, J. M., Corpas, F. J., Gómez, M., Romero-Puertas, M. C., Chatterjee, D., ... & Sandalio, L. M. (2002). Antioxidative enzymes in cultivars of pepper plants with different sensitivity to cadmium. Plant Physiology and Biochemistry, 40(10), 813-820.

Li, Y., Song, Y., Shi, G., Wang, J., & Hou, X. (2009). Response of antioxidant activity to excess copper in two cultivars of Brassica campestris ssp. chinensis Makino. Acta physiologiae plantarum, 31(1), 155-162.

Liang, B., Ma, C., Zhang, Z., Wei, Z., Gao, T., Zhao, Q., ... & Li, C. (2018). Long-term exogenous application of melatonin improves nutrient uptake fluxes in apple plants under moderate drought stress. Environmental and experimental botany, 155, 650-661.

Light, G. G., Mahan, J. R., Roxas, V. P., & Allen, R. D. (2005). Transgenic cotton (Gossypium hirsutum L.) seedlings expressing a tobacco glutathione S-transferase fail to provide improved stress tolerance. Planta, 222(2), 346-354.

Liu, T., Ye, X., Li, M., Li, J., Qi, H., & Hu, X. (2020). H2O2 and NO are involved in trehalose-regulated oxidative stress tolerance in cold-stressed tomato plants. Environmental and Experimental Botany, 171, 103961.

Loreti, E., van Veen, H., & Perata, P. (2016). Plant responses to flooding stress. Current Opinion in Plant Biology, 33, 64-71.

Lu, Z., Liu, D., & Liu, S. (2007). Two rice cytosolic ascorbate peroxidases differentially improve salt tolerance in transgenic Arabidopsis. Plant cell reports, 26(10), 1909-1917.

Mailloux, R. (2016). Application of mitochondria-targeted pharmaceuticals for the treatment of heart disease. Current pharmaceutical design, 22(31), 4763-4779.

Maurya, A. K. (2020). Oxidative stress in crop plants. In Agronomic Crops (pp. 349-380). Springer, Singapore.

Mehla, N., Sindhi, V., Josula, D., Bisht, P., & Wani, S. H. (2017). An introduction to antioxidants and their roles in plant stress tolerance. In Reactive oxygen species and antioxidant Systems in Plants: role and regulation under abiotic stress (pp. 1-23). Springer, Singapore.

Melchiorre, M., Robert, G., Trippi, V., Racca, R., & Lascano, H. R. (2009). Superoxide dismutase and glutathione reductase overexpression in wheat protoplast: photooxidative stress tolerance and changes in cellular redox state. Plant growth regulation, 57(1), 57-68.

Mhamdi, A., Noctor, G., & Baker, A. (2012). Plant catalases: peroxisomal redox guardians. Archives of Biochemistry and Biophysics, 525(2), 181-194

Milone, M. T., Sgherri, C., Clijsters, H., & Navari-Izzo, F. (2003). Antioxidative responses of wheat treated with realistic concentration of cadmium. Environmental and Experimental Botany, 50(3), 265-276.

Mittler, R. (2017). ROS are good. Trends in plant science, 22(1), 11-19.

Mobin, M., & Khan, N. A. (2007). Photosynthetic activity, pigment composition and antioxidative response of two mustard (Brassica juncea) cultivars differing in photosynthetic capacity subjected to cadmium stress. Journal of Plant Physiology, 164(5), 601-610.

Munns, R., & Tester, M. (2008). Mechanisms of salinity tolerance. Annu. Rev. Plant Biol., 59, 651-681.

Myouga, F., Hosoda, C., Umezawa, T., Iizumi, H., Kuromori, T., Motohashi, R., ... & Shinozaki, K. (2008). A heterocomplex of iron superoxide dismutases defends chloroplast nucleoids against oxidative stress and is essential for chloroplast development in Arabidopsis. The Plant Cell, 20(11), 3148-3162.

Nagamiya, K., Motohashi, T., Nakao, K., Prodhan, S. H., Hattori, E., Hirose, S., ... & Komamine, A. (2007). Enhancement of salt tolerance in transgenic rice expressing an Escherichia coli catalase gene, katE. Plant Biotechnology Reports, 1(1), 49-55.

Nahar, K., Hasanuzzaman, M., Alam, M. M., Rahman, A., Mahmud, J. A., Suzuki, T., & Fujita, M. (2017). Insights into spermine-induced combined high temperature and drought tolerance in mung bean: osmoregulation and roles of antioxidant and glyoxalase system. Protoplasma, 254(1), 445-460.

Neill, S. J., Desikan, R., Clarke, A., Hurst, R. D., & Hancock, J. T. (2002). Hydrogen peroxide and nitric oxide as signalling molecules in plants. Journal of experimental botany, 53(372), 1237-1247.

Numan, M., Bashir, S., Khan, Y., Mumtaz, R., Shinwari, Z. K., Khan, A. L., ... & Ahmed, A. H. (2018). Plant growth promoting bacteria as an alternative strategy for salt tolerance in plants: a review. Microbiological research, 209, 21-32.

Paciolla, C., Paradiso, A., & De Pinto, M. C. (2016). Cellular redox homeostasis as central modulator in plant stress response. In Redox state as a central regulator of plant-cell stress responses (pp. 1-23). Springer, Cham.

Pan, Y., Wu, L. J., & Yu, Z. L. (2006). Effect of salt and drought stress on antioxidant enzymes activities and SOD isoenzymes of liquorice (Glycyrrhiza uralensis Fisch). Plant Growth Regulation, 49(2), 157-165.

Panda, S. K. (2001). Oxidative response of green gram seeds under salinity stress. Indian Journal of Plant Physiology, 6(4), 438-440.

Panda, S. K., Choudhury, S., & Patra, H. K. (2016). Heavy-metal-induced oxidative stress in plants: physiological and molecular perspectives. Abiotic Stress Response in Plants, 1, 219-232.

Panieri, E., & Santoro, M. M. (2015). ROS signaling and redox biology in endothelial cells. Cellular and molecular life sciences, 72(17), 3281-3303.

Parankusam, S., Bhatnagar-Mathur, P., & Sharma, K. K. (2017). Heat responsive proteome changes reveal molecular mechanisms underlying heat tolerance in chickpea. Environmental and Experimental Botany, 141, 132-144.

Pareek, A., Dhankher, O. P., & Foyer, C. H. (2020). Mitigating the impact of climate change on plant productivity and ecosystem sustainability.

Pekker, I., Tel-Or, E., & Mittler, R. (2002). Reactive oxygen intermediates and glutathione regulate the expression of cytosolic ascorbate peroxidase during iron-mediated oxidative stress in bean. Plant molecular biology, 49(5), 429-438.

Radotić, K., Dučić, T., & Mutavdžić, D. (2000). Changes in peroxidase activity and isoenzymes in spruce needles after exposure to different concentrations of cadmium. Environmental and Experimental Botany, 44(2), 105-113.

Rady, M. M., Kuşvuran, A., Alharby, H. F., Alzahrani, Y., & Kuşvuran, S. (2019). Pretreatment with proline or an organic bio-stimulant induces salt tolerance in wheat plants by improving antioxidant redox state and enzymatic activities and reducing the oxidative stress. Journal of Plant Growth Regulation, 38(2), 449-462.

Rady, M. M., Belal, H. E., Gadallah, F. M., & Semida, W. M. (2020). Selenium application in two methods promotes drought tolerance in Solanum lycopersicum plant by inducing the antioxidant defense system. Scientia Horticulturae, 266, 109290.

Raja, V., Majeed, U., Kang, H., Andrabi, K. I., & John, R. (2017). Abiotic stress: Interplay between ROS, hormones and MAPKs. Environmental and Experimental Botany, 137, 142-157.

Reczek, C. R., & Chandel, N. S. (2015). ROS-dependent signal transduction. Current opinion in cell biology, 33, 8-13.

Repetto, M., Semprine, J., & Boveris, A. (2012). Lipid peroxidation: chemical mechanism, biological implications and analytical determination. Lipid peroxidation, 1, 3-30.

Santander, C., Ruiz, A., García, S., Aroca, R., Cumming, J., & Cornejo, P. (2020). Efficiency of two arbuscular mycorrhizal fungal inocula to improve saline stress tolerance in lettuce plants by changes of antioxidant defense mechanisms. Journal of the Science of Food and Agriculture, 100(4), 1577-1587.

Sharma, P., & Dubey, R. S. (2005). Modulation of nitrate reductase activity in rice seedlings under aluminium toxicity and water stress: role of osmolytes as enzyme protectant. Journal of plant physiology, 162(8), 854-864.

Simonovicova, M., Tamás, L., Huttová, J., & Mistrík, I. (2004). Effect of aluminium on oxidative stress related enzymes activities in barley roots. Biologia Plantarum, 48(2), 261-266.

Simova-Stoilova, L., Vaseva, I., Grigorova, B., Demirevska, K., & Feller, U. (2010). Proteolytic activity and cysteine protease expression in wheat leaves under severe soil drought and recovery. Plant Physiology and Biochemistry, 48(2-3), 200-206.

Singh, A., Kumar, A., Yadav, S., & Singh, I. K. (2019). Reactive oxygen species-mediated signaling during abiotic stress. Plant Gene, 18, 100173.

Sohag, A. A. M., Tahjib-Ul-Arif, M., Brestic, M., Afrin, S., Sakil, M. A., Hossain, M. T., ... & Hossain, M. A. (2020). Exogenous salicylic acid and hydrogen peroxide attenuate drought stress in rice. Plant, Soil and Environment, 66(1), 7-13.

Srivastava, A. K., Bhargava, P., & Rai, L. C. (2005). Salinity and copper-induced oxidative damage and changes in the antioxidative defence systems of Anabaena doliolum. World journal of microbiology and biotechnology, 21(6), 1291-1298.

Suzuki, N., Koussevitzky, S. H. A. I., Mittler, R. O. N., & Miller, G. A. D. (2012). ROS and redox signalling in the response of plants to abiotic stress. Plant, cell & environment, 35(2), 259-270.

Sytar, O., Kumar, A., Latowski, D., Kuczynska, P., Strzałka, K., & Prasad, M. N. V. (2013). Heavy metal-induced oxidative damage, defense reactions, and detoxification mechanisms in plants. Acta physiologiae plantarum, 35(4), 985-999.

Tanou, G., Ziogas, V., Belghazi, M., Christou, A., Filippou, P., Job, D., ... & Molassiotis, A. (2014). Polyamines reprogram oxidative and nitrosative status and the proteome of citrus plants exposed to salinity stress. Plant, cell & environment, 37(4), 864-885.

Tonhati, R., Mello, S. C., Momesso, P., & Pedroso, R. M. (2020). L-proline alleviates heat stress of tomato plants grown under protected environment. Scientia Horticulturae, 268, 109370.

Ushimaru, T., Nakagawa, T., Fujioka, Y., Daicho, K., Naito, M., Yamauchi, Y., ... & Murata, N. (2006). Transgenic Arabidopsis plants expressing the rice dehydroascorbate reductase gene are resistant to salt stress. Journal of plant physiology, 163(11), 1179-1184.

Vighi, I. L., Benitez, L. C., Amaral, M. N., Moraes, G. P., Auler, P. A., Rodrigues, G. S., ... & Braga, E. J. B. (2017). Functional characterization of the antioxidant enzymes in rice plants exposed to salinity stress. Biologia plantarum, 61(3), 540-550.

Wang, N., Yu, F. H., Li, P. X., He, W. M., Liu, F. H., Liu, J. M., & Dong, M. (2008). Clonal integration affects growth, photosynthetic efficiency and biomass allocation, but not the competitive ability, of the alien invasive Alternanthera philoxeroides under severe stress. Annals of Botany, 101(5), 671-678.

Wang, Y., Wisniewski, M., Meilan, R., Uratsu, S. L., Cui, M., Dandekar, A., & Fuchigami, L. (2007). Ectopic expression of Mn-SOD in Lycopersicon esculentum leads to enhanced tolerance to salt and oxidative stress.

Wang, Y., Ying, Y., Chen, J., & Wang, X. (2004). Transgenic Arabidopsis overexpressing Mn-SOD enhanced salt-tolerance. Plant Science, 167(4), 671-677.

Waszczak, C., Carmody, M., & Kangasjärvi, J. (2018). Reactive oxygen species in plant signaling. Annual review of plant biology, 69, 209-236.

Yamane, K., Mitsuya, S., Kawasaki, M., Taniguchi, M., & Miyake, H. (2009). Antioxidant capacity and damages caused by salinity stress in apical and basal regions of rice leaf. Plant production science, 12(3), 319-326.

Yamauchi, T., Yoshioka, M., Fukazawa, A., Mori, H., Nishizawa, N. K., Tsutsumi, N., ... & Nakazono, M. (2017). An NADPH oxidase RBOH functions in rice roots during lysigenous aerenchyma formation under oxygen-deficient conditions. The Plant Cell, 29(4), 775-790.

Yang, Y., Han, C., Liu, Q., Lin, B., & Wang, J. (2008). Effect of drought and low light on growth and enzymatic antioxidant system of Picea asperata seedlings. Acta Physiologiae Plantarum, 30(4), 433-440.

Yang, Z., Wu, Y., Li, Y., Ling, H. Q., & Chu, C. (2009). OsMT1a, a type 1 metallothionein, plays the pivotal role in zinc homeostasis and drought tolerance in rice. Plant molecular biology, 70(1), 219-229.

Ye, N., Zhu, G., Liu, Y., Li, Y., & Zhang, J. (2011). ABA controls H2O2 accumulation through the induction of OsCATB in rice leaves under water stress. Plant and cell physiology, 52(4), 689-698.

Yin, L., Wang, S., Eltayeb, A. E., Uddin, M. I., Yamamoto, Y., Tsuji, W., ... & Tanaka, K. (2010). Overexpression of dehydroascorbate reductase, but not monodehydroascorbate reductase, confers tolerance to aluminum stress in transgenic tobacco. Planta, 231(3), 609-621.

Zaid, A.,Mohammad, F., & Fariduddin, Q. (2020). Plant growth regulators improve growth, photosynthesis, mineral nutrient and antioxidant system under cadmium stress in menthol mint (Mentha arvensis L.). Physiology and Molecular Biology of Plants, 26(1), 25-39.

Zhang, R., Zhou, Y., Yue, Z., Chen, X., Cao, X., Xu, X., ... & Huang, R. (2019). Changes in photosynthesis, chloroplast ultrastructure, and antioxidant metabolism in leaves of sorghum under waterlogging stress. Photosynthetica, 57(4), 1076-1083.

Zeeshan, M., Lu, M., Sehar, S., Holford, P., & Wu, F. (2020). Comparison of biochemical, anatomical, morphological, and physiological responses to salinity stress in wheat and barley genotypes deferring in salinity tolerance. Agronomy, 10(1), 127.

Zeng, J., Dong, Z., Wu, H., Tian, Z., & Zhao, Z. (2017). Redox regulation of plant stem cell fate. The EMBO journal, 36(19), 2844-2855.

Zlatev, Z. S., Lidon, F. C., Ramalho, J. C., & Yordanov, I. T. (2006). Comparison of resistance to drought of three bean cultivars. Biologia Plantarum, 50(3), 389-394.

Chapter 7

EFFECT OF ALTITUDE ON SOME WOOD PROPERTIES: A REVIEW

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INTRODUCTION

Regarding the economic importance of wood, its use on human life, and the limitation of natural resources, it is necessary to determine the quality of wood and make the right application for appropriate use. This depends on determining the anatomical and physical properties of wood (Doosthosseini and Parsapajouh 1996) and finding the relationships between genetic and environmental factors on them (Zoghi et al. 2013). During the formation of the cell and tissue of the wood, environmental and genetic factors affect the structure and properties of the wood (Wodzicki, 2001). Environmental factors were climatic factors (air temperature, light regime, air humidity, wind, and precipitation), physiographic factors (slope, altitude, and aspect), edaphic factors (soil properties), and biotic factors (human, plants, animals, and microorganisms) (Çepel, 1995).

Altitude is one of the significant physiographic factors affecting plant development and growth, as functional characteristics can vary greatly depending on altitude (Özden Keleş, 2020). Growth rates can decrease with altitude due to reduced soil and air temperatures, increased wind exposure, shorter growing seasons, and reduced nutrient supply (Coomes and Allen, 2007). Diameter growth rates decreased with increasing altitude, and this was associated with a shortening of the growing season and a decrease in average summer temperatures (Wardle, 1984).

The fiber properties, chemical structure, and density of wood are the most important features that determine the usage areas of wood. For example, the strength properties of papers obtained from long fibers are higher than that of short fibers. There is a linear relationship between the wall thickness and the tear strength of the paper. Thin-walled and wide-lumen fibers are easily flattened and bonded to each other during paper production. Vessel elements negatively affect the surface properties and printing quality of the paper. On the other hand, the pulp yield has a positive correlation with the cellulose content of the wood. More chemicals and time are required to convert high lignin-containing wood species into pulp. Wood density is related to the cell wall thickness and latewood ratio and has a significant effect on the properties of pulp and paper (Casey, 1960). In this review, the publications regarding the effect of altitude on wood fiber morphology, wood chemical composition, and wood density are summarized

EFFECT OF ALTITUDE ON FIBER MORPHOLOGY

Fiber morphology is the key element liable for wood strength and plays a significant role in determining the quantitative and qualitative wood features and the private usage of lignocellulosic raw materials (Panshin and de Zeeuw, 1980). It has an important effect on the pulp and paper quality and on solid wood products (Clark, 1962). The fiber dimensions such as length, width, cell wall thickness, and lumen width have an effect on the paper strength.

Tree growth in the growth zones of trees and the anatomical structure of the wood are affected by seasonal climatic conditions. Water source, air and soil temperature, air humidity, altitude, latitude, and soil structure are the main environmental factors that affect the wood anatomical properties such as fiber length, fiber diameter, cell wall thickness, lumen width, Runkel ratio, flexibility ratio, and slenderness ratio (Carlquist, 1988). Due to the harsh environment of higher altitudes, the elongation time and rate of fibers and vessel elements may be slower, resulting in shorter fibers and vessel elements in plant growth at higher altitudes (Körner, 2003). The altitude has an important effect on wood anatomical structure. The influence of altitude on the wood anatomical structure has been studied by many authors.

The influence of altitude on the cell wall thickness of coast Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco) wood in the U.S.A. was determined by Lassen and Okkonen (1969). They reported that cell wall thickness values of wood samples were 6.81 μm at low altitude (less than 900 feet), 6.44 μm at middle altitude (1000-1750 feet), and 6.55 μm at high altitude (2000-3000 feet). Şanlı (1977) reported the effect of altitude on vessel element length of earlywood and latewood of oriental beech (Fagus orientalis L.). The author noted that vessel element length had a positive correlation with altitude. Vessel element length values of earlywood and latewood at the 400 m, 900 m, and 1300 m were 0.431 mm, 0.485 mm, and 0.501 mm and 0.430 mm, 0.454 mm, and 0.510 mm, respectively. In addition, they found that vessel number in 1 mm^2 was positively correlated with altitude.

Van den Oever et al. (1981) aimed to determine the effect of altitude on wood anatomical properties of 71 samples belonging to 31 species of the genus Sympiocos (Symplocaceae). They found that fiber length, fiber width, vessel element diameter, and vessel element length decreased with increasing altitude. Ladrach (1984) found that fiber length of the 30-years-old tree of patula pine (Pinus patula Schiede ex Schltdl. & Cham.) at altitude of 1800 m, 2200 m, and 3000 m was 6.3 mm, 6.2 mm, and 5.9 mm, respectively. Dodd and Power (1986) investigated the effects of altitude (1280 m, 1676 m, and 2103 m) on fiber properties of white fir (Abies concolor (Gord. & Glend.) Lindl. ex Hildebr.). The authors noted that fiber lengths in the 1280 m, 1676 m, and 2103 m were 2.17 mm, 2.18 mm, and 1.93 mm, respectively. On the other hand, Xinying et al. (1988) studied the wood structure variation of Syringa oblata var. giraldii growing on the northern slope of Mount Taibei in China with increasing altitude (obtained wood samples from trees at 50 m intervals between 1000 m and 1800 m altitude). They found that fiber length, fiber width, vessel element diameter, and vessel element length were increased with increasing altitude.

Noshiro et al. (1994) examined the influence of diameter at breast height (DBH), tree height, and altitude on the wood anatomical properties of Nepalese alder (Alnus nepalensis D. Don.) growing in East Nepal. The altitude had the greatest effect on the wood structure of Nepalese alder, and DBH comes secondly. The authors also noted that vessel element length and fiber length were decreased with increasing altitude. Noshiro et al. (1995) aimed to determine the relationship between the wood anatomical structure of Nepalese Rhododendron and plant height, stem diameter, plant form, and altitude. They found that fiber length, vessel element length, and vessel element width were decreased with increasing altitude levels. As the altitude increased, the air temperature decreased by 0.4-0.6 °C for every 100 m rise (Çepel, 1995). Due to the temperature drop, the water uptake of the plants decreased, as the low temperatures of the high altitudes inhibited the water uptake, and the plants minimized the vessel width for the safety of the water supply (Carlquist, 1988).

Merev and Yavuz (2000) investigated the influence of altitude on anatomical properties of Rhododendron ungernii Trautv., Rhododendron luteum Sweet., Rhododendron caucasicum Pallas, Rhododendron smirnovii Trautv, and Rhododendron ponticum L. in the Eastern Black Sea Region of Turkey. In Rhododendron luteum, there was no significant correlation between altitude and anatomical properties. The largest variation was determined between altitude and some wood anatomical properties in Rhododendron smirnovii and Rhododendron caucasicum. There was an important negative correlation between altitude and tangential pore diameter, fiber-tracheid length, fiber-tracheid wall thickness, and lumen width in Rhododendron caucasicum wood samples. In Rhododendron ponticum wood samples, tangential pore diameter, vessel element length, fiber-tracheid length, libriform fiber length were negatively correlated with altitude. There was a negative correlation between altitude and fiber length in Rhododendron smirnovii wood samples. Gindl et al. (2001) examined the tracheid differentiation and lignification of Norway spruce (Picea abies L. Karst.) wood samples at altitudes of 580 m and 1260 m in Austria. They reported that trees at an altitude of 580 had wider growth rings and thicker cell walls.

Liu and Noshiro (2003) revealed that there was no relation between altitude and the anatomical structure of Dodonaea viscosa wood. Yaman and Sarıbaş (2004) found that the influence of altitude on vessel element length of European aspen (Populus tremula L.) and white poplar (Populus alba L.) wood samples was statistically insignificant. Pande et al. (2005)

studied variations in wood anatomical characters of four species of Castanopsis from different localities in relation to altitude and latitude. They found that the influence of altitude on vessel element length and fiber length was not significant. Serdar and Gerçek (2007) explained that vessel element diameter Populus L. was increased, while fiber length and vessel element length were decreased with increasing altitudes. Gürboy (2007) compared fiber properties of Brutia pine (Pinus brutia Ten.) at different altitudes (200 m, 450 m, and 800 m). The author reported that fiber length, fiber width, fiber lumen width, and cell wall thickness were 2.72 mm, 54.04 µm, 34.83 µm, and 9.28 µm at 200 m, 2.51 mm, 52.45 µm, 39.59 µm, and 6.43 µm at 450 m, and 3.02 mm, 51.87 µm, 34.35 µm, and 8.76 µm at 800 m, respectively.

Hemasi et al. (2007) found that the fiber length of Iranian beech was decreased with increased altitude. However, fiber width and lumen width were decreased irregularly with increasing g altitude. Lumen diameter differences of wood samples at 1000 m and 1400 m were insignificant. The cell wall thickness had a positive correlation with altitude. Slenderness ratio and flexibility ratio had a negative correlation with altitude. In addition, the Runkel ratio was increased with increasing altitude. The influence of altitude on vessel element properties of common walnut (Juglans regia L.) in the Black Sea region of Turkey was determined by Yaman (2008). The author noted that tangential and radial vessel element diameters were decreased with increasing altitude. The effect of altitude on fiber properties of pontine oak (Quercus pontica C. Koch) wood growing at 1300-2000 m altitudes in the Eastern Black Sea region of Turkey was investigated by Yilmaz et al. (2008). Their results showed that fiber length and vessel element length were decreased with increasing altitude. Fiber width values were 19.8 µm at 1300 m, 14.7 µm at 1700 m, and 19.4 µm at 2000 m. Cell wall thickness values at 1300 m, 1700 m, and 2000 m altitudes were 3.8 µm, 3.5 µm, and 3.8 µm, respectively.

Moya and Tomazello Fo (2008) evaluated the differences in the wood anatomy of Gmelina (Gmelina arborea Roxb.) trees growing in different geographic locations (altitude, longitude, and latitude), and precipitation levels in Costa Rica. The authors revealed that altitude had less effect on the wood anatomy than latitude, longitude, and precipitation levels. Especially, vessels and fibers were significantly affected by altitude, longitude, precipitation, and latitude. Yang and Fu (2009) noted that the fiber length and slenderness ratio of Bambusa chungii exhibit a decreased tendency from high altitude level to low altitude level. Vaziri et al. (2009) aimed to determine the effect of altitude (450 m, 750 m, and 960 m) on fiber properties of Brutia pine (Pinus brutia Ten.) in Iran. Their results showed that altitude was significantly affected the fiber properties. The longest and the shortest fibers were measured at 750 m and 960 m altitudes, respectively. Sarıbaş and Yaman (2009) found that the earlywood vessel diameter of hackberry (Celtis australis L.) growing naturally in Antalya and Zonguldak provinces of Turkey was decreased with increasing altitude. But, they found that the latewood vessel diameter was increased.

Effect of altitude on the wood structure of Rhododendron arboreum Sm. (Ericaceae) were studied in Nepal by Noshiro et al. (2010). They found that altitude had a significant negative correlation with fiber length and vessel element length. Genç (2010) aimed to determine the effect of altitude on wood anatomical properties of Castanea sativa and Alnus glutinosa in Artvin-Camili, Turkey. She found that vessel number in 1 mm^2 and vessel element diameter of Castanea sativa were decreased with increasing altitude. In the Alnus glutinosa, fiber length, vessel element tangential diameter, and vessel element length had a negative correlation with altitude. Dönmez (2010) compared fiber properties of Scots pine (Pinus sylvestris L.) wood samples at altitudes of 100 m, 500 m, 900 m, and 1300 m. The author reported that fiber length was decreased with increasing altitude. Fiber length at altitudes of 100 m, 500 m, 900 m, and 1300 m was 3.91 mm, 3.53 mm, 2.42 mm, and 1.79 mm, respectively. Fiber width was 45.55 μm at 100 m, 49.75 μm at 500 m, 48.75 μm at 900 m, and 37.45 μm at 1300 m. Lumen width and cell wall thickness were 31.00 μm and 7.27 μm at 100 m, 33.40 μm and 8.17 μm at 500 m, 31.00 μm and 7.27 μm at 900 m, and 33.40 μm and 8.17 μm at 1300 m, respectively. While the flexibility ratio and slenderness ratio were decreased with increasing altitude, the Runkel ratio was increased.

Birtürk (2011) studied the relationship between the wood anatomical characteristics of native maple tree (Acer L.) taxa of the Black Sea region of Turkey and different growth environments. He found that fiber length, fiber diameter, fiber lumen width, and vessel element diameter of Acer trautvetteri and Acer cappadocicum were negatively correlated with altitude. Fiber morphology of Phyllostachys heterocycla cv. pubescens plantation from different altitudes was evaluated by Liu et al. (2011). The differences in the altitude were significantly affected the fiber morphology. The authors noted that samples at the altitude of 300 m had longer fibers and a higher slenderness ratio than those of samples at the altitude of 600 m and 900 m. Pathak et al. (2011) differences in lengths of fiber and vessel element of Rhododendron lepidotum and Rhododendron anthopogon wood were studied in relation to altitude in Sagarmatha National Park, eastern Nepal. Fiber length and vessel element length were decreased with increasing altitude. The authors noted that this result was due to environmental conditions at the high altitude level.

Pourtahmasi et al. (2011) evaluated the relationship between altitude and vessel element properties of oriental beech (Fagus orientalis Lipsky) in the Caspian forest, Iran. They found that vessel element lumen width was decreased towards the high-altitude site. Kiaei (2011) compared fiber properties of common hornbeam (Carpinus betulus L.) at different altitudes (300 m, 750 m, and 1200 m). The author noted that fiber length, fiber diameter, lumen width, flexibility ratio, and slenderness ratio values of fibers were statistically significantly decreased with increasing altitude. However, cell wall thickness and Runkel ratio of fibers had a positive correlation with altitude. Kiaei and Samariha (2011) investigated the cell wall thickness and fiber length of Eldar pine (Pinus eldarica Medw) as a function of altitude index. Wood samples were obtained from three altitudes (500 m - low altitude, 1200 m - intermediate altitude, and 1400 m - high altitude) in the forestry of the Western Mazandaran province of Iran. The results of statistical analyses showed that the altitude index was a significant factor influencing the cell wall thickness and fiber length of Eldar pine. The authors found that fiber length, the cell wall thickness in intermediate altitude was more than in other altitude levels. The fiber length was 2.75 mm at 500 m, 2.80 mm at 1200 m, and 2.54 mm at 1400 m. In addition, cell wall thickness values at 500 m, 1200 m, and 1400 m were 5.11 µm, 5.99 µm, and 4.61 µm, respectively.

Chung et al. (2013) determined the influence of altitude on the fiber length of Taiwania cryptomerioides. Fiber length was 3.25 mm at 1200 m and 2.87 mm at 1900 m. Zoghi et al. (2013) noted that effect of altitude (550 m and 850 m) on the fiber dimensions such as fiber length, lumen width, fiber width, cell wall thickness, flexibility ratio, slenderness ratio, and Runkel ratio of oriental beech (Fagus orientalis L.) was statistically insignificant. Seo et al. (2014) investigated the relationship between fiber length of Pinus densiflora and altitude. They found that there was a positive correlation between fiber length and altitude. The fiber length of earlywood of Pinus densiflora was 2.98 mm at 500 m and 3.15 mm at 900 m. Latewood fiber length was 3.14 mm at 500 m and 3.30 mm at 900 m. Usta et al. (2014) noted the effect of altitude on cell wall thickness and vessel element length of black alder (Alnus glutinosa) was insignificant. Malkocoglu and Yilmaz compared the influence of three different altitude zones (0-400 m, 401-800 m, and 801-1200 m) on fiber properties of black alder wood. They were noted that fiber length and altitude were positively correlated. The altitude had no effect on vessel element length and fiber width. Cell wall thickness and lumen width were irregularly changed with increasing altitude.

Sulaiman (2014) evaluated the influence of altitude (605 m, 670 m, 775 m, 960 m, and 1070 m) on the fiber morphology of the oriental plane (Platanus orientalis L.) in Iraq. The author reported that the fiber length, fiber width, and cell wall thickness were irregularly changed with increasing altitude. The longest and shortest fibers were measured with 0.75 mm at 1070 m and 0.71 mm at 670 m, respectively. Topaloğlu et al. (2016) compared the fiber morphology of oriental beech (Fagus orientalis L.) at the different altitudes (0-200 m, 200-400 m, 400-600 m, 600-800 m, and 800-1000 m). The results showed that fiber length and vessel element length were decreased with increasing altitudes. Fiber length and vessel element length values at the increasing altitudes were 1.28 mm and 0.62 mm, 1.30 mm and 0.59 mm, 1.29 mm and 0.56 mm, 1.22 mm and 0.57 mm, and 1.15 mm and 0.56 mm, respectively. The authors reported that fiber width, cell wall thickness, and lumen width were irregularly changed with increasing altitudes. In addition, the number of vessel elements in 1 mm^2 increased as the diameter of the vessel elements narrowed due to the increasing altitude.

Erşen Bak and Eren (2016) evaluated the effect of altitude on some wood anatomical properties of 8 taxa (4 species) of the genus Fraxinus L. in Turkey. They were revealed that altitude had a negative correlation with the tangential and radial diameter of the vessel, vessel elements length, fiber length, fiber width, and the fiber lumen diameter. Moossavi et al. (2016) compared the fiber properties of common hornbeam (Carpinus betulus L.) trees from three different altitudes (400, 800, and 1100 m). The authors noted that the fiber length values of hornbeam wood at 400 m, 800 m, and 1100 m were 1.34 mm, 1.21 mm, and 1.37 mm, respectively. They also reported that the effects of altitude on lumen width, cell wall thickness, and fiber width were statistically insignificant. Hosseini (2016) aimed to investigate the influence of intermediate and high altitudes on the fiber length of the oriental beech tree (Fagus orientalis L.) of the Caspian forest located in the Sari region in northern Iran. The author noted that fiber length was insignificantly increased with increasing altitude.

Soosai Raj et al. (2017) studied the fiber properties and fiber-derived indices of the 21 Gmelina (Gmelina arborea Roxb.) trees selected randomly at different altitudes (37-1387 m) in the Tamil Nadu state of India. The authors also aimed to determine the dimensions of wood elements to investigate their pulping quality. They revealed that the wood samples of four (107 m, 483 m, 560 m, and 1174 m) of the 21 altitudes had notable slenderness ratio, Runkel ratio, and fiber length. Syofyan et al. (2019) determined the relationship between wood density and anatomical characters Senna sumatrana, Gliricidia sepium, and Pterocarpus indicus wood in West Sumatra, Indonesia based on altitude levels. Fiber length shows a positive correlation with the altitude for Gliricidia sepium and Pterocarpus indicus, but a significantly negative correlation in Senna sumatrana. Fiber wall thickness shows a positive correlation with the altitude for Gliricidia sepium and Pterocarpus indicus, but a significantly negative correlation in Senna sumatrana. The lumen diameter of Senna sumatrana showed a significantly positive correlation, but a significantly negative correlation on Gliricidia sepium and Pterocarpus indicus.

Kiaei et al. (2019) compared the fiber properties of common hornbeam (Carpinus betulus L.). wood at six different altitudes (300 m, 500 m, 700 m, 900 m, 1100 m, and 1300 m) in Iran. The average cell wall thickness was increased, while fiber length and fiber width were decreased with increasing altitude levels. Fiber length and fiber width at 300 m, 500 m, 700 m, 900 m, 1100 m, and 1300 m were 1.83 mm, 1.57 mm, 1.37 mm, 1.34 mm, 1.23 mm, and 1.21 mm and 32.16 µm, 26.64 µm, 25.12 µm, 23.63 µm, 23.02 µm, and 22.92 µm, respectively. Cell wall thickness was 4.88 µm, 4.89 µm, 5.05 µm, 6.09 µm, 6.21 µm, and 7.22 µm, respectively. On the other hand, the slenderness ratio and flexibility ratio were negatively correlated, while the Runkel ratio was positively correlated with altitude. Tashani et al. (2020) aimed to determine the influence of altitude (248 m, 413 m, and 830 m) on the tracheid length of Aleppo pine (Pinus halepensis Mill) and Phoenician juniper (Juniperus phoenicea L.) in Libya. They noted that fiber length values of Aleppo pine and Phoenician juniper were positively correlated with altitude.

The influence of altitude (1730, 1980, and 2250 m) and slope (<30%, 30–45%, and >45%) on fiber dimensions of Persian oak (Quercus brantii Lindl.) wood was evaluated by Nazari et al. (2020). They were noted that fiber length and fiber diameter were negatively correlated with altitude in the three slope levels. The authors revealed that the relationship between cell wall thickness and altitude was differed according to the slope levels. They also claimed that the wood properties of growing trees at the higher altitudes will become similar to those at lower altitudes due to climate change. Özden Keleş (2020) compared the influence of two different altitudes (795 m and 1350 m) on wood fiber properties of Trojan fir (Abies nordmanniana subsp. equi-trojani [Asch. & Sint. ex Boiss] Coode & Cullen) sapling in the Kastamonu-Gölköy forest nursery in Turkey. The relationship between altitude and fiber properties (fiber length, fiber width, and fiber lumen width) was not significant. However, there was a positive correlation between cell wall thickness and altitude. The cell wall thickness was 1.80 µm at 795 m and 2.70 µm at 1395 m.

Kumaş et al. (2021) investigated the effect of altitude (50 m and 250 m) on the anatomical properties of black alder wood (Alnus glutinosa subsp. barbata (C.A.Mey.) Yalt.) in Turkey. The vessel element length values were 0.78 mm at 50 m and 0.84 mm at 250 m. The authors noted that the effect of altitude on fiber width, fiber length, lumen width, and wall thickness was statistically insignificant. Saima et al. (2021) noted that cell wall thickness, flexibility ratio, and Runkel ratio of perennial shrubs in Pakistan were not changed with altitude. Nazari et al. (2021) evaluated the influence of altitude on fiber properties of hawthorn (Crataegus azarolus L.) wood grown in Iran. They found that an important influence of altitude levels on fiber length, fiber width, and cell wall thickness. They also noted that average fiber length was increased, while average fiber width was decreased with increasing altitude. Biricik et al. (2021) determined to determine the influence of altitude and aspect on the wood anatomical characteristics of oriental beech (Fagus orientalis L.) in Turkey. Wood samples were obtained from six different altitudes separated by 200 m (550–1550 m) on Uludağ mountain. The results showed that the fiber length, vessel element length, lumen width, fiber width, and cell wall thickness were increased from 550 m to 1550 m. They claimed that high precipitation and mild temperature at the upper altitudes caused longer fibers and longer vessel elements. The authors also noted that altitude was more effective than aspect on the anatomical properties of the oriental beech. At the upper altitude, the vessel element diameter was larger, the vessel element length was longer due to the high precipitation and mild temperature. It showed that there was no problem in terms of safety in the water transport of vessel elements at high altitudes of Uludağ. Recently, Akkemik et al. (2021) examined the influence of different growing site conditions on trees with the vessel properties in the woods of holm oak (Quercus ilex L.) wood growing in different regions of Turkey. The authors found that the vessel element length of holm oak was nearly stable at the different altitudes in all regions.

EFFECT OF ALTITUDE ON CHEMICAL COMPOSITION

While the structural features of wood appear to have clear trends in altitude and latitude, the patterns of chemical wood properties are uncertain (Gindl et al. 2001). The altitude has an important effect on wood chemical composition. Several authors have studied the relationship between wood chemical composition and altitude.

Gindl et al. (2001) compared the lignin content of Norway spruce (Picea abies L. Karst.) wood at altitudes of 580 m and 1260 m in Austria. The authors noted that lignin content was higher at an altitude of 1260 m. The authors hypothesized that trees growing at higher altitudes compensate for thinner cell walls by increasing the lignin content to maintain the mechanical strength of the wood. Nylinder and Hägglund (1954) and Beadle et al. (1996) found that the pulp yield of trees at higher altitudes was lower than that of lower altitudes. Vaziri et al. (2009) evaluated the effect of altitude (450 m, 750 m, and 960 m) on the wood chemical composition of Brutia pine (Pinus brutia Ten.) in Iran. They revealed that 750 m altitude had the highest cellulose content, while 960 m altitude had the highest lignin and extractive content. Ash content differences at three altitudes were not significant. Liu et al. (2011) determined the influence of altitude on the chemical composition of Phyllostachys heterocycla cv. pubescens. They were revealed that hot water solubility, ethanol-benzene solubility, ash content, and Klason lignin were increased with the increasing altitude. However, 1% NaOH solubility and cellulose content were decreased.

Dönmez et al. (2013) compared the chemical composition of Scots pine (Pinus sylvestris L.) wood samples at altitudes of 118 m, 526 m, 914 m, and 1296 m in Turkey. The authors noted that holocellulose content at altitudes of 118 m, 526 m, 914 m, and 1296 m was 64.15%, 62.72%, 69.50%, and 62.32%, respectively. α-cellulose content and lignin content were decreased with increased altitude. Nevertheless, hot water and 1%NaOH solubility values were positively correlated with altitude. They also reported that lower altitudes are more suitable for pulp and paper production regarding holocellulose, α-cellulose, and lignin contents of the wood. Camarena-Tello et al. (2015) investigated the relationship between the chemical composition of Psidium guajava branch wood and altitude. They noted that the holocellulose content, α-cellulose content, Runkel lignin content, hemicellulose content, ash content, acetone solubility, and hot water solubility of wood was irregularly changed with increased altitudes. For example, holocellulose content values of branch wood of trees at 533 m, 1251 m, 1659 m, and 2030 m altitudes were 69.49%, 60.55%, 64.80%, and 60.20%, respectively. Sandak et al. (2015) compared the chemical composition of Norway spruce (Picea abies L. Karst.) wood samples at altitudes of 135 m, 600-810 m, and 490-540 m in Poland. They reported that holocellulose, cellulose, hemicellulose, extractive, and ash content values of wood were irregularly changed with increased altitude. They also noted that lignin content was positively correlated with altitude.

Kiaei et al. (2015) determined chemical properties (cellulose, lignin, ash, and extractive) of Persian ironwood (Parrotia persica CA Meyer) obtained from northern natural forests in Iran in relation to above sea level (100, 500, and 700 m). The authors revealed that cellulose content was slightly decreased with increasing altitude. They also noted that lignin, extractive, and ash contents had positively correlated with altitude. Recently, the effect of altitude on chemical composition of Scots pine (Pinus sylvestris L.) wood from five sampling sites having different altitudes (Gerês - 815 m, Marão - 935 m, Penada - 1105 m, Vinhais - 1128 m, Serra da Estrela - 1424 m) in Portugal was investigated by Fernandes et al. (2017). They reported that samples from higher altitude sites (Serra da Estrela - 27.81% and Vinhais - 27.67%) had slightly higher lignin content than those from low altitude sites (Gerês - 27.59%, Peneda - 27.58%, Marão - 26.87%). They also noted that wood samples from higher altitude sites (Serra da Estrela – 14.99% and Vinhais – 15.41%) had the highest total extractive content, while the lowest total extractive content was found in Peneda (10.72%).

EFFECT OF ALTITUDE ON WOOD DENSITY

Wood density is central to the ecology of trees and shrubs as it reflects the allocation of carbon to the structural support, which is the basis for variation in various life-history traits (Preston et al. 2006). The wood density varies by species and is often the main wood quality assessment for industry, with higher values providing stronger woods and more pulp (Stamm and Sanders, 1966). Also, latewood ratio, earlywood ratio, cell wall thickness, annual ring width, horizontal and vertical location in the stem of wood sample, chemical composition, reaction wood occurrence, and environmental and genetic factors have a significant effect on wood density. For example, wood density generally has a close relationship with cell wall thickness. Usually, trees with the same cell wall thickness have wider diameter cells than others. Trees having small cell walls will have higher wood density due to smaller lumens (Zobel and Van Buijtenen, 1989).

The water viscosity in the soil and stem affect by immensely low temperatures. This situation is an important factor limiting the transport of water from the soil to leaves (Çepel, 1993). Wood anatomical structure changes with varying water viscosity and hence wood density changes Roderick and Berry (2001). The altitude has an important effect on wood density. Harris (1965) noted that wood density in radiata pine (Pinus radiata D. Don) in New Zealand increases by about 0.01 g/cm^3 with each 100 m increase in altitude. Several authors have studied the effect of altitude on wood density.

The effect of altitude on the wood density of coast Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco) wood growing west of the Cascade Range in Washington and Oregon of U.S.A. was determined by Lassen and Okkonen (1969). The altitude ranges were less than 900 feet (low altitude), 1000 to 1750 feet (middle altitude), and 2000 to 3000 feet (high altitude). They noted that specific gravity values of wood samples were 0.504 g/cm^3 at low altitude, 0.455 g/cm^3 at middle altitude, and 0.477 g/cm^3 at high altitude. They also stated that higher wood density at low altitude could be attributed to its lower latewood ratio and thinner cell wall thickness. Cown (1974) found that the wood density of Corsican pine (Pinus nigra Arnold) was decreased with increasing altitude.

Ladrach (1984) noted that the wood density of 30-years-old tree of patula pine (Pinus patula Schiede ex Schltdl. & Cham.) at altitude of 1800 m, 2200 m, and 3000 m was 0.48 g/cm^3, 0.47 g/cm^3, and 0.44 g/cm^3, respectively. Dodd and Power (1986) investigated the effects of altitude on the wood density of white fir (Abies concolor (Gord. & Glend.) Lindl. ex Hildebr.). The authors noted that specific gravity values in the 1280 m, 1676 m, and 2103 m were 0.31 g/cm^3, 0.33 g/cm^3, and 0.33 g/cm^3, respectively. Kiaei and Samariha (2001) compared the wood density of Eldar pine (Pinus eldarica Medw) wood from three altitudes (low, intermediate, and high) in the forestry of the Western Mazandaran province of Iran as a function of altitude index. The authors found that wood density in intermediate altitude was more than in other altitude levels. The wood density was 0.462 g/cm^{3}at low altitude level, 0.478 g/cm^{3}at intermediate altitude level, and 0.397 g/cm^3 at high altitude level.

Govorčin et al. (2003) found that the wood density of European beech (Fagus sylvatica L.) declined with increasing altitude. However, Hernández and Restrepo (1995) noted that the effect of altitude on the wood density of Andean alder (Alnus acuminata Kunth) was statistically insignificant. Barij et al. (2007) revealed that there was a positive correlation between wood density and altitude in downy oak (Quercus pubescens Willd.). Gryc et al. (2008) noted that the wood density of European beech (Fagus sylvatica L.) was negatively correlated with altitude. They found that wood density values were 0.768 g/cm^3 at 460 m and 0.736 g/cm^3 at 560 m. Hemasi et al. (2007) noted that the oven-dry density of Iranian beech was decreased with the increased height from sea level. Kiaei (2011) compared the wood density of common hornbeam (Carpinus betulus L.) at different altitudes (300 m, 750 m, and 1200 m). The author noted that wood density values at 300 m, 750 m, and 1200 m were 0.662 g/cm^3, 0.673 g/cm^3, and 0.681 g/cm^3, respectively. Martinez-Meier et al. (2011) reported that the wood density of ponderosa (Pinus ponderosa Dougl. Ex Laws.) had a positive correlation with altitude.

Sheikh et al. (2011) investigated the specific gravity of 34 tree species distributed in the Garhwal Himalayan mountains in India and determined that the wood density increases as the altitude increases. The wood density was 0.631 g/cm^3 at lower altitudes and 0.727 g/cm^3 at upper altitudes. Chung et al. (2013) determined the effect of altitude on the wood density of Taiwania cryptomerioides. They reported that wood density was 0.351 g/cm^3 at 1200 m and 0.340 g/cm^3 at 1900 m. Sulaiman (2014) aimed to determine the effect of altitude (605 m, 670 m, 775 m, 960 m, and 1070 m) on the wood density of the oriental plane (Platanus orientalis L.) in Iraq. The author noted that the wood density values at altitudes of 605 m, 670 m, 775 m, 960 m, and 1070 m were 0.57 g/cm^3, 0.54 g/cm^3, 0.57 g/cm^3, 0.58 g/cm^3, 0.59 g/cm^3, respectively.

Usta et al. (2014) noted the altitude had no effect on the wood density of black alder (Alnus glutinosa). Sulaiman (2014) evaluated the effect of altitude (400 m, 800 m, and 1200 m) on the wood density of the oriental plane (Platanus orientalis L.) in Iraq. The author noted that the wood density values at altitudes of 605 m, 670 m, 775 m, 960 m, and 1070 m were 0.57 g/cm^3, 0.54 g/cm^3, 0.57 g/cm^3, 0.58 g/cm^3, 0.59 g/cm^3, respectively. Kiaei et al. (2015) determined the wood density of Persian ironwood (Parrotia persica CA Meyer) in Iran in relation to altitude levels (100, 500, and 700 m). The authors revealed that wood density values were 0.733 g/cm^3 at 100 m, 0.796 g/cm^3 at 500 m, and 0.777 g/cm^3 at 700 m. The effect of altitude on the wood density of black spruce (Picea mariana (Mill.) BSP) wood in the coniferous boreal forest of Quebec (Canada) was determined by Rossi et al. (2015). They noted that the growth rate was reduced in the sites at higher altitudes, which led to lower stem volume at a given cambial age. However, wood density was higher in the sites at lower altitudes. Temperatures vary with altitude and latitude, with sites at higher altitudes being least warm in summer and coldest in winter.

Sandak et al. (2015) studied the relationship between altitude and wood density of Norway spruce (Picea abies (L.) Karst.) in Poland. The authors noted that wood density was 0.46 g/cm^3 at 135 m, 0.43 g/cm^3 at 490-540 m, and 0.47 g/cm^3 at 600-810 m. They also reported that wood density and latewood ratio were positively correlated. Topaloğlu et al. (2016) compared the wood density of oriental beech (Fagus orientalis L.) at different altitudes. Wood density values at altitudes of 0-200 m, 200-400 m, 400-600 m, 600-800 m, and 800-1000 m were 0.69 g/cm^3, 0.76 g/cm^3, 0.76 g/cm^3, 0.75 g/cm^3, and 0.74 g/cm^3, respectively. Moosavi et al. (2016) investigated the wood density of common hornbeam (Carpinus betulus L.) trees from three different altitudes (400, 800, and 1100 m). They reported that the wood density values of hornbeam wood were 0.35 g/cm^3 at 400 m, 0.55 g/cm^3 at 800 m, and 0.59 g/cm^3 at 1100 m. The authors also reported that the wood density differences between 800 m and 1100 m were statistically insignificant.

Kaygin et al. (2016) examined the influence of altitude difference on the wood density of Scots pine (Pinus sylvestris L.) wood in Sinop province of Turkey. Oven-dry wood density was 0.479 at g/cm^3 at 250 m, 0.634 g/cm^3 at 700 m, and 0.443 g/cm^3 at 1200 m. The effect of altitude on the wood density of Scots pine (Pinus sylvestris L.) wood from five sampling sites in Portugal was explained by Fernandes et al. (2017). They reported that trees growing at lower altitude sites had higher wood density. Kiaei and Mosavi Paloj (2018) studied the relationship between wood density and the altitude of common hornbeam in the Mazandaran province of northern Iran. The authors noted that wood density was 0.721 g/cm^3 at 400 m, 0.628 g/cm^3 at 800 m, and 0.681 g/cm^3 at 1200 m. Dias et al. (2018) determined the effect of altitude, annual mean precipitation, and the average temperature on the wood density of European black pine (Pinus nigra Arnold) wood from six Portuguese sites. The authors were reported that wood density had a positive correlation with temperature, but it had a negative correlation with altitude and precipitation.

Syofyan et al. (2019) studied the relationship between wood density and anatomical characters of Senna sumatrana, Gliricidia sepium, and Pterocarpus indicus wood in West Sumatra, Indonesia based on altitude levels. The authors found that there was an important negative correlation between altitude and wood density for Senna sumatrana, but a positive correlation for Gliricidia sepium, and Pterocarpus indicus. Kiaei et al. (2019) compared the wood density of common hornbeam (Carpinus betulus L.) wood at different altitudes in Iran. Wood density values at 300 m, 500 m, 700 m, 900 m, 1100 m, and 1300 m altitudes were 0.68 g/cm^3, 0.68 g/cm^3, 0.69 g/cm^3, 0.70 g/cm^3, 0.72 g/cm^3, and 0.72 g/cm^3, respectively. The influence of altitude (1730, 1980, and 2250 m) and slope (<30%, 30–45%, and >45%) on the wood density of Persian oak (Quercus brantii Lindl.) wood was investigated by Nazari et al. (2020). They were determined that the highest and the lowest oven-dry density values were trees growing in the intermediate altitude (1980 m) and the lowest altitude (1730 m), respectively. The authors also revealed that temperature and altitude are the most significant factors affecting wood properties.

Özden Keleş (2020) compared the influence of two different altitudes (795 m and 1350 m) on the wood density of Trojan fir (Abies nordmanniana subsp. equi-trojani [Asch. & Sint. ex Boiss] Coode & Cullen) in Turkey. The average wood density was 0.45 g cm^{-3} at 795 m and 0.53 g cm^{-3} at 1395 m. She also found that fiber wall thickness was significantly related to wood density, as wood was denser at high altitudes, showing thicker cell walls. Tashani et al. (2020) investigated the influence of altitude (248 m, 413 m, and 830 m) on the specific gravity of Aleppo pine (Pinus halepensis Mill) and Phoenician juniper (Juniperus phoenicea L.) in Libya. The authors revealed that the specific gravity of Aleppo pine wood was increased with increasing altitude. In Phoenician juniper wood, specific gravity was irregularly changed with increasing altitude. Kumaş et al. (2021) determined the effect of altitude (50 m and 250 m) on the wood density of black alder wood. Wood density values of wood were 0.513 g/cm^3 at 50 m, 0.528 g/cm^3 at 250 m. However, this difference in wood density values was statistically insignificant. Recently, Nazari et al. (2021) evaluated the influence of site conditions on the wood density of hawthorn (Crataegus azarolus L.) wood growing in Iran. The results revealed that trees growing at the 1800-2000 m altitude level had the maximum oven-dry density value (0.78 g/cm^3), and those at the >2000 m altitude level had the minimum value (0.66 g/cm^3). Average wood density values were 0.70

g/cm^3 at <1800 m altitude, 0.75 g/cm^3 at 1800-2000 m altitude, and 0.70 g/cm^3 at 1800-2000 m altitude.

CONCLUSIONS

In this study, the influences of altitude on anatomical structure, chemical composition, and wood density were reviewed. Altitude plays an important role in the wood properties of both hardwood and softwood species. In addition, there are positive and negative correlations between altitudes with different wood properties (Sulaiman, 2014). Altitude has direct or indirect effects on the soil and climate properties of a site. Change of climate and soil properties cause changes in the physiological, morphological, and anatomic properties of trees. In addition, the changes in these properties are reflected different degrees in the mechanical and physical properties of wood (Usta et al. 2014). Further research is needed to better explain the relationship between environmental factors and wood properties of various tree species (Topaloğlu et al. 2016). Knowing the relationship between environmental factors and wood properties is also important for both wood applications and forestry management (Nazari et al. 2020). While determining the usage areas of wood, the effect of altitude on chemical composition, anatomical structure, and density of wood could be taken into consideration.

REFERENCES

Akkemik, Ü., Genç, S., Yilmaz, O. Y., Selvi, E., Yilmaz, H., Sevgi, E., Sevgi, O., Akarsu, F. (2021). Effects of Growing Site Parameters on Vessel Elements of Quercus ilex through Turkey and Evaluating in Respect of Forestry. Turkish Journal of Agriculture & Forestry, 45(5): 599-616.

Barij, N., Stokes, A., Bogaard, T., Beek, R. V. (2007). Does Growing on a Slope Affect Tree Xylem Structure and Water Relations? Tree Physiology, 27(5), 757-764.

Beadle, C.L., Turnbull, C.R.A., Dean, G.H. (1996). Environmental Effects on Growth and Kraft Pulp Yield of Eucalyptus globulus and E. nitens. Appita Journal, 49, 239–242.

Bergès, L., Nepveu, G., Franc, A. (2008). Effects of Ecological Factors on Radial Growth and Wood Density Components of Sessile Oak (Quercus petraea Liebl.) in Northern France. Forest Ecology and Management, 255(3-4), 567-579.

Biricik, Y., Akkemik, U., Köse, N. (2021). Effects of Altitudes and Aspects on Wood Features of Oriental Beech in mt. Uludag (Turkey). Forestist, 71(3), 210-226.

Birtürk, T. (2011). Wood Anatomical Characteristics of Native Maple Tree (Acer L.) Taxa of Black Sea Region and the Effetcs of Different Growth Environments on These Characteristics. PhD Thesis, Black Sea Technical University, Graduate School of Natural and Applied Sciences, Department of Forest Engineering, Trabzon, Turkey.

Camarena-Tello, J. C., Rocha-Guzmán, N. E., Gallegos-Infante, J. A., González-Laredo, R. F., Pedraza-Bucio, F. E., López-Albarrán, P., Herrera-Bucio, R., Rutiaga-Quiñones, J. G. (2015). Chemical Composition of Biomass Generated in the Guava Tree Pruning. EXCLI Journal, 14, 204-212.

Carlquist, S. (1988). Comparative Wood Anatomy. London, UK: Springer-Verlag.

Casey, J. P. (1960). Pulp and Paper. Chemistry and Chemical Technology. John Wiley and Sons, New York,

Chung, J.D., Chiu, C.M., Nigh, G., Chien, C.T., Ying, C.C. (2013). Genetic Variation in wood Property and Growth of Taiwania (Taiwania cryptomerioides Hayata). Silvae Genetica, 62(1-6): 265-276.

Clark, J. (1962). Effects of Fiber Coarseness and Length, I. Bulk, Burst, Tears, Fold and Tensile Tests. Tappi Journal, 45, 628-634.

Cown, D.J. (1974). Physical Properties of Corsican Pine Grown in New Zealand. New Zealand Journal of Forestry Science, 4: 76-93.

Çepel, N. (1993). Soil-Water-Plant Relationships. Istanbul University Press. Istanbul, Turkey.

Çepel, N. (1995). Forest Ecology. Istanbul University Press. Istanbul, Turkey.

Dias, A., Gaspar, M. J., Carvalho, A., Pires, J., Lima-Brito, J., Silva, M. E., Louzada, J. L. (2018). Within-and Between-Tree Variation of Wood Density Components in Pinus nigra at Six Sites in Portugal. Annals of Forest Science, 75(2), 58.

Dodd, R.S., Power, A.B. (1986). Variation in Wood Structure of White Fir Along an Elevational Transect. Canadian Journal of Forest Research, 16(2): 303–310.

Doosthosseini, K., Parsapajouh, D. (1996). Physical Properties and Fiber Length Variations of Beech (Fagus orientalis) in Radial and Longitudinal Directions of Tree. Iranian Journal of Natural Resources, 48, 33-46.

Dönmez, İ.E. (2010). The changes in the Anatomical and Chemical Composition of Scots Pine (Pinus sylvestris L.) With Altitudes. Ph.D. Thesis, Bartin University, Graduate School of Natural and Applied Sciences, Department of Forest Industry Engineering, Bartin, Turkey.

Dönmez, İ. E., Hafızoğlu, H., Kılıç, A. (2013). Effect of Altitude on the Main Chemical Composition of Scots Pine (Pinus sylvestris L.). In International Caucasian Forestry Symposium, 866-869 pp.

Erşen Bak, F., Merev, N. (2016). Ecological Wood Anatomy of Fraxinus L. in Turkey (Oleaceae): Intraspecific and Interspecific Variation. Turkish Journal of Botany, 40(4), 356-372.

Fernandes, C., Gaspar, M. J., Pires, J., Alves, A., Simões, R., Rodrigues, J. C., Silva, M. E., Carvalho, A., Brito, J. E., Lousada, J. L. (2017). Physical, Chemical and Mechanical Properties of Pinus sylvestris Wood at Five Sites in Portugal. iForest, 10: 669-679.

Genç, R. (2010). Ecological Wood Anatomy of Some Woody Angiospermae Taxa in Camili. M.Sc. Thesis, Black Sea Technical University, Graduate School of Natural and Applied Sciences, Department of Forest Engineering, Trabzon, Turkey.

Gindl, W., Grabner, M., Wimmer, R. (2001). Effects of Altitude on Tracheid Differentiation and Lignification of Norway spruce. Canadian Journal of Botany, 79(7), 815-821.

Govorčin, S., Sinković, T., Trajković, J. (2003). Some Physical and Mechanical Properties of Beech Wood Grown in Croatia. Wood Research, 48, 39-52.

Gryc, V., Vavrčík, H., Gomola, Š. (2008). Selected Properties of European Beech (Fagus sylvatica L.). Journal of Forest Science, 54(9), 418-425.

Gürboy, B. (2007). Fiber Morphology of Calabrian Pine (Pinus brutia Ten.) Naturally Grown in North Cyprus. Süleyman Demirel University, Journal of Forest Faculty, A(2): 119-127.

Harris, J. M. (1965). Survey of the Wood Density, Tracheid Length and Latewood Characteristics of Radiata Pine Grown in New Zealand. New Zealand Forest Service Technical Report 47, 31 pp.

Hemasi, A., Soodmand, R., Varshouei, A., Bazyar, B. (2007). Study of Height Effect on Oven-Dry Specific Gravity and Biometrical Ratios in Iranian Beech Tree Wood from Siahkal Forest. Journal of Agricultural Sciences, 12(4): 913-923.

Hernández, R. E., Restrepo, G. (1995). Natural Variation in Wood Properties of Alnus acuminata HBK Grown in Colombia. Wood and Fiber Science, 27(1), 41-48.

Hosseini, S. Z. (2006). The Effect of Altitude on Juvenile Wood Formation and Fiber Length, a Case Study in Iranian Beech Wood (Fagus orientalis). Journal of Agricultural Science and Technology, 8: 221-231.

Kaygin, B., Esnaf, S., Aydemir, D. (2016). The Effect of Altitude Difference on Physical and Mechanical Properties of Scots Pine Wood Grown in Turkey-Sinop Province. Drvna Industrija, 67(4), 393-397.

Kiaei, M. (2011). Basic Density and Fiber Biometry Properties of Hornbeam Wood in Three Different Altitudes at Age 12. Middle East Journal of Scientific Research, 8(3), 663-668.

Kiaei, M., Samariha, A. (2011). Relationship Between Altitude Index and Wood Properties of Pinus eldarica Medw. Gazi University Journal of Science, 24(4): 911-918.

Kiaei, M., Kord, B., Chehalmardian, A., Moya, R., Farsi, M. (2015). Mineral Content in Relation to Radial Position, Altitude, Chemical Properties and Density of Persian Ironwood. Maderas. Ciencia y Tecnología, 17(3), 657-672.

Kiaei, M., Mosavi Paloj, R. (2018). Surface Roughness in Relation to Altitude of Hornbeam Wood. Madera y Bosques, 24(1): e241964.

Kiaei, M., Moosavi, V., Ebadi, S. E. (2019). Effects of Altitude on Density and Biometric Properties of Hornbeam Wood (Carpinus betulus). Forest Systems, 28(2), e011.

Körner, C. (2003). Alpine Plant Life. 2nd edition. Springer-Verlag, Berlin.

Kumaş, İ., Aras, U., Kalaycioğlu, H., Serdar, B., Yel, H. (2021). Effect of Growing Altitude, Particle Drying Temperature and Press Temperature on Some Technological Properties of Particleboard Produced from Black Alder Wood. Drewno, 64(207): 59-71.

Ladrach, W. E. (1984). Wood Quality of Pinus patula. Investigacion Forestal, Carton de Colombia Cali, Colombia, Research Report, 92, 17 pp.

Lassen, L. E., Okkonen, E. A. (1969). Effect of Rainfall and Elevation on Specific Gravity of Coast Douglas-fir. Wood and Fiber Science, 1(3), 227-235.

Liu, J., Noshiro, S. (2003). Lack of Latitudinal Trends in Wood Anatomy of Dodonaea viscosa (Sapindaceae), a Species with a Worldwide Distribution. American Journal of Botany, 90(4), 532-539.

Liu, Z.H., Wang, S.Y., Lin J.G., Yu Y. (2011). Difference in Fiber Morphology and Chemical Composition of Phyllostachys heterocycla cv. pubescens from Plantations of Different Altitudes. Journal of Northwest Forestry University, 26(2): 196-199.

Malkocoglu, S., Yilmaz, M. (2018). Effects of Local Ecological Conditions on Some Anatomical Features of Black Alder (Alnus glutinosa Gaertn. subsp. barbata (CA Mey.) Yalt.) Wood. International Journal of Scientific and Technological Research, 4(10): 96-110.

Martinez-Meier, A., Gallo, L., Pastorino, M., Mondino, V., Rozenberg, P. (2011). Phenotypic Variation of Basic Wood Density in Pinus ponderosa Plus Trees. Bosque, 32(3), 221-226.

Merev, N., Yavuz, H. (2000). Ecological Wood Anatomy of Turkish Rhododendron L.(Ericaceae). Intraspecific Variation. Turkish Journal of Botany, 24(4), 227-238.

Moosavi, V., Khademi Eslam, H., Bazyar, B., Najafi, A., Talaeepoor, M. (2016). Bending Creep Behavior of Hornbeam Wood. Drvna Industrija, 67(4), 341-350.

Moya, R., Tomazello Fo, M. (2008). Variation in the Wood Anatomical Structure of Gmelina arborea (Verbenaceae) Trees at Different Ecological Conditions in Costa Rica. Revista de Biología Tropical, 56(2), 689-704.

Nazari, N., Bahmani, M., Kahyani, S., Humar, M., Koch, G. (2020). Geographic Variations of the Wood Density and Fiber Dimensions of the Persian Oak Wood. Forests, 11(9), 1003.

Nazari, N., Bahmani, M., Kahyani, S., Humar, M. (2021). Effect of Site Conditions on the Properties of Hawthorn (Crataegus azarolus L.) Wood. Journal of Forest Science, 67(3), 113-124.

Noshiro, S., Joshi, L., & Suzuki, M. (1994). Ecological Wood Anatomy of Alnus nepalensis (Betulaceae) in East Nepal. Journal of Plant Research, 107(4), 399-408.

Noshiro, S., Suzuki M., Ohba, H. (1995). Ecological Wood Anatomy of Nepalese Rhododendron (Ericaceae). 1. Interspecific Variation. Journal of Plant Research, 108:1-9.

Noshiro, S, Ikeda, H., Joshi, L. (2010). Distinct Altitudinal Trends in the Wood Structure of Rhododendron arboreum (Ericaceae) in Nepal. IAWA Journal, 31(4):443-456.

Nylinder, P., Hägglund, E. (1954). The Influence of Stand and Tree Properties on the Yield and Quality of Sulphite Pulp of Swedish Spruce (Picea excelsa). Stockholm. Report 44 (11), 184 pp.

Özden Keleş, S. (2020). The Effect of Altitude on the Growth and Development of Trojan fir (Abies nordmanniana subsp. equi-trojani [Asch. & Sint. ex Boiss] Coode & Cullen) Saplings. Cerne, 26, 381-392.

Pande, P. K., Chauhan, L., Singh, M. (2005). Wood Anatomical Variations within the Genus Castanopsis. Journal of Tropical Forest Science, 17(3), 366-371.

Panshin, A. J., de Zeeuw, C. (1980). Textbook of Wood Technology. Structure, Identification, Properties, and Uses of the Commercial Woods of the United States and Canada. 4th ed. McGraw-Hill Series in Forest Resources. New York, McGraw-Hill Book Co.

Pathak, M. L., Shrestha, B. B., Joshi, L., Jha, P. K. (2011). Variation in Length of Vessel Element and Fibre of Two Species of Rhododendron Along the Altitudinal Gradient in Eastern Nepal. Bulletin of the Department of Plant Resources, 33, 47-55.

Pourtahmasi, K., Lotfiomran, N., Brauning, A., Parsapajouh, D. (2011). Tree-Ring Width and Vessel Characteristics of Oriental Beech (Fagus orientalis L.) Along an Altitudinal Gradient in the Caspian Forests, Northern Iran, IAWA Journal, 32(4): 461-473.

Preston, K. A., Cornwell, W. K., DeNoyer, J. L. (2006). Wood Density and Vessel Traits as Distinct Correlates of Ecological Strategy in 51 California Coast Range Angiosperms. New Phytologist, 170(4), 807-818.

Roderick, M. L., Berry, S. L. (2001). Linking Wood Density with Tree Growth and Environment: A Theoretical Analysis Based on the Motion of Water. New Phytologist, 149(3), 473-485.

Rossi, S., Cairo, E., Krause, C., Deslauriers, A. (2015). Growth and Basic Wood Properties of Black Spruce Along an Alti-Latitudinal Gradient in Quebec, Canada. Annals of Forest Science, 72(1), 77-87.

Saima, S., Saeed, A., Iqbal, M., Waheed, M., Fatima, K., Arshad, F. (2021). Changes in Anatomical Features Along the Altitudinal and Rainfall Gradients in Pakistan. JAPS: Journal of Animal & Plant Sciences, 31(4): 1107-1115.

Sandak, J., Sandak, A., Cantini, C., Autino, A. (2015). Differences in Wood Properties of Picea abies L. Karst. in Relation to Site of Provenance and Population Genetics. Holzforschung, 69(4), 385-397.

Sarıbaş, M., Yaman, Ö. (2009). Xylological Study on Hackberry (Celtis australis L.) Growing Naturally in Antalya-Kemer and Zonguldak Devrek. Journal of Bartin Forestry Faculty, 11(15), 1-15.

Seo, J.W., Eom, C.D., Park, S.Y. (2014). Study on the Variations of Inter-Annual Tracheid Length for Korean Red Pine from Sokwang-ri in Uljin. Journal of the Korean Wood Science and Technology, 42(6): 646-652.

Serdar, B., Gerçek, Z. (2007). Variations of Wood Anatomical Features of Poplar (Populus L.) Depending on Non-Anatomical Factors. Düzce University Forest Faculty Journal of Forestry, 3(1), 76-89.

Sheikh, M. A., Kumar, M., Bhat, J. A. (2011). Wood Specific Gravity of Some Tree Species in the Garhwal Himalayas, India. Forestry Studies in China, 13(3), 225-230.

Soosai Raj, J., Mayavel, A., Mutharaian, V. N., Nicodemus, A. (2017). Variations on Pulping Properties of Gmelina arborea Roxb. grown in Different Geographical Regions of Tamil Nadu, India. In Wood is Good (pp. 189-197). Springer, Singapore.

Stamm, A. J. Sanders, H. T. (1966) Specific Gravity of the Wood Substance of Loblolly Pine as affected by Chemical Composition. Tappi, 49, 397–400.

Sulaiman, H. H. (2014). Effect of Altitude on Wood Morphology Characters of (Platanus orientalis L.) in Duhok Provenance. Journal of University of Duhok, 17(1): 90-102.

Syofyan, L., Maideliza, T. Syamsuardi, Mansyurdin (2019). Variation of Wood Density and Anatomical Characters from Altitude Differences: Case Study of Selected Fabaceae Trees in West Sumatra Secondary Forest, Indonesia. In: International Conference on Basic Sciences and Its Applications, KnE Engineering, pages 190-203.

Şanlı, İ. (1977). Doğu kayını (Fagus orientalis Lipsky.) nin Türkiye'de çeşitli yörelerde oluşan odunları üzerine anatomik araştırmalar. İstanbul Üniversitesi Orman Fakültesi Dergisi, Seri A, 27(1): 207-282.

Tashani, A., El-Settawy, A. A., Mohareb, A. (2020). Effect of Environmental Conditions on Wood Properties of Some Tree Species Growing in El-Jabal El-Akhdar region, Libya. Al-Bayan Scientific Journal, 6: 205-215.

Topaloğlu, E., Ay, N., Altun, L., Serdar, B. (2016). Effect of Altitude and Aspect on Various Wood Properties of Oriental Beech (Fagus orientalis Lipsky) wood. Turkish Journal of Agriculture and Forestry, 40(3): 397-406.

Usta, A., Yılmaz, M., Kahveci, E., Yılmaz, S., Özturk, H. (2014). Effects of Different Site Conditions on Some of the Wood Properties of Black alder (Alnus glutinosa (L.) Gaertner subsp. barbata (CA Meyer) Yalt). Fresenius Environmental Bulletin, 23(8): 1840-1851.

Van den Oever, L., Baas, P., Zandee, M. (1981). Comparative Wood Anatomy of Symplocos and latitude and altitude of provenance. IAWA Bulletin, 2, 3-24.

Vaziri, V., Hosseini, S., Dehghani, M. R. (2009). Effect of Altitude on Fiber Characteristics, Chemical Composition and Kraft Yield Pulp of Brutian Pine (Pinus brutia). Journal of Wood and Forest Science and Technology, 16(1):1-13.

Wardle, J. (1984). The New Zealand Beeches: Ecology, Utilisation and Management. New Zealand Forest Service, New Zealand.

Wodzicki, T. J. (2001). Natural Factors Affecting Wood Structure. Wood Science and Technology, 35(1-2), 5-26.

Yaman, B. (2008). Variation in Quantitative Vessel Element Features of Juglans regia Wood in the Western Black Sea Region of Turkey. Agrociencia, 42(3), 357-365.

Yaman, B., Sarıbaş, M. (2004). Vessel Size Variability of Poplar (Populus L.) Species in Relation to Altitude in Euxine Region of Turkey. Turkish Journal of Forestry, A(1), 111-123.

Yang, X., Fu, M. (2009). Geographic Variations in Wood Properties of Bambusa chungii for Pulpwood. Journal of Northeast Forestry University, 37(6), 10-15.

Yilmaz, M., Serdar, B., Altun, L., Usta, A. (2008). Relationships Between Environmental Variables and Wood Anatomy of Quercus pontica C. KOCH (Fagaceae). Fresenius Environmental Bulletin, 17: 902-910.

Zobel, B. J., Van Buijtenen, J. P. (1989). Wood Variation: Its Causes and Control, Springer-Verlag, Berlin, Heidelberg, New York.

Zoghi, Z., Azadfar, D., Khazaeian, A. (2013). Study of Altitude and Selection on Fiber Biometry Properties of Fagus orientalis Lipsky. Nusantara Bioscience, 5(1): 30-34.

Chapter 8

TREE AND SHRUB PLANTS IN THE BLACK SEA REGION OF TURKEY AND IUCN RISK CATEGORIES

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1. INTRODUCTION

Turkey is located at the intersection of the Mediterranean, Euro-Siberian and Irano-Turanian Phytogeographical Regions, which are among the main gene centers of the world (Davis et al., 1971; Davis, 1975). Therefore, Turkey is in a unique position in terms of plant genetic diversity (Karagöz et al., 2010). The number of plant taxa reached to 12,476 and 4,080 of which correspond to 32.7% of this number are endemic (Özhatay and Kültür, 2006; Özhatay et al., 2009). In other words, Turkey is the origin or diversity center of many important cultivated plants and other plant species. The floristic richness of Turkey can be better understood if it is considered that the European continental flora has 12000 ferns and seed plants and 2750 endemic species, and the continent is approximately 15 times the size of Turkey (Özhatay et al., 2009; Atik et al., 2010).

The moist forests, which spread on the north-facing slopes of the Black Sea Mountains, change towards the interior in parallel with the distance from the sea. Depending on both precipitation and temperature conditions, a continental climate character begins to manifest itself. The forest community also turns into dry forests. Dry forests gain density on the south-facing slopes of the Black Sea Mountains and on the mountains in the interior ranges (Günal, 2013).

In this study, trees, shrubs or small tree-formed plants distributed in the province were examined and some data were given for these plants, and they were examined according to IUCN (International Union for the Conservation of Nature and Natural Resources) Red List Classes.

2. MATERIALS AND METHOD

2.1. Research Area

The study was carried out in all provinces of the Black Sea Region. The Black Sea Region is one of the seven geographical regions of Turkey, named after the Black Sea, stretching from the east of the Sakarya Plain to the Georgian border. Georgia is neighbors with Eastern Anatolia, Central Anatolia Region and Marmara Regions and the sea from which it takes its name. It ranks third among the regions in Turkey in terms of size, and is the region with the largest east-west width and local time difference. There are 18 provinces in the region (Figure 1).

The Black Sea climate is rainy and temperate throughout the year on the coast. The humid air masses coming from the Black Sea leave plenty of precipitation on the northern Anatolian mountain slopes extending parallel to the coast. In the Black Sea region, which is the wettest region of Turkey, precipitation did not concentrate in one season, but spread throughout the year. Due to the high humidity and cloudiness, the annual and daily temperature differences are at least in this region. Since the mountains extend parallel to the coast, the interior parts behind the mountains could not be under the influence of the sea and the climate became continental and arid (Şenoy et al., 2008; Öztürk et al., 2017). The natural vegetation of the region consists of broad-leaved dense forests due to the high humidity and precipitation on the coasts. It contains 25% of Turkey's forests and is the region with the most forests in Turkey.

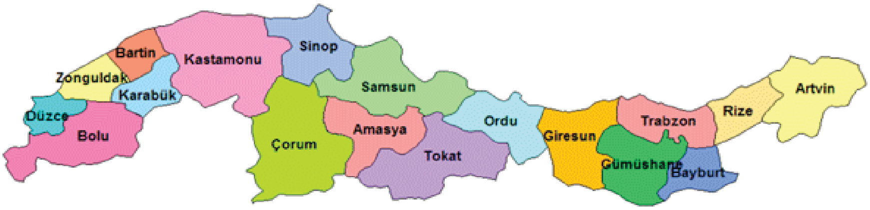


Figure 1. Black Sea Region provinces where the study was conducted

2.2. IUCN (Internatıonal Union for Conservation of Nature & Natural Resources) Risk Categories

The risk categories determined by IUCN are given in Figure 2.

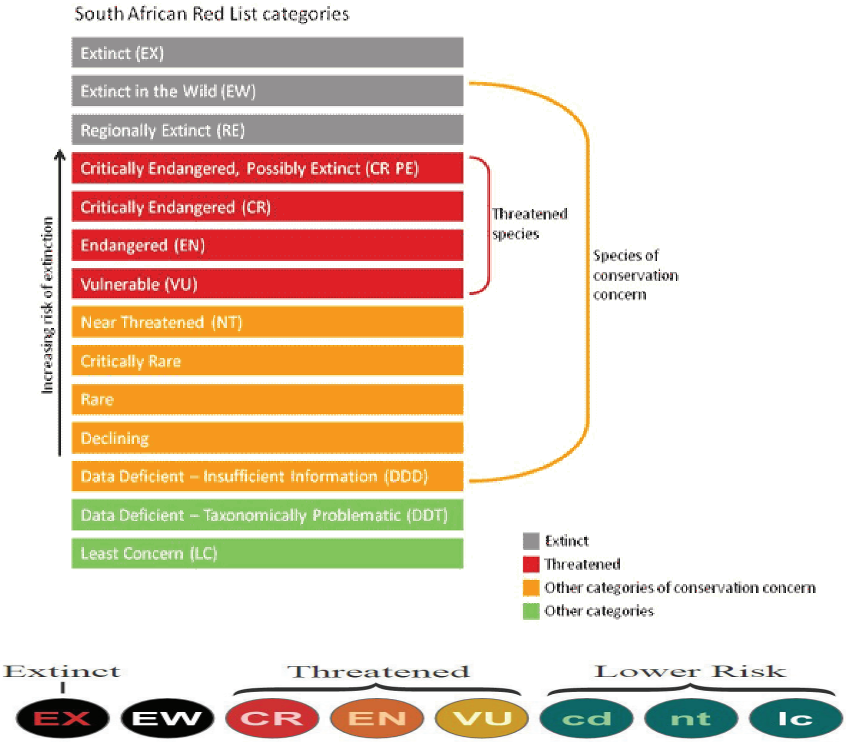


Figure 2. IUCN Risk Categories (Allen et al., 2014; IUCN, 2020).

The main material of this study consisted of shrub or tree plants that spread and grow in the provinces of the Black Sea Region. In this context, studies were carried out on all plants that spread and grow in the provinces of the Black Sea Region. Plants in the study were grouped according to their forms, families, whether they are endemic or not, and IUCN risk classes. In this context, TÜBİVES database and International Union for Conservation of Nature and Natural Resources (IUCN) records were examined.

3. RESULTS AND DISCUSSION

3.1. Plants in Black Sea Region

Number of plants as endemic, shrub or tree shaped at the provincial level of the Black Sea Region were analysed and given in Table 1 according to the TUBIVES (Turkish Plant Data Service, data provided by Babac, 2004; Bakis et al., 2011). A total of 415 species were grouped as shrub or tree shaped in the region.

Table 1. Number of plants as endemic, shrub or tree shaped at the provincial level of the Black Sea Region

Province	Number of Family/Plant	Number of endemics	Shrubs	Tree	Shrub or small tree
Artvin	36/143	6	87	35	20
Rize	28/69	5	38	13	13
Trabzon	39/117	3	62	37	18
Gümüşhane	25/87	0	63	13	11
Bayburt	14/35	2	27	2	6
Giresun	24/38	0	22	12	4
Ordu	18/30	0	15	11	3
Tokat	19/41	5	24	10	7
Samsun	36/80	3	44	25	11
Amasya	26/85	13	49	20	16
Sinop	32/81	3	38	31	12
Çorum	14/24	4	19	4	1
Kastamonu	34/123	16	65	35	23
Karabük	23/49	6	25	11	12
Bolu	27/84	9	40	28	16
Zonguldak	28/52	1	22	16	14
Bartın	3/4	0	4	0	0
Düzce	16/29	0	17	10	2

3.2. Common plants in Artvin

Artvin ranks first in the Black Sea Region in terms of the number of shrub or tree shaped species with 36 families and 143 species (Babac, 2004; Bakis et al., 2011). For this reason, Artvin was determined as a reference province and compared with other provinces. According to this comparison, in terms of the number of common plants, Trabzon is in the first place, Kastamonu is in the second and Sinop is in the third place.

Plant numbers of Black Sea Region common with Artvin province (36 families/143 plants) were shown in Table 2. We determined that Artvin has many common plants with each province (Table 2).

Table 2. Plant numbers of Black Sea Region common with Artvin province (36 familyes/143 plants)

Province	Numbers of family/plant	Number of common plants with Artvin	Province	Numbers of family/plant	Number of common plants with Artvin
Rize	28/69	27	Sinop	32/81	32
Trabzon	39/117	65	Çorum	14/24	8
Gümüşhane	25/87	30	Kastamonu	34/123	38
Bayburt	14/35	5	Karabük	23/49	11
Giresun	24/38	21	Bolu	27/84	28
Ordu	18/30	16	Zonguldak	28/52	16
Tokat	19/41	15	Bartın	3/4	2
Samsun	36/80	31	Düzce	16/29	11
Amasya	26/85	18			

3.3. Number of Plants Specific to Provinces

Figure 3. Number of plants specific to the provinces in the Black Sea Region

3.4. Families with the most numbers of Species in the Black Sea Region

When the families are listed in terms of the number of species in the Black Sea Region, Rosaceae (89) is the first, Fabaceae (58) is the second, and Salicaceae (24) is the third (Table 3).

Table 3. Families in terms of the number of species analysed data from TUBIVES

Family	Number of species
Rosaceae	89
Fabaceae	58
Salicaceae	24
Ericaceae	21
Fagaceae	17

3.5. Endangered Shrub and Tree Formed Plant Species in the Black Sea Region

Grouping of endemic and non-endemic plants in the Black Sea Region according to IUCN risk categories were given in Table 4. Approximately 46.6% of plants in Turkey are endangered. 27% of the plants distributed in the Black Sea region are in the IUCN risk category. 29.5% (5) of 17 endemic plant species are in the risk category (Table 4) (IUCN, 2020).

Table 4. Grouping of endemic and non-endemic plants in the Black Sea Region according to IUCN risk categories

	CR	EN	VU	NT	LC	DD	NE	Total
Endemic	3	0	2	0	0	2	10	17
Non-endemic	0	1	7	3	68	12	309	401
Total	3	1	9	3	68	14	317	415

3.6. Endemic and Non-Endemic Plants of Black Sea Region by IUCN Risk Categories (CR, EN, VU, NT)

Endemic and non-endemic plants according to Black Sea Region IUCN Risk Categories (CR, EN, VU, NT) were given in Table 5. There are 3 species in CR categories, 1 species in EN category, 9 species in VU category, 3 species in NT category and 68 species in LC category in Black Sea Region. Five of these species is endemic (Table 5).

Table 5. Endemic and non-endemic plants according to Black Sea Region IUCN Risk Categories (CR, EN, VU, NT)

Species	Family	IUCN risk category	Endemism
Astragalus acmophylloides	Fabaceae	CR	Endemic
Stachys sosnowskyi	Lamiaceae	CR	Endemic
Rhus coriaria	Anacardiaceae	VU	-
Rhodothamnus sessilifolius	Ericaceae	CR	Endemic
Rhododendron caucasium	Ericaceae	EN	-
Rhododendron ungernii	Ericaceae	VU	-
Rhododendron x rosifaciensis	Ericaceae	VU	-
Rhododendron smirnovii	Ericaceae	VU	Endemic
Osmanthus decorus	Oleaceae	VU	-
Quercus pontica	Fagaceae	VU	-
Betula browiczana	Betulaceae	VU	Endemic
Betula medwediewii	Betulaceae	NT	-
Salix caucasica	Salicaceae	VU	-
Cedrus libani var. libani	Pinaceae	VU	-
Buxus sempervirens	Buxaceae	NT	-
Quercus coccifera	Fagaceae	NT	-

3.7. Trees and Shrubs of the Black Sea Region in Low Risk (LC) Category

A total of 68 plants in the Black Sea Region are in the IUCN low risk (LC) category. This number constitutes 16.4% of the total number of shrubs and trees in the region.

Species in the Black Sea Region low risk (LC) category; Picea orientalis, Pinus pinea, Juniperus oxycedrus subsp. oxycedrus, Tamarix tetrandra, Tilia platyphyllos, Acer platanoides, Acer campestre subsp. campestre, Robinia pseudoacacia, Mespilus germanica, Cotoneaster morulus, Crataegus pontica, Sorbus aucuparia, Sorbus persica, Sorbus torminalis var. torminalis, Punica granatum, Cornus mas, Staphylea pinnata, Padus avium, Celtis australis, Salix alba, Rhamnus catharticus, Ulex europaeus, Erica arborea, Andromeda polifolia, Phillyrea latifolia, Ulmus minor subsp. minor, Populus tremula, Juniperus foetidissima, Juniperus Sabina, Juniperus excelsa subsp. excels, Juniperus excels subsp. polycarpos, Corylus maxima, Betula pendula, Alnus glutinosa subsp. barbata, Juniperus communis var. saxatilis, Corylus avellana var. pontica, Asparagus aphyllus subsp. orientalis, Oenanthe fistulosa, Ostrya carpinifolia, Diospyros lotus, Arceuthobium oxycedri, Juglans regia, Fagus orientalis, Carpinus betulus, Carpinus orientalis, Ostrya carpinifolia, Salix excels, Abies nordmanniana subsp. nordmanniana, Pinus sylvestris var. hamata, Ephedra majör, Celtis caucasica, Acer negundo, Euonymus verrucosus, Crataegus monogyna subsp. monogyna, Oenanthe silaifolia, Arbutus unedo, Salix amplexicaulis, Pistacia atlantica, Prunus spinose subsp. dasyphyll, Corylus colurna, Chamaecytisus austriacus, Taxus baccata, Sorbus torminalis var. orientalis, Pyrus amygdaliformis var. lanceolata, Pistacia terebinthus subsp. terebinthus, Quercus frainetto, Salix cinerea, Abies nordmanniana subsp. bornmuelleriana.

3.8. IUCN Risk Categories of Artvin's Plants

Endemic and non-endemic plant numbers of Artvin according to IUCN risk categories were given in Table 6. IUCN risk (CR, EN, VU, NT, LC) categories of plant species in Artvin were given in Table 7. There are one species in CR categories, one species in EN category, 9 species in VU category, two species in NT category and 24 species in LC category in Artvin province. Six of these species are endemic (Table 6, Table 7).

Table 6. Endemic and non-endemic plant numbers of Artvin according to IUCN risk categories

	CR	EN	VU	NT	LC	DD	NE	Total
Endemic	1	1	2	0	0	2	0	6
Non-endemic	0	0	7	2	24	6	98	137
Total	1	1	9	2	24	8	98	143

Table 7. IUCN risk (CR, EN, VU, NT, LC) categories of plant species in Artvin

Species	Family	IUCN risk category	Endemism	Turkish name
Astragalus acmophylloides	Fabaceae	CR	Endemic	Bayır geveni
Rhus coriaria	Anacardiaceae	VU	-	Derici sumağı
Rhodothamnus sessilifolius	Ericaceae	EN	Endemic	Dağgülü

Rhododendron ungernii	Ericaceae	VU	-	Beyaz çiçekli ormangülü
Rhododendron x rosifaciensis	Ericaceae	VU	-	-
Rhododendron smirnovii	Ericaceae	VU	Endemic	Kumar
Epigaea gaultherioides	Ericaceae	VU	-	Dağ elması
Osmanthus decorus	Oleaceae	VU	-	-
Quercus pontica	Fagaceae	VU	-	Doğu Karadeniz meşesi
Betula browiczana	Betulaceae	VU	Endemic	Rize huşu
Salix caucasica	Salicaceae	VU	-	Yayla söğüdü
Betula medwediewii	Betulaceae	NT	-	Kızılağaç yapraklı huş
Buxus sempervirens	Buxaceae	NT	-	Şimşir
Picea orientalis	Pinaceae	LC	-	Doğu ladini
Pinus pinea	Pinaceae	LC	-	Fıstık çamı
Tamarix tetrandra	Tamaricaeae	LC	-	Ilgın
Acer platanoides	Aceraceae	LC	-	Çınar yapraklı akçaağaç
Acer campestre subsp. campestre	Aceraceae	LC	-	Ova akçaağacı
Robinia pseudoacacia	Fabaceae	LC	-	Beyaz çiçekli yalancı akasya
Mespilus germanica	Rosaceae	LC	-	Muşmula
Cotoneaster morulus	Rosaceae	LC	-	Dut muşmulası
Crataegus pontica	Rosaceae	LC	-	Alıç
Sorbus aucuparia	Rosaceae	LC	-	Kuş üvezi
Sorbus torminalis var. torminalis	Rosaceae	LC	-	Akçaağaç yapraklı üvez
Punica granatum	Rosaceae	LC	-	Nar
Diospyros lotus	Ebenaceae	LC	-	Kara hurma
Arceuthobium oxycedri	Loranthaceae	LC	-	Ardıç ökse otu
Juglans regia	Juglandaceae	LC	-	Adi ceviz
Fagus orientalis	Fagaceae	LC	-	Doğu kayını
Carpinus betulus	Corylaceae	LC	-	Adi gürgen
Carpinus orientalis	Corylaceae	LC	-	Doğu gürgeni
Ostrya carpinifolia	Corylaceae	LC	-	Gürgen yapraklı kayacık
Corylus avellana var. pontica	Corylaceae	LC	-	Çubuk fındığı
Corylus maxima	Corylaceae	LC	-	Lambert fındığı
Betula pendula	Betulaceae	LC	-	Adi huş
Alnus glutinosa subsp. barbata	Betulaceae	LC	-	Adi kızılağaç
Cornus mas	Cornaceae	LC	-	Kızılcık

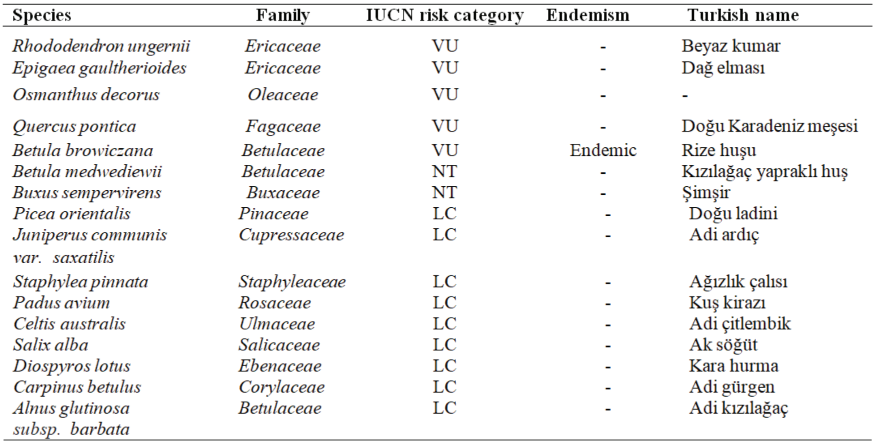
3.9. IUCN Risk Categories of Rize's Plants

Endemic and non-endemic plant numbers of Rize according to IUCN risk categories were given in Table 8. IUCN risk (CR, EN, VU, NT, LC) categories of plant species in Rize were given in Table 9. There are 5 species in VU category, 2 species in NT category and 9 species in LC category in Rize province. One of these species is endemic (Table 8, Table 9).

Table 8. Endemic and non-endemic plant numbers of Rize according to IUCN risk categories

	CR	EN	VU	NT	LC	DD	NE	Total
Endemic	0	0	1	0	0	0	0	1
Non-endemic	0	0	4	2	9	1	52	68
Total	0	0	5	2	9	1	52	69

Table 9. IUCN risk (CR, EN, VU, NT, LC) categories of plant species in Rize



Species	**Family**	**IUCN risk category**	**Endemism**	**Turkish name**
Rhododendron ungernii	*Ericaceae*	VU	-	Beyaz kumar
Epigaea gaultherioides	*Ericaceae*	VU	-	Dağ elması
Osmanthus decorus	*Oleaceae*	VU	-	-
Quercus pontica	*Fagaceae*	VU	-	Doğu Karadeniz meşesi
Betula browiczana	*Betulaceae*	VU	Endemic	Rize huşu
Betula medwediewii	*Betulaceae*	NT	-	Kızılağaç yapraklı huş
Buxus sempervirens	*Buxaceae*	NT	-	Şimşir
Picea orientalis	*Pinaceae*	LC	-	Doğu ladini
Juniperus communis var. saxatilis	*Cupressaceae*	LC	-	Adi ardıç
Staphylea pinnata	*Staphyleaceae*	LC	-	Ağızlık çalısı
Padus avium	*Rosaceae*	LC	-	Kuş kirazı
Celtis australis	*Ulmaceae*	LC	-	Adi çitlembik
Salix alba	*Salicaceae*	LC	-	Ak söğüt
Diospyros lotus	*Ebenaceae*	LC	-	Kara hurma
Carpinus betulus	*Corylaceae*	LC	-	Adi gürgen
Alnus glutinosa subsp. barbata	*Betulaceae*	LC	-	Adi kızılağaç

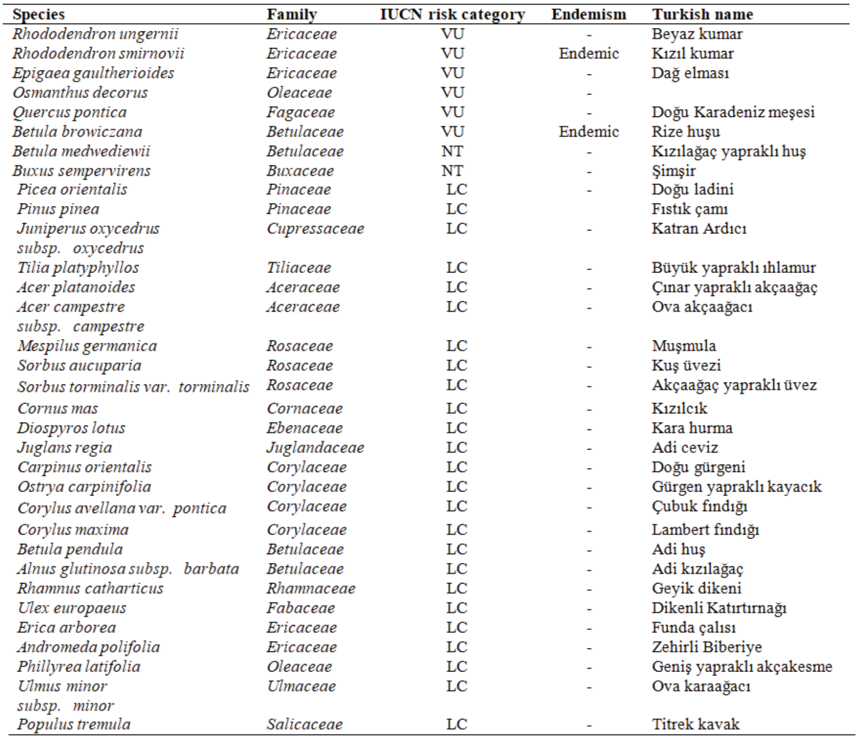
3.10. IUCN Risk Categories of Trabzon's Plants

Endemic and non-endemic plant numbers of Trabzon according to IUCN risk categories were given in Table 10. IUCN risk (CR, EN, VU, NT, LC) categories of plant species in Trabzon were given Table 11. There are 6 species in VU category, 2 of them are endemic, 2 species in NT category and 25 species in LC category in Trabzon province (Table 10, Table 11).

Table 10. Endemic and non-endemic plant numbers of Trabzon according to IUCN risk categories

	CR	EN	VU	NT	LC	DD	NE	Total
Endemic	0	0	2	0	0	0	0	2
Non-endemic	0	0	4	2	25	4	80	115
Total	0	0	6	2	25	4	80	117

Table 11. IUCN risk (CR, EN, VU, NT, LC) categories of plant species in Trabzon



Species	Family	IUCN risk category	Endemism	Turkish name
Rhododendron ungernii	*Ericaceae*	VU	-	Beyaz kumar
Rhododendron smirnovii	*Ericaceae*	VU	Endemic	Kızıl kumar
Epigaea gaultherioides	*Ericaceae*	VU	-	Dağ elması
Osmanthus decorus	*Oleaceae*	VU	-	
Quercus pontica	*Fagaceae*	VU	-	Doğu Karadeniz meşesi
Betula browiczana	*Betulaceae*	VU	Endemic	Rize huşu
Betula medwediewii	*Betulaceae*	NT	-	Kızılağaç yapraklı huş
Buxus sempervirens	*Buxaceae*	NT	-	Şimşir
Picea orientalis	*Pinaceae*	LC	-	Doğu ladini
Pinus pinea	*Pinaceae*	LC		Fıstık çamı
Juniperus oxycedrus subsp. oxycedrus	*Cupressaceae*	LC	-	Katran Ardıcı
Tilia platyphyllos	*Tiliaceae*	LC	-	Büyük yapraklı ıhlamur
Acer platanoides	*Aceraceae*	LC	-	Çınar yapraklı akçaağaç
Acer campestre subsp. campestre	*Aceraceae*	LC	-	Ova akçaağacı
Mespilus germanica	*Rosaceae*	LC	-	Muşmula
Sorbus aucuparia	*Rosaceae*	LC	-	Kuş üvezi
Sorbus torminalis var. torminalis	*Rosaceae*	LC	-	Akçaağaç yapraklı üvez
Cornus mas	*Cornaceae*	LC	-	Kızılcık
Diospyros lotus	*Ebenaceae*	LC	-	Kara hurma
Juglans regia	*Juglandaceae*	LC	-	Adi ceviz
Carpinus orientalis	*Corylaceae*	LC	-	Doğu gürgeni
Ostrya carpinifolia	*Corylaceae*	LC	-	Gürgen yapraklı kayacık
Corylus avellana var. pontica	*Corylaceae*	LC	-	Çubuk fındığı
Corylus maxima	*Corylaceae*	LC	-	Lambert fındığı
Betula pendula	*Betulaceae*	LC	-	Adi huş
Alnus glutinosa subsp. barbata	*Betulaceae*	LC	-	Adi kızılağaç
Rhamnus catharticus	*Rhamnaceae*	LC	-	Geyik dikeni
Ulex europaeus	*Fabaceae*	LC	-	Dikenli Katırtırnağı
Erica arborea	*Ericaceae*	LC	-	Funda çalısı
Andromeda polifolia	*Ericaceae*	LC	-	Zehirli Biberiye
Phillyrea latifolia	*Oleaceae*	LC	-	Geniş yapraklı akçakesme
Ulmus minor subsp. minor	*Ulmaceae*	LC	-	Ova karaağacı
Populus tremula	*Salicaceae*	LC	-	Titrek kavak

3.11. IUCN Risk Categories of Gümüşhane's Plants

Endemic and non-endemic plant numbers of Gümüşhane according to IUCN risk categories were given in Table 12. IUCN risk (CR, EN, VU, NT, LC) categories of plant species in Gümüşhane were given in Table 13. There are one species in VU category and 8 species in LC category in Gümüşhane province (Table 12, Table 13).

Table 12. Endemic and non-endemic plant numbers of Gümüşhane according to IUCN risk categories

	CR	EN	VU	NT	LC	DD	NE	Total
Endemic	0	0	0	0	0	0	0	0
Non-endemic	0	0	1	0	8	0	78	87
Total	0	0	1	0	8	0	78	87

Table 13. IUCN risk (CR, EN, VU, NT, LC) categories of plant species in Gümüşhane

Species	Family	IUCN risk category	Endemism	Turkish name
Rhus coriaria	Anacardiaceae	VU	-	Derici sumağı
Carpinus betulus	Ericaceae	LC	-	Funda çalısı

Alnus glutinosa subsp. barbata	Ericaceae	LC	-	Adi kızılağaç
Juniperus foetidissima	Cupressaceae	LC	-	Kokulu ardıç
Juniperus sabina	Cupressaceae	LC	-	Sürüngen ardıç
Juniperus excelsa subsp. excelsa	Cupressaceae	LC	-	Boz ardıç
Juniperus excelsa subsp. polycarpos	Cupressaceae	LC	-	Daltaban ardıç
Elaeagnus angustifolia	Elaeagnaceae	LC	-	Kuş iğdesi
Salix excelsa	Salicaceae	LC	-	Boylu söğüt

3.12. IUCN Risk Categories of Bayburt's Plants

Endemic and non-endemic plant numbers of Bayburt according to IUCN risk categories were given in Table 14. In Bayburt, none of the 35 plant species are in the IUCN risk category (Table 14).

Table 14. Endemic and non-endemic plant numbers of Bayburt according to IUCN risk categories

	CR	EN	VU	NT	LC	DD	NE	Total
Endemic	0	0	0	0	0	0	2	2
Non-endemic	0	0	0	0	0	0	33	33
Total	0	0	0	0	0	0	35	35

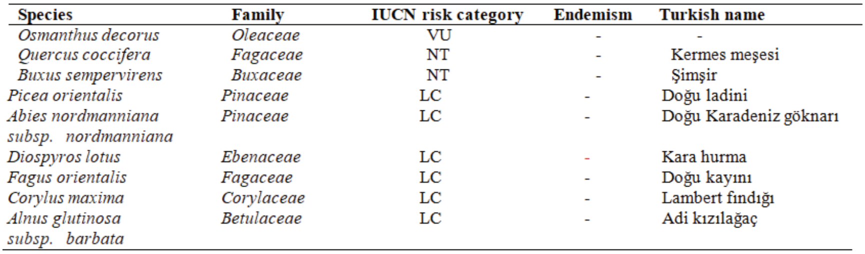
3.13. IUCN Risk Categories of Giresun's Plants

Endemic and non-endemic plant numbers of Giresun according to IUCN risk categories were given in Table 15. IUCN risk (CR, EN, VU, NT, LC) categories of plant species in Giresun were given in Table 16. In Giresun, there are one species in VU category, 6 species in LC and 2 species in NT category (Table 15, Table 16).

Table 15. Endemic and non-endemic plant numbers of Giresun according to IUCN risk categories

	CR	EN	VU	NT	LC	DD	NE	Total
Endemic	0	0	0	0	0	0	0	0
Non-endemic	0	0	1	2	6	0	29	38
Total	0	0	1	2	6	0	29	38

Table 16. IUCN risk (CR, EN, VU, NT, LC) categories of plant species in Giresun



Species	**Family**	**IUCN risk category**	**Endemism**	**Turkish name**
Osmanthus decorus	*Oleaceae*	VU	-	-
Quercus coccifera	*Fagaceae*	NT	-	Kermes meşesi
Buxus sempervirens	*Buxaceae*	NT	-	Şimşir
Picea orientalis	*Pinaceae*	LC	-	Doğu ladini
Abies nordmanniana subsp. nordmanniana	*Pinaceae*	LC	-	Doğu Karadeniz göknarı
Diospyros lotus	*Ebenaceae*	LC	-	Kara hurma
Fagus orientalis	*Fagaceae*	LC	-	Doğu kayını
Corylus maxima	*Corylaceae*	LC	-	Lambert fındığı
Alnus glutinosa subsp. barbata	*Betulaceae*	LC	-	Adi kızılağaç

3.14. IUCN Risk Categories of Ordu's Plants

Endemic and non-endemic plant numbers of Ordu according to IUCN risk categories were given in Table 17. IUCN risk (CR, EN, VU, NT, LC) categories of plant species in Ordu were given in Table 18. There are no species in CR, EN and VU categories in Ordu province. One species is in NT category and 2 species are in LC category in Ordu province (Table 17, Table 18).

Table 17. Endemic and non-endemic plant numbers of Ordu according to IUCN risk categories

	CR	EN	VU	NT	LC	DD	NE	Total
Endemic	0	0	0	0	0	0	0	0
Non-endemic	0	0	0	1	2	0	27	30
Total	0	0	0	1	2	0	27	30

Table 18. IUCN risk (CR, EN, VU, NT, LC) categories of plant species in Ordu

Species	Family	IUCN risk category	Endemism	Turkish name
Buxus sempervirens	Buxaceae	NT	-	Şimşir
Picea orientalis	Pinaceae	LC	-	Doğu ladini
Alnus glutinosa subsp. barbata	Betulaceae	LC	-	Adi kızılağaç

3.15. IUCN Risk Categories of Tokat's Plants

Endemic and non-endemic plant numbers of Tokat according to IUCN risk categories were given in Table 19. IUCN risk (CR, EN, VU, NT, LC) categories of plant species in Tokat were given in Table 20. There is one species in VU category and 8 species are in LC category in Tokat province (Table 19, Table 20).

Table 19. Endemic and non-endemic plant numbers of Tokat according to IUCN risk categories

	CR	EN	VU	NT	LC	DD	NE	Total
Endemic	0	0	0	0	0	0	1	1
Non-endemic	0	0	1	0	8	1	30	40
Total	0	0	1	0	8	1	31	41

Table 20. IUCN risk (CR, EN, VU, NT, LC) categories of plant species in Tokat

Species	Family	IUCN risk category	Endemism	Turkish name
Cedrus libani var. libani	Pinaceae	VU	-	Lübnan sediri
Pinus sylvestris var. hamata	Pinaceae	LC	-	Sarı çam
Ephedra major	Ephedraceae	LC	-	Deniz üzümü
Celtis caucasica	Ulmaceae	LC	-	Kafkas çitlenbiği
Sorbus torminalis var. torminalis	Rosaceae	LC		Akçaağaç yapraklı üvez
Juglans regia	Juglandaceae	LC	-	Ceviz
Fagus orientalis	Fagaceae	LC	-	Doğu kayını
Carpinus orientalis	Betulaceae	LC	-	Doğu gürgeni
Ostrya carpinifolia	Betulaceae	LC	-	Gürgen yapraklı kayacık

3.16. IUCN Risk Categories of Samsun's Plants

Endemic and non-endemic plant numbers of Samsun according to IUCN risk categories were given in Table 21. IUCN risk (CR, EN, VU, NT, LC) categories of plant species in Samsun were given in Table 22. There is one species in CR category and one species endemic, 17 species are in LC category in Samsun province (Table 21, Table 22).

Table 21. Endemic and non-endemic plant numbers of Samsun according to IUCN risk categories

	CR	EN	VU	NT	LC	DD	NE	Total
Endemic	1	0	0	0	0	0	0	1
Non-endemic	0	0	0	0	17	2	60	79
Total	1	0	0	0	17	2	60	80

Table 22. IUCN risk (CR, EN, VU, NT, LC) categories of plant species in Samsun

Species	Family	IUCN risk category	Endemism	Turkish name
Stachys sosnowskyi	Lamiaceae	CR	Endemic	Otlu deliçayı
Oenanthe silaifolia	Apiaceae	LC	-	At tohumu
Juniperus oxycedrus subsp. oxycedrus	Cupressaceae	LC	-	Diken ardıç
Acer campestre subsp. campestre	Aceraceae	LC	-	Ova akçaağacı
Acer negundo	Aceraceae	LC	-	Dişbudak yapraklı akçaağaç
Mespilus germanica	Rosaceae	LC	-	Muşmula, töngel
Punica granatum	Punicaceae	LC	-	Nar
Diospyros lotus	Ebenaceae	LC	-	Kara Hurma
Carpinus betulus	Betulaceae	LC	-	Gürgen ağacı
Euonymus verrucosus	Celastraceae	LC	-	Benli iğcik
Crataegus monogyna subsp. monogyna	Rosaceae	LC	-	Adi alıç

Staphylea pinnata	Staphyleaceae	LC	-	Ağızlık çalısı
Celtis australis	Ulmaceae	LC	-	Adi çitlembik
Celtis caucasica	Ulmaceae	LC	-	Kafkas çitlenbiği
Salix alba	Salicaceae	LC	-	Ak söğüt
Salix amplexicaulis	Salicaceae	LC	-	Çifte Söğüt
Rhamnus catharticus	Rhamnaceae	LC		Adi Cehri
Arbutus unedo	Ericaceae	LC	-	Kocayemiş

3.17. IUCN Risk Categories of Amasya's Plants

Endemic and non-endemic plant numbers of Amasya according to IUCN risk categories were given in Table 23. IUCN risk (CR, EN, VU, NT, LC) categories of plant species in Amasya were given in Table 24. There is one species in VU category and 7 species are in LC category in Amasya province (Table 23, Table 24).

Table 23. Endemic and non-endemic plant numbers of Amasya according to IUCN risk categories

	CR	EN	VU	NT	LC	DD	NE	Total
Endemic	0	0	0	0	0	0	0	0
Non-endemic	0	0	1	0	7	1	76	85
Total	0	0	1	0	7	1	76	85

Table 24. IUCN risk (CR, EN, VU, NT, LC) categories of plant species in Amasya

Species	Family	IUCN risk category	Endemism	Turkish name
Rhus coriaria	Anacardiaceae	VU	-	Derici Sumağı
Tamarix tetrandra	Tamaricaeaee	LC	-	Ilgın
Acer platanoides	Aceraceaee	LC	-	Çınar yapraklı akçaağaç
Sorbus aucuparia	Rosaceae	LC	-	Kuş üvezi
Fagus orientalis	Fagaceae	LC	-	Doğu kayını
Pistacia atlantica	Anacardiaceae	LC	-	Sakız ağacı
Prunus spinosa subsp. dasyphylla	Rosaceae	LC	-	Çakal eriği
Corylus colurna	Corylaceae	LC	-	Ağaç fındık

3.18. IUCN Risk Categories of Sinop's Plants

Endemic and non-endemic plant numbers of Sinop according to IUCN risk categories were given in Table 25. IUCN risk (CR, EN, VU, NT, LC) categories of plant species in Sinop were given in Table 26. There is no plant species in CR, EN and VU categories in Sinop province. There are one species in NT category and 7 species in LC category (Table 25, Table 26).

Table 25. Endemic and non-endemic plant numbers of Sinop according to IUCN risk categories

	CR	EN	VU	NT	LC	DD	NE	Total
Endemic	0	0	0	0	0	0	0	0
Non-endemic	0	0	0	1	7	2	71	81
Total	0	0	0	1	7	2	71	81

Table 26. IUCN risk (CR, EN, VU, NT, LC) categories of plant species in Sinop

Species	Family	IUCN risk category	Endemism	Turkish name
Buxus sempervirens	Buxaceae	NT	-	Şimşir
Juniperus oxycedrus subsp. oxycedrus	Cupressaceae	LC	-	Bodur ardıç
Acer campestre subsp. campestre	Aceraceaee	LC	-	Ova akçaağacı
Mespilus germanica	Rosaceae	LC	-	Muşmula
Sorbus torminalis var. torminalis	Rosaceae	LC	-	Akçaağaç yapraklı üvez
Carpinus betulus	Corylaceae	LC	-	Adi gürgen
Ostrya carpinifolia	Corylaceae	LC	-	Gürgen yapraklı kayacık
Chamaecytisus austriacus	Fabaceae	LC	-	Koru keçitırfılı

3.19. IUCN Risk Categories of Çorum's Plants

Endemic and non-endemic plant numbers of Çorum according to IUCN risk categories were given in Table 27. IUCN risk (CR, EN, VU, NT, LC) categories of plant species in Çorum were given in Table 28. There is no plant species in CR, EN, VU and NT categories in Çorum province. There are 3 species in LC category (Table 27, Table 28).

Table 27. Endemic and non-endemic plant numbers of Çorum according to IUCN risk categories

	CR	EN	VU	NT	LC	DD	NE	Total
Endemic	0	0	0	0	0	0	0	0
Non-endemic	0	0	0	0	3	0	21	24
Total	0	0	0	0	3	0	21	24

Table 28. IUCN risk (CR, EN, VU, NT, LC) categories of plant species in Çorum

Species	Family	IUCN risk category	Endemism	Turkish name
Cornus mas	Cornaceae	LC	-	Kızılcık
Juglans regia	Juglandaceae	LC	-	Adi ceviz
Carpinus orientalis	Corylaceae	LC	-	Doğu gürgeni

3.20. IUCN Risk Categories of Kastamonu's Plants

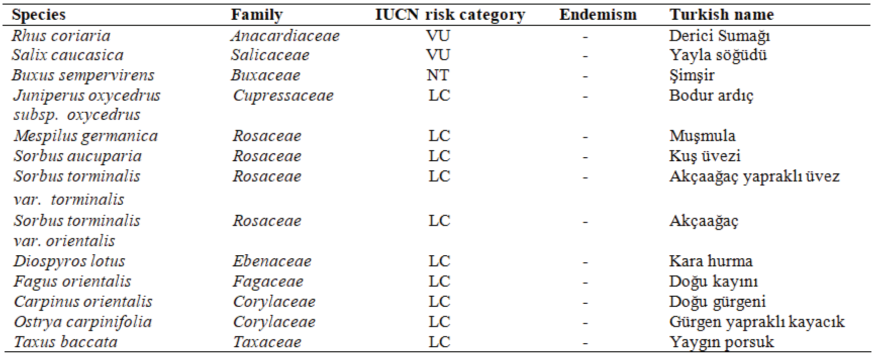
Endemic and non-endemic plant numbers of Kastamonu according to IUCN risk categories were given in Table 29. IUCN risk (CR, EN, VU, NT, LC) categories of plant species in Kastamonu were given in Table 30.

There are two species in VU categories, one species in NT category and 10 species in LC category in Kstamonu province (Table 29, Table 30).

Table 29. Endemic and non-endemic plant numbers of Kastamonu according to IUCN risk categories

	CR	EN	VU	NT	LC	DD	NE	Total
Endemic	0	0	0	0	0	0	0	0
Non-endemic	0	0	2	1	10	3	107	123
Total	0	0	2	1	10	3	107	123

Table 30. IUCN risk (CR, EN, VU, NT, LC) categories of plant species in Kastamonu



Species	**Family**	**IUCN risk category**	**Endemism**	**Turkish name**
Rhus coriaria	*Anacardiaceae*	VU	-	Derici Sumağı
Salix caucasica	*Salicaceae*	VU	-	Yayla söğüdü
Buxus sempervirens	*Buxaceae*	NT	-	Şimşir
Juniperus oxycedrus subsp. oxycedrus	*Cupressaceae*	LC	-	Bodur ardıç
Mespilus germanica	*Rosaceae*	LC	-	Muşmula
Sorbus aucuparia	*Rosaceae*	LC	-	Kuş üvezi
Sorbus torminalis var. torminalis	*Rosaceae*	LC	-	Akçaağaç yapraklı üvez
Sorbus torminalis var. orientalis	*Rosaceae*	LC	-	Akçaağaç
Diospyros lotus	*Ebenaceae*	LC	-	Kara hurma
Fagus orientalis	*Fagaceae*	LC	-	Doğu kayını
Carpinus orientalis	*Corylaceae*	LC	-	Doğu gürgeni
Ostrya carpinifolia	*Corylaceae*	LC	-	Gürgen yapraklı kayacık
Taxus baccata	*Taxaceae*	LC	-	Yaygın porsuk

3.21. IUCN Risk Categories of Karabuk's Plants

Endemic and non-endemic plant numbers of Karabük according to IUCN risk categories were given in Table 32. IUCN risk (CR, EN, VU, NT, LC) categories of plant species in Karabük were given in Table 32. There is no plant species in CR, EN and VU categories in Karabuk province. There are 1 species in NT category and 2 species in LC category (Table 31, Table 32).

Table 31. Endemic and non-endemic plant numbers of Karabük according to IUCN risk categories

	CR	EN	VU	NT	LC	DD	NE	Total
Endemic	0	0	0	0	0	0	0	0
Non-endemic	0	0	0	1	2	3	43	49
Total	0	0	0	1	2	3	43	49

Table 32. IUCN risk (CR, EN, VU, NT, LC) categories of plant species in Karabük

Species	Family	IUCN risk category	Endemism	Turkish name
Buxus sempervirens	Buxaceae	NT	-	Şimşir
Corylus avellana var. pontica	Corylaceae	LC	-	Çubuk fındığı
Pyrus amygdaliformis var. lanceolata	Rosaceae	LC	-	Çöğür armudu

3.22. IUCN Risk Categories of Bartın's Plants

Endemic and non-endemic plant numbers of Bartın according to IUCN risk categories were given in Table 33. There is no plant species in CR, EN, VU and LC categories in Bartın province. There is only one species in NT category (Table 33).

Table 33. Endemic and non-endemic plant numbers of Bartın according to IUCN risk categories

	CR	EN	VU	NT	LC	DD	NE	Total
Endemic	0	0	0	0	0	0	0	0
Non-endemic	0	0	0	1	0	0	3	4
Total	0	0	0	1	0	0	3	4

In the province of Bartın, Buxus sempervirens (Boxwood) species is in the NT category in the Buxaceae family.

3.23. IUCN Risk Categories of Zonguldak's Plants

Endemic and non-endemic plant numbers of Zonguldak according to IUCN risk categories were given in Table 34. IUCN risk (CR, EN, VU, NT, LC) categories of plant species in Zonguldak were given in Table 35. There is no plant species in CR, EN and VU categories in Zonguldak province. There are 2 species in NT category and 9 species in LC category (Table 34, Table 35).

Table 34. Endemic and non-endemic plant numbers of Zonguldak according to IUCN risk categories

	CR	EN	VU	NT	LC	DD	NE	Total
Endemic	0	0	0	0	0	0	0	0
Non-endemic	0	0	0	2	9	1	40	52
Total	0	0	0	2	9	1	40	52

Table 35. IUCN risk (CR, EN, VU, NT, LC) categories of plant species in Zonguldak

Species	Family	IUCN risk category	Endemism	Turkish name
Quercus coccifera	Fagaceae	NT	-	Kermes meşesi
Buxus sempervirens	Buxaceae	NT	-	Şimşir

Pistacia terebinthus subsp. terebinthus	Anacardiaceae	LC	-	Menengiç
Quercus frainetto	Fagaceae	LC	-	Macar meşesi
Salix cinerea	Salicaceae	LC	-	Boz Söğüt
Asparagus aphyllus subsp. orientalis	Liliaceae	LC	-	Kuşkonmaz
Tamarix tetrandra	Tamaricaeae	LC	-	Ilgın
Sorbus torminalis var. torminalis	Rosaceae	LC	-	Akçaağaç yapraklı üvez
Diospyros lotus	Ebenaceae	LC	-	Kara Hurma
Ostrya carpinifolia	Corylaceae	LC	-	Gürgen yapraklı kayacık
Corylus avellana var. pontica	Corylaceae	LC	-	Çubuk fındığı

3.24. IUCN Risk Categories of Bolu's Plants

Endemic and non-endemic plant numbers of Bolu according to IUCN risk categories were given in Table 36. IUCN risk (CR, EN, VU, NT, LC) categories of plant species in Bolu were given in Table 37. There is no plant species in CR, EN and VU categories in Bolu province. There are 1 species in NT category and 6 species in LC category (Table 36, Table 37).

Table 36. Endemic and non-endemic plant numbers of Bolu according to IUCN risk categories

	CR	EN	VU	NT	LC	DD	NE	Total
Endemic	0	0	0	0	0	0	0	0
Non-endemic	0	0	0	1	6	2	75	84
Total	0	0	0	1	6	2	75	84

Table 37. IUCN risk (CR, EN, VU, NT, LC) categories of plant species in Bolu

Species	Family	IUCN risk category	Endemism	Turkish name
Buxus sempervirens	Buxaceae	NT	-	Şimşir
Acer platanoides	Aceraceae	LC	-	Çınar yapraklı akçaağaç
Acer campestre subsp. campestre	Aceracea	LC	-	Ova akçaağacı
Cornus mas	Cornaceae	LC	-	Kızılcık
Arceuthobium oxycedri	Loranthaceae	LC	-	Ardıç güveleği
Juglans regia	Juglandaceae	LC	-	Adi ceviz
Quercus petraea subsp. petraea	Fagaceae	LC	-	Sapsız meşe

3.25. IUCN Risk Categories of Düzce's Plants

Endemic and non-endemic plant numbers of Düzce according to IUCN risk categories were given in Table 38. IUCN risk (CR, EN, VU, NT, LC) categories of plant species in Düzce were given in Table 39. There is no plant species in CR, EN, VU in Düzce province. There is one species in NT categories are 3 species in LC category (Table 38, Table 39).

Table 38. Endemic and non-endemic plant numbers of Düzce according to IUCN risk categories

	CR	EN	VU	NT	LC	DD	NE	Total
Endemic	0	0	0	0	0	0	0	0
Non-endemic	0	0	0	1	3	2	23	29
Total	0	0	0	1	3	2	23	29

Table 39. IUCN risk (CR, EN, VU, NT, LC) categories of plant species in Düzce

Species	Family	IUCN risk category	Endemism	Turkish name
Buxus sempervirens	Buxaceae	NT	-	Şimşir
Mespilus germanica	Rosaceae	LC	-	Muşmula
Corylus maxima	Corylaceae	LC	-	Lambert Fındığı
Oenanthe fistulosa	Apiaceae	LC	-	Kazyak

4. CONCLUSION AND RECOMMENDATIONS

The Black Sea Region is an important geographical area of Turkey in terms of population and plant richness. In this study, the species numbers, groups, endemism status of shrub and tree-form plants in the rich plant diversity of the Black Sea Region and risk categories in the IUCN red list classes were determined.

In this study, we determined that there are a total of 415 species grouped as shrubs, trees, shrubs or small trees in the Black Sea Region. When the provinces are examined in terms of families, the provinces with the most families were listed as Trabazon (39), Artvin (36), Samsun (36), while the least families were found in the provinces of Bartın (3), Bayburt (14) and Karabük (14). In terms of the number of plant species, the provinces with the highest number of species were Artvin (145), Kastamonu (123) and Trabzon (117), while the provinces with the lowest number of species were determined as the provinces of Bartın (4), Çorum (24) and Düzce (29). The highest number of endemic species in the region is located in Kastamonu (16), Amasya (13) and Bolu (9).

When the families are listed in terms of the number of species in the Black Sea Region, Rosaceae (89) is the first, Fabaceae (58) and Salicaceae (24) families are the third.

When the shrubs and trees, shrubs or small tree-form plants distributed in the region are evaluated according to IUCN risk categories, 3 species are in critical (CR) class, 1 species is endangered (EN), 9 species are susceptible (VU), 3 species are near threat (NT), 68 species were categorized as low risk (LC), 14 species as insufficient data (DD) and 317 plant species as unevaluated (NE). All of 3 critical species, 2 of 9 susceptible species, 2 of 14 species with insufficient data, and 10 of 317 unevaluated species are endemic species.

Approximately 46.6% of plants in Turkey are endangered. On the other hand, 27% of the plants distributed in the Black Sea region are in the IUCN risk category. 41% (7) of 17 endemic plant species are in the risk category. In this study, it was determined that the Buxus sempervirens species, which is very important due to its ornamental plant and wood characteristics, is in the NT category in the IUCN risk category. However, in the study of Sarı and Çelikel (2021), we determined that approximately 90% of the boxwood locations were destroyed due to the effect of the boxwood moth. Ak et al. (2021) also detected the boxwood moth in the Mediterranean Region Hatay province. It was determined that the boxwood location in the Samandağ district of Hatay province disappeared due to the boxwood moth. In the light of this information, it was concluded that the condition of Buxus sempervirens species in Turkey has reached the critical (CR) level. It would be useful to review and present the situation of many other species such as this one.

In addition, as a result of this study, the determination of shrubs and trees, shrubs or small tree-shaped plants at the provincial level in the Black Sea Region will be a guide and guide for the studies to be carried out on these species. In addition, the study has revealed important data in terms of determining the plants that can be used as ornamental plants and especially outdoor ornamental plants in the region.

As a result, these data obtained by revealing the status of plant existence in the region contain predictable information about the future of plants in the region. The endangered plant species are increasing day by day. In order to protect these species and transfer them to the future, it is important to increase the efforts to reduce the pressure on the species and to protect them.

REFERENCES

Ak, K., Sarı, Ö., Altaş, K. & Yaşar, H. (2021). Hatay ili şimşir alanlarında yeni bir zararlı, Cydalima perspectalis (Walker, 1859) (Lepidoptera: Crambidae). Artvin Çoruh Üniversitesi Orman Fakültesi Dergisi, 22(1), 109-116.

Allen, D., Bilz, M., Leaman, D.J., Miller, R.M., Timoshyna, A. & Window, J. (2014). European Red list of medicinal plants, http://www.iucnredlist.org/initiatives/europe/publications. 20 Ekim 2020.

Babac, M. T. (2004) "Possibility of an information system on plants of South-West Asia with particular reference to the Turkish Plants Data Service (TÜBİVES)" Turk J Bot, 28, 119-127.

Bakis, Y., Babac, M.T. & Uslu, E. (2011) "Updates and improvements of Turkish Plants Data Service (TÜBİVES)" In Health Informatics and Bioinformatics (HIBIT), 2011 6th International Symposium on (pp. 136-140). IEEE.

Davis, P. H. & PH, D. (1975). The flora of Turkey: past, present and future.

Davis, P.H., Harper, P.C. & Hedge, I.C. (1971). Plant Life of South West Asia. The Botanical Society of Edinburgh, Edinburgh.

Günal, N. (2013). Türkiye'de iklimin doğal bitki örtüsü üzerindeki etkileri. Acta Turcica Çevrimiçi Tematik Türkoloji Dergisi, Online Thematic Journal of Turkic Studies, Yıl V, 1, 1-22.

IUCN, (2020). The IUCN Red List of Threatened Species. Version 2017-3. <http://www.iucnredlist.org>. Downloaded on 05 December 2021.

Karagöz, A., Zencirci, N., TAN, A., Taşkın, T., Köksel, H., Sürek, M. & Toker, C. (2010). Özbek K., Bitki genetik Kaynaklarının Korunması ve Kullanımı, Türkiye Ziraat Mühendisliği VII. Teknik Kongresi, 2010., 155-177.

Özhatay, N. & Kültür, Ş. (2006). Check-list of Additional Taxa to the Supplement Flora of Turkey III. Turk J Bot. 30:281-316.

Özhatay, N., Kültür, Ş. & Aslan, S. (2009).Check-list of Additional Taxa to the Supplement Flora of Turkey IV., Turk J Bot, 33, 191-226.

Öztürk, M. Z., Çetinkaya, G. & AYDIN, S. (2017). Köppen-Geiger iklim sınıflandırmasına göre Türkiye'nin iklim tipleri. Coğrafya Dergisi, (35), 17-27.

Sarı, Ö. & Çelikel, F. G. (2019). (2021). Boxwoods in The World and Turkey. Gece Kitap Evi. (In the publication phase).