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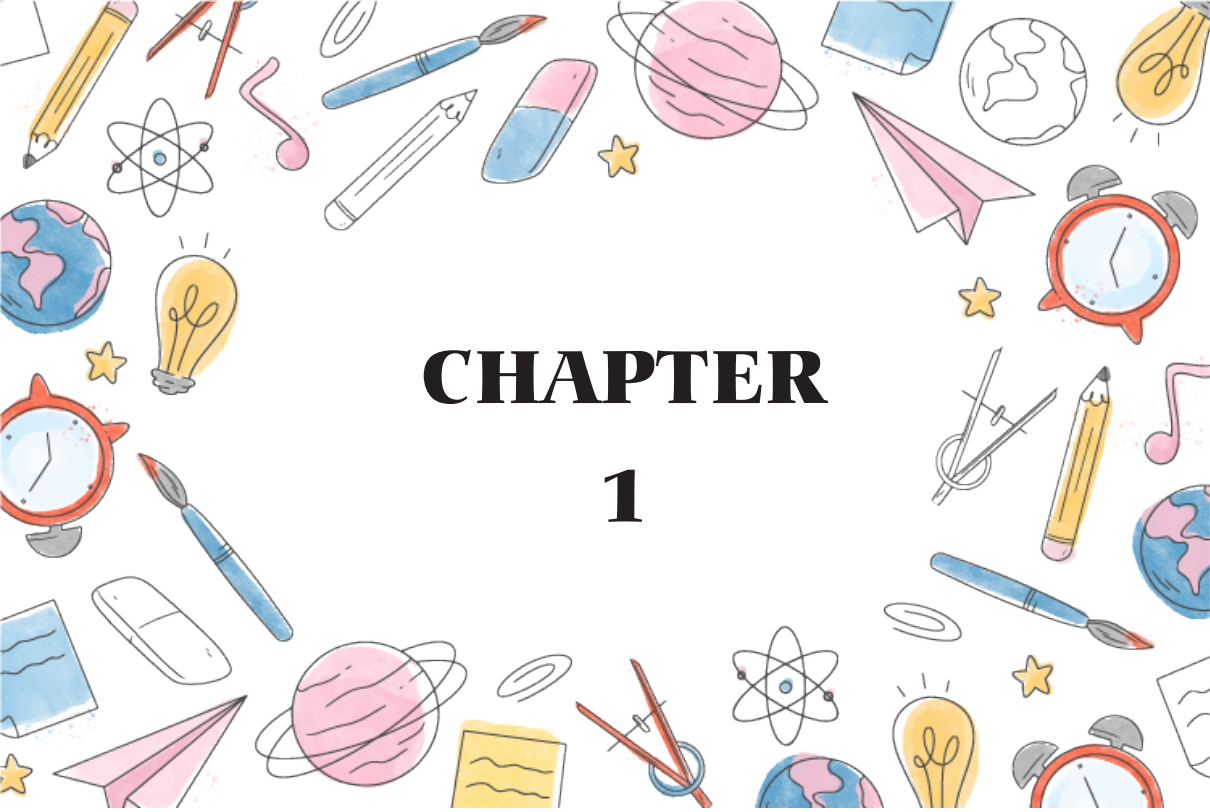

CHAPTER 1

EFFECT OF NATURAL/ORGANIC MEDICAL AROMATIC HERB EXTRACT STRUCTURE ON THE USAGE LEVEL OF WOOD

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INTRODUCTION

Wood The necessity of taking wood usage seriously is emerging. As it is known, since the majority of wood species are naturally not durable for outdoor applications, they are put into service by being treated with various protection methods. One of the standard applied wood protection methods is the process of impregnating wood with effective chemical preservatives against the conditions and pests to which it may be exposed (Reinprecht, 2016). However, in impregnation processes, the penetration performance of wood species with protective impregnation agents varies considerably and this situation is largely related to the permeability of the species (Costanza and Miyara, 2000). In addition to being naturally durable in the spruce, which is the subject of the present thesis, since its permeability, i.e. permeability, is low, it is difficult to achieve sufficient preservative retention in standard impregnation processes. Therefore, it is not suitable for outdoor applications. For this reason, searches for sustainable methods to improve the impregnability of spruce and expand its application areas are still ongoing (Bakır et al. 2022)

Wood is an indispensable material for living spaces. Therefore, the demand for wood is increasing rapidly in parallel with the rapid increase in the world population, and this situation necessitates the inclusion of all local wood species in the industry. At this point, the Eastern spruce, which grows naturally in our country and has a very large distribution area, constitutes approximately 2% (OGM, 2012) of the 21.7 million hectares of forest area in our country (Buğahan, 2013). Wood, which has been used for various purposes since the beginning of human history, is one of the most important raw materials. With the rapid development of technology, the areas of use of wood have diversified and the amount used has increased. This increase in the use of wood causes it to be among the decreasing natural resources today (Kartal and Imamura, 2004). Impregnated wood is an important building material due to its aesthetic appearance, economy, and resistance to biotic and abiotic pests. Impregnated wood is used as roof elements, joinery and coating material, and as a carrier and decorative material in molds and scaffolding (Kartal, 2000; Can, 2018). The use of medicinal aromatic plants (MAPs) dates to ancient times. These medicinal plants have been used by humans for therapeutic and other purposes. In addition, essential oils obtained from these medicinal plants have been used with the physical and emotional treatment method called aromatherapy. According to the World Health Organization (WHO), in most developing countries

such as Asia, Africa and Latin America, about 80% of the population still relies on traditional herbal medicines for their primary medical requirements . It is estimated that there are 320,000 plant species used as food sources in the world. 25.000 are used for medical treatment, 5.000 for industrial purposes, 15.000 as ornamental plants and other species for various other purposes. The richest region in the world in terms of spice species is the northern part of South America and the Indonesian archipelago (Parvin et. al., 2023). The use of Medicinal and Aromatic Plants (MAPs), present in numerous plants and products, dates to ancient times. Humans have utilized these products for therapeutic and various other purposes. Moreover, MAPs are employed to create diverse products like essential oils and solvent extracts used in food, cosmetics, and pharmaceuticals. These value-added products have also been commercialized globally. Turkey is advantageous in terms of its geopolitical structure and rich flora. The production, cultivation, and export activities of these products are also prominent in Turkey (Atak, 2024). Güngörmez (2015) The most positive aspect of the organic dyeing process is the economic recovery of waste plant material in addition to obtaining healthy products. Today, many different cancers are rapidly occurring and the lack of this aspect of the organic dye structure, the antimicrobial structure of some plants, and their easy use in children's toys has been reported.

It is aimed to use the extracts of meadow onion, chasir and rhubarb plants, which have been determined to have antioxidant/antibacterial properties, in wood industry, indoor/outdoor furniture, wooden toys, hospitals, and all places and areas requiring hygiene, based on the ability to impregnate wood and the determined findings by preparing various concentrations (1%, 3%) of extracts.

1. MATERIAL and METHOD

1.1. Wood Material and Treatment

Within Chestnut/Scots pine woods were used in the experimental study; radial cuts were made in accordance with TS 2470 (1976) standards. Meadow onion (*Allium schoenoprasum L.*), Ferula (*Ferula comunis L.*), Esgin (*Rheum ribes L.*) which are identified as medicinal aromatic plants in the literature (antibacterial/antioxidant), were used.

1.2. Preparation of Experiment Samples

It was paid attention that the wood materials used in the study were sapwood parts with smooth fibers, no cracks, no knots, no density and color difference, no reaction wood, not damaged by fungi and insects, and were processed according to TS 2471,2472 standards.

1.3. Impregnation Process

Impregnation was carried out according to ASTM–D 1413-76 principles. It was subjected to 45 minutes of vacuum and 45 minutes of diffusion.

1.4. Extract Preparation

Medicinal and aromatic plant species were supplied from Erzurum province and dried in the Artvin Coruh University laboratory for 1-2 months to reach a constant weight. After 1-2 months of drying, they were turned into powder by passing through a cutter grinder (Ceylan, 2017).

1.5. Percentage Retention (net dry matter amount)

After impregnation, the amount of substance remained (tkoao-% retention) compared to dry wood was calculated from the specified formula.

$$R\ (\%) = \frac{Moes - Moeö}{Moeö} \times 100 \qquad (1)$$

Moes = Sample full dry weight after impregnation (g)
Moeö = Sample full dry weight before impregnation (g)

1.6. Evaluation of Data

SPSS statistics program was applied to evaluate the data. Homogeneity groups were formed by analyzing values resulting from wood type effect and % concentration change and simple variance analysis was applied.

2. RESULTS AND DISCUSSION

2.1. Solution Properties

Solution properties are given in Table 1. There was no significant change in solution pH and densities.

Table 1. *Solution Properties.*

Impregnation Material	Concentration (%)	Solvent	Temperature (ºC)	pH		Density (g/ml)	
				BI	AI	BI	AI
Meadow onion	%1	Distilled water	22ºC	7.38	7.25	0.988	0.988
Ferula				7.17	7.17	0.987	0.987
Esgin				7.09	7.09	0.747	0.747
Meadow onion	%3			6.63	6.60	0.989	0.990
Ferula				7.14	7.16	0.965	0.968
Esgin				6.76	6.76	0.776	0.778

BI: Before impregnation **AI:** After ımpregnation

2.2. Retention Amount (% Retention)

The net dry impregnation material remaining amount as (%) is given in Table 2.

Table 2. *% Retention*

Wood Type	Impregnation Material	Concentration (%)	Retention (%)	
			Mean	HG
Chestnut Wood	Meadow onion	%1	**0.76**	A
	Ferula		0.44	C
	Esgin		0.38	E
	Meadow onion	%3	0.54	B
	Ferula		0.35	F
	Esgin		0.41	D
Scotch Pine Wood	Meadow onion	%1	0.45	C
	Ferula		0.25	I
	Esgin		0.31	G
	Meadow onion	%3	0.26	I
	Ferula		0.34	F
	Esgin		0.29	H

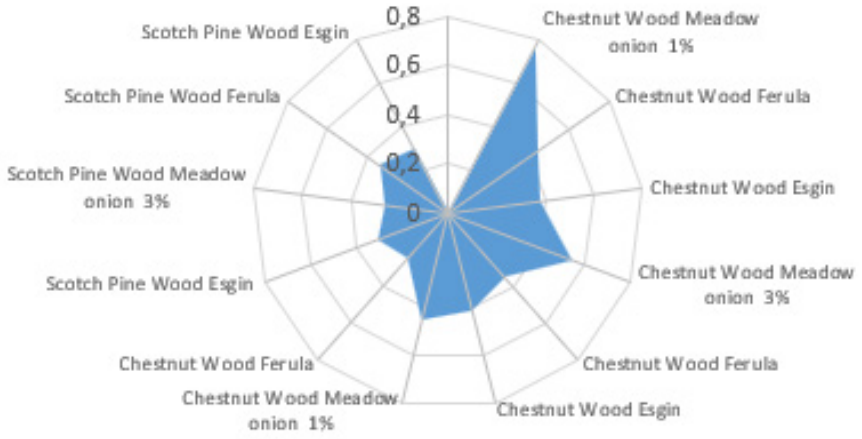


Figure 1. *Change of Retention*

The highest retention change was determined in chestnut wood with 1% meadow onion (% 0.76), the lowest retention was determined in Scots pine with 1% ferula extract (% 0.25). In general, retention was determined in both wood types. The resulting retention difference may be due to wood type, anatomical structure, plant concentration and type, impregnation method, vacuum time/diffusion time.

The highest retention values were observed in samples impregnated with 1% solution. It is stated that the retention ratio varies due to the properties of the solutions and the anatomical structure (Alkan, 2016).

CONCLUSION

The highest retention change was determined in chestnut wood with 1% meadow onion (% 0.76), the lowest retention was determined in Scots pine with 1% chasir extract (% 0.25). The retention was achieved in the vacuum impregnation method. Both wood types have a high statistical significance level compared to the control samples; we can say that wood type, anatomical structure, humidity, impregnation material, impregnation method are effective on all technological features.

REFERENCES

Kartal, S., N. ve Unamura, Y., (2004), Borlu Bileşiklerin Emprenye Maddesi Olarak Ağaç Malzeme ve Kompozitlerde Kullanılması, Ü. Uluslararası Bor Sempozyumu (23-25 Eylül), Eskisehir, 334.

Reinprecht, L., (2016) Wood Deterioration, Protection and Maintenance", John Wiley & Sons, Hoboken, NJ, USA.

Costanza, V. and Miyara, A. J., (2000) "Dynamical Aspects of Hardwood Impregnation", Holzforschung, 54 (2):183-187 .

Bakır, D., (2019) "Biyolojik Yöntemle Permeabilitesi İyileştirilen Odunun Bazı Özelliklerinin ve Bakır Dağılımının İncelenmesi", Doktora tezi, İstanbul Üniversitesi, İstanbul.

OGM (2012) Orman Genel Müdürlüğü, Ankara.

Buğahan, B., (2013)"Borçka - Balcı Yöresinde Montan Zonda Yapılan Doğu Ladini (Picea Orientalis L. Link.) Yaz Sonu Dikimlerinin Başarısının Araştırılması", Yüksek Lisans Tezi, Artvin Çoruh Üniversitesi Fen Bilimleri Enstitüsü, Artvin .

Kartal, S.N., ve Imamura, Y., (2004). Borlu Bileşiklerin Emprenye Maddesi Olarak Ağaç Malzeme ve Kompozitlerde Kullanılması. Üçüncü Uluslararası Bor Senpozyumu., Bildiriler Kitabı, Eskişehir, CiltIi, 333-338s.

Kartal, S., (2000). The Leachability, Fungal Resistance, And Mechanical Properties Of Wood Treated With CCA And CCB Wood Preservatives. Journal Of The Faculty Of Forestry Istanbul University|, 50(2), 177–194.

Can, A., (2018). 'Su İtici Maddeler İle Kombine Edilmiş Bazı Emprenye Maddelerinin Performansının İncelenmesi'. Doktora Tezi, Bartın Üniversitesi Fen Bilimleri Enstitüsü, Bartın, Türkiye.

Parvin, S., Reza, A., Das, S., Miah, M. M. ve Karim, S., (2023). Potential Role and International Trade of Medicinal and Aromatic Plants in the World. European Journal of Agriculture and Food Sciences, 2684-1827.

Atak, G., (2024) Tıbbi aromatik bitkiler ve esansiyel yağlar ihracat potansiyeli ve pazar analizi, Dokuz Eylül Üniversitesi / Sosyal Bilimler Enstitüsü, Yüksek lisans tezi, İzmir.

Güngörmez, H., (2015). Doğal Boyalar ve Tuz-Natural Dyes and Salt", Iğdır Üni. Fen Bilimleri Enst. Der. / Iğdır Univ. J. Inst. Sci. & Tech, Volume: 5, Issue: 1

TS 2470 (1976) Odunda Fiziksel ve Mekaniksel Deneyler İçin Numune Alma Metodları ve Genel Özellikler, TSE, Ankara.

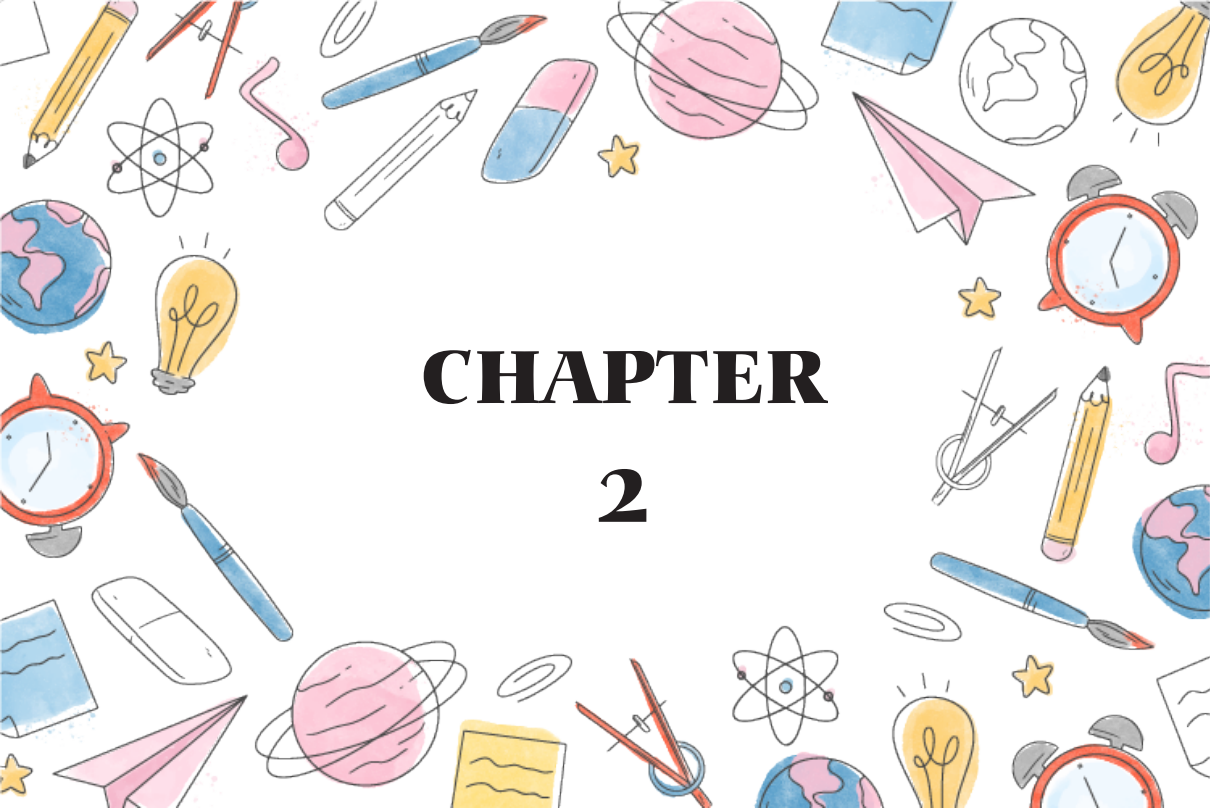
TS 2471 (1976) Odunda Fiziksel ve Mekaniksel Deneyler İçin Rutubet Miktarı Tayini, TSE, Ankara

TS 2472 (1976 Odunun Fiziksel Ve Mekanik Özellikleri – Kusursuz Küçük Ahşap Numunelerin Deney Yöntemleri - Bölüm 2: Fiziksel Ve Mekanik Deneyler Için Yoğunluğun Belirlenmesi

ASTM D 1413–76 (1984) Standartd Methods of Testing Preservatives by Laboratory Soilblock Cultures, Annual Book of ASTM Standarts, USA Wood

Ceylan, Ş., (2020) Işgın Bitki (Antioksidan/antibakteriyel) Özütünün Ahşap Endüstrisinde (Mobilya/İnşaat) Kullanılabilme Olanakları, Artvin Çoruh Üniversitesi , BAP Projesi, Artvin

Alkan, E., (2016) Doğal Emprenye Maddeleri Ve Borlu Bileşikler Ile Emprenye Edilen Sarıçam (Pinus Sylvestris L.) Odununun Fiziksel Ve Mekanik Özelliklerinin Incelenmesi, Gümüşhane Üniversitesi, Fen Bilimleri Enstitüsü, Yüksek Lisans Tezi, 76 S, Gümüşhane.



CHAPTER 2

EFFECTS OF VARIOUS MEDICINAL AND AROMATIC PLANT EXTRACTS ON SOME TECHNOLOGICAL PROPERTIES OF WOOD MATERIALS

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INTRODUCTION

Many studies are being conducted to maximize the positive qualities of wood and to minimize its negative qualities, and various methods and techniques are being developed for this purpose. The methods and techniques developed in the context of the research in question are called "Wood Modification Methods" (WMM) as a general term (Korkut, 2009). Yıldız (2002) Methods related to wood modification can be effective in chemical and physical terms. In chemically effective wood modification methods, chemical substances that react with cell wall components and thus cause the chemical composition of the wood to change are used, and it is aimed to reduce the harmful qualities of the wood by changing its chemical structure. In physically effective wood modification methods, the aim is generally to fill the cell gaps and other gaps in the wood using organic or inorganic substances and to reinforce them as a material. Exposure to chemical effects in the environment we live in poses serious threats. Importance has increased for natural raw materials. The use of natural building products in our homes, where we spend most of our lives, is of great importance for our family and our own health, such as the toys used by our children, wooden products used in the workplace, etc. Recent years have shown that along with the increase in diseases, interest in natural, healthy products and the increasing environmental attitude have also increased, and interest in the use of environmentally friendly, natural and healthy products in the production and use of wooden materials has also increased. Natural plants are used for a variety of purposes (phytotherapy, spices, tea, insecticide, paint, utilization of oils, industry, cosmetics, etc.) (Yılmaz, 2022)

Against fungal disease agents Fusarium oxysporum f.sp. cucumerinum (FOC) and Monilinia fructigena that cause problems in apple and cucumber plants, different concentrations of plant extracts were used as control group 5, 10, and 20 mg/ml and Lethal Dose and Mycelium values were determined in the data obtained with this contract. Resin and leaf extracts (extract) showed antifungal activity at every concentration used against fungal disease agents. It was determined that the Mycelium Development Inhibition value increased as the dose of the concentration increased. When resin and leaf extract were compared, a more effective result was found for resin extract compared to leaf extract (Onaran, 2018). Impregnation process was carried out with waste oils and the effect of the wood material on its physical properties after impregnation was investigated and as a result of the research, it was observed that its physical properties gave positive results (Özkan et al. 2020). In a study conducted on Scots pine wood, it was determined that valex, which is expected to be used as a herbal preservative, generally negatively affected the physical, mechanical

and biological properties of the wood. The toxicity effects of CCA and CBA-A were observed to be low in biological tests (Şimşek, 2013).

Impregnation Agent Potential of Kuzuluk, Taraklı and Geyve (Sakarya) Geothermal Waters and Their Effects on Some Physical Properties of Red Pine (P. Brutia Ten.) Wood' researched the findings of the tests conducted and included 12 wood impregnation agents constituting 55% of the total geothermal chemical and varying between 450.00 mg/L and 1232.24 mg/L. While the geothermal treatments performed did not have a significant contribution to the density and tangential expansion of red pine wood, they significantly affected the other properties of red pine wood (Var et al. 2017). In a study, the effect of resin production on the physical and mechanical properties of red pine wood was investigated and it was observed that there was no significant difference in air-dry and fully dry specific gravity, volume and density values between trees where resin production was made and trees where resin production was not made in terms of north, south, east and west directions (Öktem et al.1995).

The main theme of the study is that wood has hundreds of areas of use beyond knowing its organic structure and that using this material in every environment where people are together will provide healthier/hygienic (antibacterial/antioxidant) properties. In the study, onion, rhubarb, and chasir plant extracts were prepared in concentrations of (1.3%) and their technological properties were determined.

1. MATERIAL and METHOD

1.1. Wood Material and Treatment

Within Chestnut wood were used in the experimental study; radial cuts were made in accordance with TS 2470 (1976) standards. Esgin (*Rheum ribes L.*), Ferula (*Ferula comunis L.*),Meadow onion (*Allium schoenoprasum L.*), were used.

1.2. Preparation of Experiment Samples

It was paid attention that the wood materials used in the study were sapwood parts with smooth fibers, no cracks, no knots, no density and color difference, no reaction wood, not damaged by fungi and insects, and were processed according to TS 2471,2472 ,2474 standards.

1.3. Impregnation Process

Impregnation was carried out according to ASTM–D 1413-76 principles. It was subjected to 45 minutes of vacuum and 45 minutes of diffusion.

1.4. Extract Preparation

10.26 g of the powdered ışgın, ferula, onıon plant was weighed and the extraction process was carried out in water for 24 hours at room temperature with the help of a shaker. Then, it was passed through filter paper (filtering) and the completion process was done at a certain volume scale. It was then filtered using filter paper and the final volume was completed with water to be 5 L. Medicinal and aromatic plant species were supplied from Erzurum (Ceylan, 2017).

1.5. Air/ Fully Dry Specific Density (g/cm^3)

The moisture content of the test samples was determined according to TS 2471, and the specific gravity was determined according to TS 2472. Constant weight was achieved at 20±2 °C and 65±5% relative humidity, and all weighing and measurements were determined.

1.6. Static Bending Strength and Modulus of Elasticity

Bending strength/modulus of elasticity was based on TS 2474-TS 2478 (1976) standard. Samples were prepared in 20x20x300 mm dimensions. Samples were sanded and air-conditioned (20 ± 2 ºC/ 65 ± 5% relative humidity) and experiments were carried out to 12% moisture conten

2. RESULTS AND DISCUSSION

2.1. Solution Properties

Solution properties are given in Table 1. There was no significant change in solution pH and densities.

Table 1. *Solution Properties.*

Impregnation Material	Concentration (%)	Solvent	Temperature (ºC)	pH		Density (g/ml)	
				BI	AI	BI	AI
Meadow onion	%1	Distilled water	22ºC	7.38	7.25	0.988	0.988
Ferula				7.17	7.17	0.987	0.987
Esgin				7.09	7.09	0.747	0.747

BI: Before impregnation **AI:** After ımpregnation

2.2. Air/ Fully Dry Specific Density (g/cm³)

Air/Fully dry specific gravity change is given in Table 2.

Table 2. *Wood Density (g/cm³)*

Wood Type	Impregnation Material	Concentration (%)	Wood Density			
			Air Density	HG	Full Dry Density	HG
Chestnut Wood	Control	%1	0.50	B	0.48	B
	Meadow onion		0.49	C	0.47	C
	Ferula		0.51	A	0.50	A
	Esgin		0.51	A	0.50	A

The highest air-dry specific density was determined in ferula/eşgin impregnation (0.51 g/cm³), the lowest air-dry specific density was determined in meadow onion (0.49 g/cm³); the highest fully dry specific density was determined in ferula/eşgin (0.51 g/cm³).

2.3 Static Bending Strength (N/mm²)

Static bending strength values and duncan test results are given in Table 3.

Table 3. *Static Bending Strength*

Wood Type	Impregnation Material	Concentration (%)	Static Bending Strength	
			Mean	HG
Chestnut Wood	Control	%1	70.45	D
	Meadow onion		78.56	A
	Ferula		73.73	C
	Esgin		77.49	B

The highest bending strength was in the esgin extract (77.49 N/mm²) and the lowest in the control sample (70.45 N/mm²).

2.4 Modulus of elasticity (N/mm²)

Elasticity module values and duncan test results are given in Table 4.

Table 4. *Modulus of Elasticity*

Wood Type	Impregnation Material	Concentration (%)	Modulus of Elasticity	
			Mean	HG
Chestnut Wood	Control	%1	6750	C
	Meadow onion		7450	B
	Ferula		7637	B
	Esgin		8247	A

All extract groups increased the elastic modulus value compared to the control sample. The highest elastic modulus was in the equivalent extract (8247 N/mm^2) and the lowest was in the control sample.

CONCLUSION

When evaluated in terms of all general properties; it has been reported by the sources that the acidic structure degrades all these properties in determining the specific gravity, bending resistance/elasticity properties, and the basic structure does not have a negative effect. It has also been reported in the literature that the biggest factors in adhesion are wood moisture, thickness, anatomical structure, impregnation material/impregnation method. When this situation is compared with other sources, we can say that the medicinal aromatic plant structure gives positive results.

The specific density change in wood is effective in all properties of wood (technological etc.). The usage level of the material changes depending on whether the specific density is low or high in all areas including wood/furniture/construction industry. Kaçamer (2010) impregnated Uludağ fir and oriental beech woods with Imersol Aqua, Tanalith-E and determined the highest air-dry density value in beech impregnated with Imersol Aqua (0.672 g/cm^3). Kara (2015) impregnated Larix wood with boric acid, borax and pyrite and reported that the full dry density value was pyrite+Ba (0.61 g/cm^3) and the air-dry density value was pyrite+Ba (0.64 g/cm^3).

Çakır (2012) They subjected the vineyard pruning residues to chipping and impregnation with boron compounds (1%-4%) and it was reported that the impregnation process with boron compounds and the increase in solution concentration in general caused decreases in the bending strength and elasticity modulus in bending of the test samples. Dağlıoğlu (2010) impregnated sessile oak, black walnut, Eastern beech, black poplar, ash and Scots pine wood with Tanalith-E and determined that the highest bending strength/elasticity modulus value was in ash and Eastern beech wood.

REFERENCES

Korkut, S. ve Kocaefe, D., (2009) Isıl İşlemin Odun Özellikleri Üzerine Etkisi, Düzce Üniversitesi Ormancılık Dergisi, 5(2): 11-34.

Yıldız, S., (2002) Isıl işlem uygulanan Doğu kayını ve Doğu ladini odunlarının fiziksel, mekanik ve kimyasal özellikleri, Doktora Tezi, Karadeniz Teknik Üniversitesi, Trabzon. 285s.

Yılmaz, S.Ş., (2022) Sığla (Antioksidant/Antibakteriyel) Bitki Özütünün Emprenye Edilebilme Olanağı Ve Ahşap Endüstrisinde Kullanımı, Muğla Sıtkı Koçman Üniversitesi Fen Bilimleri enstitüsü Yüksek Lisans Tezi,Muğla.

Onaran, A., (2018) Endemik Anadolu Sığla Ağacı (*Liquidambar orientalis Mill*.) Bitki Ekstraktlarının Bazı Bitki Patojeni Funguslara Karşı Antifungal Etkilerinin Belirlenmesi , GÜFBED,cilt:8/202-208s.

Özkan, E., Arpacı, Ş. S., Dizman Tomak, E., Yıldırım, N., (2020) Atık yağ ile emprenye işleminin ahşap malzemenin fiziksel özelliklerine etkisi, Ağaç ve Orman, 1(1), 36-41s

Şimşek, U.B., (2013) Bitkisel ve Kimyasal Koruyucularla Emprenye Edilen Sarıçam Odununun Bazı Fiziksel ve Biyoloji Özellikleri, Yüksek Lisans, Karadeniz Teknik Üniversitesi, Trabzon, 91s.

Var, A.A., Soygüder, A.,(2017) Kuzuluk, Taraklı ve Geyve (Sakarya) Jeotermal Sularının Emprenye Maddesi Potansiyeli ve Kızılçam (*P. Brutia Ten*.) Odununda Bazı Fiziksel Özellikler Üzerine Etkisi, Bartın Orman Fakültesi Dergisi, 19(1)/102-116s.

Öktem E.. Sözen M. R.,(1995) Reçine Üretiminin Kızlçam (*Pinus Brutia Ten*.) Odununun Fiziksel Ve Mekaniksel Özellikleri Üzerine Etkisi, İç Anadolu Ormancılık Araştırma Enstitüsü Yayınları. No:256/27-80s.

TS 2470, (1976) Odunda Fiziksel Ve Mekaniksel Deneyler İçin Numune Alma Metodları ve Genel Özellikler, TSE, Ankara.

TS 2471, (1976). Odunda Fiziksel ve Mekaniksel Deneyler İçin Rutubet Miktarı Tayini, TSE, Ankara

TS 2472, (1976) Odunda, Fiziksel ve Mekaniksel Deneyler için Birim Hacim Ağırlığı Tayini, TSE, Ankara

TS 2474.(1976). Odunun Statik Eğilme Dayanımının Tayini,TSE, Ankara.

TS 2478,(1976), Odunun statik eğilmede elastikiyet modülünün tayini, Türk Standartları Enstitüsü, Ankara, 34.

Kaçamer, S., (2010) İmersol Aqua ve Tanalith-E İle Emprenye Edilmiş Isıl İşlemli Ağaç Malzemelerin Yapışma ve Yanma Dirençlerinin Belirlenmesi, Yüksek Lisans Tezi, Karabük Üniversitesi Fen Bilimleri Enstitüsü, Karabük, 72 s.

Kara, F., (2015) Prit (FeS_2) Maddesinin Odunda Emprenye Edilebilme Özelliği Ve Bazı Teknolojik Özelliklerine Etkileri, Artvin Çoruh Üniversitesi, Fen Bilimleri Enstitüsü, Yüksek Lisans Tezi, Artvin.

Çakır, G., (2012) Bor Katkılı Zeytin Karasuyu İle Emprenye Edilmiş Bağ Budama Artıklarından Üretilmiş Yonga Levhaların Fiziksel, Mekanik ve Çürüklük Direncine Olan Etkisinin Belirlenmesi. Yüksek Lisans Tezi, Muğla Üniversitesi Fen Bilimleri Enstitüsü, Muğla, 116 s.

Reinprecht, L., (2016) Wood Deterioration, Protection and Maintenance", John Wiley & Sons, Hoboken, NJ, USA.

Costanza, V. and Miyara, A. J., (2000) "Dynamical Aspects of Hardwood Impregnation", Holzforschung, 54 (2):183-187 .

Bakır, D., (2019) "Biyolojik Yöntemle Permeabilitesi İyileştirilen Odunun Bazı Özelliklerinin ve Bakır Dağılımının İncelenmesi", Doktora tezi, İstanbul Üniversitesi, İstanbul.

OGM (2012) Orman Genel Müdürlüğü, Ankara.

Buğahan, B., (2013)"Borçka - Balcı Yöresinde Montan Zonda Yapılan Doğu Ladini (Picea Orientalis L. Link.) Yaz Sonu Dikimlerinin Başarısının Araştırılması", Yüksek Lisans Tezi, Artvin Çoruh Üniversitesi Fen Bilimleri Enstitüsü, Artvin .

Kartal, S.N., ve Imamura, Y., (2004). Borlu Bileşiklerin Emprenye Maddesi Olarak Ağaç Malzeme ve Kompozitlerde Kullanılması. Üçüncü Uluslararası Bor Senpozyumu., Bildiriler Kitabı, Eskişehir, CiltIi, 333-338s.

Kartal, S., (2000). The Leachability, Fungal Resistance, And Mechanical Properties Of Wood Treated With CCA And CCB Wood Preservatives. Journal Of The Faculty Of Forestry Istanbul University|, 50(2), 177–194.

Can, A., (2018). 'Su İtici Maddeler İle Kombine Edilmiş Bazı Emprenye Maddelerinin Performansının İncelenmesi'. Doktora Tezi, Bartın Üniversitesi Fen Bilimleri Enstitüsü, Bartın, Türkiye.

Parvin, S., Reza, A., Das, S., Miah, M. M. ve Karim, S., (2023). Potential Role and International Trade of Medicinal and Aromatic Plants in the World. European Journal of Agriculture and Food Sciences, 2684-1827.

Atak, G., (2024) Tıbbi aromatik bitkiler ve esansiyel yağlar ihracat potansiyeli ve pazar analizi, Dokuz Eylül Üniversitesi / Sosyal Bilimler Enstitüsü, Yüksek lisans tezi, İzmir.

Güngörmez, H., (2015). Doğal Boyalar ve Tuz-Natural Dyes and Salt", Iğdır Üni. Fen Bilimleri Enst. Der. / Iğdır Univ. J. Inst. Sci. & Tech, Volume: 5, Issue: 1

TS 2470 (1976) Odunda Fiziksel ve Mekaniksel Deneyler İçin Numune Alma Metodları ve Genel Özellikler, TSE, Ankara.

TS 2471 (1976) Odunda Fiziksel ve Mekaniksel Deneyler İçin Rutubet Miktarı Tayini, TSE, Ankara

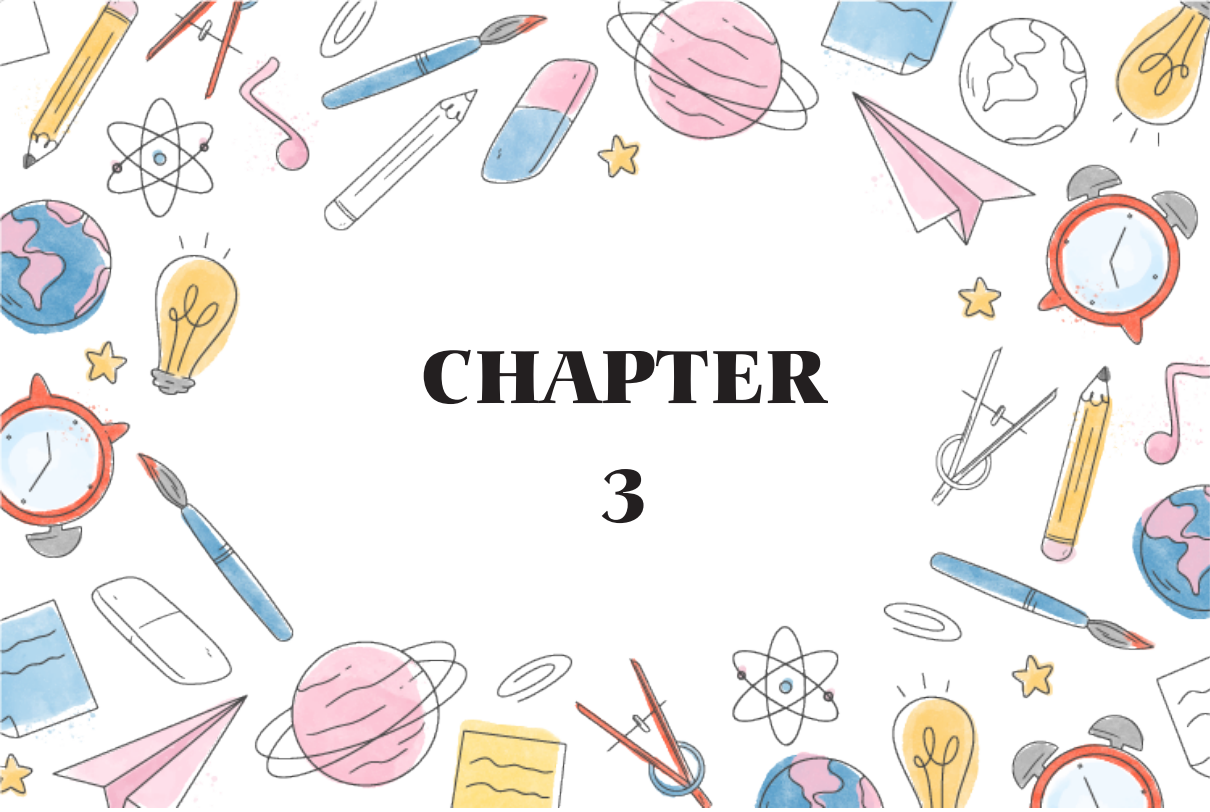
TS 2472 (1976 Odunun Fiziksel Ve Mekanik Özellikleri – Kusursuz Küçük Ahşap Numunelerin Deney Yöntemleri - Bölüm 2: Fiziksel Ve Mekanik Deneyler Için Yoğunluğun Belirlenmesi

ASTM D 1413–76 (1984) Standartd Methods of Testing Preservatives by Laboratory Soilblock Cultures, Annual Book of ASTM Standarts, USA Wood

Ceylan, Ş., (2020) Işgın Bitki (Antioksidan/antibakteriyel) Özütünün Ahşap Endüstrisinde (Mobilya/İnşaat) Kullanılabilme Olanakları, Artvin Çoruh

Üniversitesi , BAP Projesi, Artvin

Alkan, E., (2016) Doğal Emprenye Maddeleri Ve Borlu Bileşikler Ile Emprenye Edilen Sarıçam (Pinus Sylvestris L.) Odununun Fiziksel Ve Mekanik Özelliklerinin Incelenmesi, Gümüşhane Üniversitesi, Fen Bilimleri Enstitüsü, Yüksek Lisans Tezi, 76 S, Gümüşhane.



CHAPTER 3

CLIMATE CHANGE AND AGRICULTURAL SYSTEMS IN TURKEY: ANALYZING RISKS, VULNERABILITIES, AND ADAPTIVE RESPONSES

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1. Introduction

Climate change represents one of the most pressing and multifaceted challenges to agriculture in the 21st century. Across the globe, the increasing frequency of extreme weather events, shifts in precipitation regimes, rising average temperatures, and accelerating evapotranspiration are imposing serious risks to food production systems. These risks are particularly acute in semi-arid and transitional climate zones, such as Turkey, where agriculture is both climate-sensitive and economically vital (Özdogan, 2011; Komuscu et al., 1998; Vanli et al., 2019).

Turkey's geographical and climatic diversity renders its agricultural systems especially vulnerable to the impacts of climate change. Observed trends include rising annual mean temperatures, a decline in winter and spring precipitation in the western and central regions, and increasing drought frequency in already water-stressed areas (Sen et al., 2012; Ozturk et al., 2015; Bagcaci, 2023). Model projections for the 21st century under both moderate and high-emission scenarios (RCP4.5 and RCP8.5) point to 2–6°C increases in surface temperature and significant spatial-temporal variation in precipitation patterns (Bagcaci, 2023; Ozturk et al., 2015; IPCC, 2021).

The agricultural sector in Turkey contributes substantially to national employment and rural livelihoods, yet it faces growing pressure due to climate-related stressors. These include reduced water availability, shifts in crop phenology, decreased yields—particularly in cereals such as wheat and barley—and enhanced soil degradation due to intensified rainfall erosivity (Kilic & Gunal, 2021; Önder et al., 2009; Komuscu et al., 1998). Multiple crop simulation studies reveal that wheat yields could decline by 10–35% depending on emission scenario and region (Özdogan, 2011; Vanli et al., 2019).

Moreover, the indirect consequences of climate change, such as increased food losses, heightened reliance on imports, and inflationary pressures on food prices, are beginning to surface in policy discourses (Ahmed et al., 2023; Dellal et al., 2011). These impacts threaten not only food security but also Turkey's broader developmental goals, particularly those related to poverty alleviation and rural resilience.

In light of these complex and intersecting risks, Turkey has initiated a number of adaptation strategies at national and regional levels. These include the development of the National Climate Change Adaptation Strategy and Action Plan (2011–2023), which emphasizes water management, agricultural innovation, and local-level resilience building (MEU, 2012). However, the gap between projected risks and current policy response still

remains wide, necessitating more robust, localized, and interdisciplinary approaches to climate adaptation in agriculture.

This chapter synthesizes the current scientific understanding of climate change impacts on agriculture in Turkey by analyzing spatial vulnerabilities, biophysical and economic effects, and adaptation responses at multiple scales. Drawing upon recent empirical research, crop modeling, and climate projections, the chapter aims to provide a comprehensive foundation for policy and research efforts geared towards fostering climate-resilient agricultural systems.

2. Agricultural Structure and Climatic Zones in Turkey

Turkey's diverse topography and its position at the intersection of Mediterranean, continental, and oceanic climatic systems result in a highly varied agricultural structure and climatic zonation. The country spans multiple agro-ecological zones, each characterized by distinctive climate patterns, soil types, and cropping systems. These differences shape both the productivity potential and the vulnerability of Turkish agriculture to climate-related stressors (Önder et al., 2009; Komuscu et al., 1998; Vanli et al., 2019).

The General Directorate of Meteorology classifies Turkey into seven main climatic regions, with further granularity offered through agro-climatic zoning. These include:

Mediterranean Region: Dominated by mild, wet winters and hot, dry summers, this region supports intensive horticulture, citrus production, and greenhouse agriculture.

Aegean Region: Similar to the Mediterranean but slightly more temperate, favoring olive cultivation, cotton, and vineyards.

Southeastern Anatolia: A semi-arid climate prevails, where large-scale irrigated agriculture under the Southeastern Anatolia Project (GAP) is practiced. However, this region faces severe soil moisture deficits under projected climate scenarios (Komuscu et al., 1998; Pilevneli et al., 2023).

Central Anatolia: Steppe climate with low precipitation, extensive cereal production (mainly wheat and barley), and significant livestock activity.

Black Sea Region: A humid climate zone suitable for hazelnuts, tea, and maize due to year-round precipitation.

Eastern Anatolia and Thrace: These regions face a harsher continental climate, influencing crop variety and growing season length.

Recent studies using climate modeling (e.g., WRF, RegCM, CMIP6) have shown that these climatic zones are undergoing a systematic shift under global warming scenarios. The aridity index analyses demonstrate a clear trend toward drier conditions, particularly in Central, Southeastern, and Mediterranean regions (Önder et al., 2009; Bagcaci, 2023). These shifts are projected to have profound implications on land cover, crop suitability, and water demand patterns.

Moreover, Turkey's agricultural production is unevenly distributed. For example, cereals dominate in the Central and Eastern Anatolia regions, while horticulture and industrial crops are more common in coastal and irrigated zones (Dellal et al., 2011). Livestock is more prevalent in mountainous regions where cropping is limited. This regional structure contributes to differential vulnerability levels: areas with higher dependency on rain-fed agriculture, such as Central Anatolia, are inherently more sensitive to precipitation variability and drought.

In conclusion, Turkey's agricultural landscape is intimately shaped by its climatic heterogeneity. This diversity creates both opportunities and challenges under a changing climate. Adaptation strategies must therefore be regionally differentiated, taking into account the unique characteristics and vulnerabilities of each agro-climatic zone (MEU, 2012; Sen et al., 2012).

3. Observed and Projected Climate Change Trends in Turkey

Turkey has experienced significant shifts in its climate system over recent decades, driven largely by global warming and regional atmospheric circulation anomalies. Long-term observational data reveal a clear upward trend in average temperatures, an increasing frequency of extreme weather events, and changes in the spatial-temporal distribution of precipitation (Türkeş & Sümer, 2004; Komuscu et al., 1998; Ozturk et al., 2015).

3.1. Observed Trends

Meteorological records indicate that Turkey's mean annual surface temperature has increased by approximately 1.5°C since the 1960s, with the most rapid warming occurring after the 1990s (Bagcaci, 2023; IPCC, 2021). Regional analyses show that:

Western and Southern Turkey have seen the highest increases in summer maximum temperatures, exceeding +2.5°C in some areas.

Central and Eastern Anatolia exhibit greater increases in winter minimum temperatures, indicating a reduction in frost days.

Precipitation patterns have shifted, with a decline in winter and spring precipitation over the Aegean, Mediterranean, and Southeastern Anatolia regions, while some increases have been observed in the Eastern Black Sea region (Sen et al., 2012; Bagcaci, 2023).

These observed changes have already manifested in increased drought frequency, streamflow reductions, and longer dry seasons, especially in semi-arid basins (Pilevneli et al., 2023).

3.2. Projected Trends

Future climate projections using global and regional climate models (e.g., CMIP5, CMIP6, RegCM4, WRF) suggest that Turkey will continue to warm significantly under all major emission scenarios (RCP4.5, RCP8.5; SSP2-4.5, SSP5-8.5).

Temperature Increases: Mean surface temperatures are projected to rise between 2–4°C under RCP4.5 and 4–6°C under RCP8.5 by the end of the 21st century (Ozturk et al., 2015; Bagcaci, 2023).

Precipitation Patterns: Seasonal shifts are expected, with reduced winter and spring precipitation across most agricultural regions and increased summer rainfall variability (Kilic & Gunal, 2021; Önder et al., 2009).

Extreme Events: Studies forecast more frequent and intense heatwaves, dry spells, and heavy rainfall events (Ozturk et al., 2015; Kilic & Gunal, 2021).

Specifically, the Mediterranean and Southeastern Anatolia regions are projected to face the most severe reductions in precipitation and increases in evapotranspiration, exacerbating water stress and soil degradation (Komuscu et al., 1998; Bagcaci, 2023).

Climate models also project substantial increases in rainfall erosivity in the Black Sea region and reductions in soil moisture availability across most inland areas, which may significantly affect crop productivity and land sustainability (Kilic & Gunal, 2021; Komuscu et al., 1998).

3.3. Implications

These observed and projected climate changes underscore the urgency of integrating climate resilience into Turkey's agricultural policies. The shifting climatic baselines redefine the biophysical conditions under which crops are grown, livestock is raised, and water is allocated. Anticipating these changes is critical to ensuring food security, rural stability, and sustainable resource use in the coming decades.

4. Impacts on Crop Production and Livestock

Climate change exerts multidimensional pressures on agricultural systems, with both direct and indirect effects on crop production and livestock performance. In Turkey, these impacts have already begun to manifest through altered crop yields, shifting growing seasons, and rising vulnerability of livestock to heat and water stress. The interplay between increasing temperatures, precipitation variability, and extreme events poses a systemic threat to food security and rural economies (Dellal et al., 2011; Vanli et al., 2019; Pilevneli et al., 2023).

4.1. Crop Production

The effects of climate change on crop production in Turkey vary by crop type, region, and cultivation system. Rain-fed cereal crops, particularly wheat and barley, are among the most vulnerable to climatic variability due to their dependence on winter-spring precipitation and limited soil moisture reserves (Özdogan, 2011; Vanli et al., 2019). Regional crop modeling studies have demonstrated that:

Winter wheat yields could decline by 5–35% by the end of the century under RCP8.5, particularly in semi-arid areas like Central and Southeastern Anatolia (Özdogan, 2011).

Crop development is accelerated under higher temperatures, resulting in shortened grain-filling periods, decreased biomass accumulation, and lower yields (Vanli et al., 2019).

In the Southeastern Anatolia region, where irrigation is widespread, studies reveal that increased irrigation demand will not be met sustainably, leading to productivity and income losses up to 100% in some basins under RCP8.5 by 2100 (Pilevneli et al., 2023).

The spatial-temporal variability of climate change has also shifted phenological stages of key crops, altered pest and disease dynamics, and increased the risk of late frosts or early heatwaves during sensitive reproductive stages (Sen et al., 2012).

4.2. Livestock Production

The livestock sector is increasingly affected by rising temperatures, reduced water availability, and declining forage productivity. Key observed and projected impacts include:

Heat stress in animals reduces feed intake, fertility, and milk production—particularly in dairy cattle and small ruminants (FAO, 2021; Vanli et al., 2019).

Pasture degradation and declining forage quality are projected to reduce the carrying capacity of rangelands in Eastern and Southeastern Anatolia (Komuscu et al., 1998).

Increased frequency of drought events leads to fodder shortages, rising feed costs, and higher mortality risks, particularly in extensive livestock systems (IPCC, 2021).

Extreme weather events such as hail, floods or cold snaps can cause livestock mortality and disrupt supply chains.

Furthermore, livestock contributes significantly to greenhouse gas (GHG) emissions through enteric fermentation and manure management. Thus, climate-smart livestock systems are necessary not only to reduce vulnerability but also to mitigate emissions (Climate and Livestock, 2020).

4.3. Interactions and Future Outlook

The interaction between crop and livestock systems under climate stress will likely amplify rural vulnerabilities. Declines in cereal yields affect feed supply, while rangeland degradation affects soil carbon and biodiversity. These feedback loops indicate that future adaptation strategies must be integrated and systems-based, combining improved crop varieties, precision irrigation, rotational grazing, and feed diversification (MEU, 2012; Vanli et al., 2019).

5. Water Resources and Irrigation Challenges

Water availability is the single most critical input for agricultural productivity in Turkey**,** especially in regions where semi-arid and arid climates dominate. Climate change is significantly altering the hydrological cycle, leading to increasing evapotranspiration, declining surface water flows, and more frequent droughts—all of which compound the already pressing irrigation challenges faced by Turkish agriculture (Komuscu et al., 1998; Pilevneli et al., 2023).

5.1. Current Water Use and Agricultural Dependency

Turkey’s agriculture accounts for approximately 74–76% of total water consumption, making it the most water-dependent sector in the country (MEU, 2012; Sen et al., 2012). Irrigated agriculture, particularly in regions

such as Southeastern Anatolia (GAP), Konya Plain, and the Çukurova Basin, is both highly productive and increasingly unsustainable under future climate conditions. Most irrigation systems still rely on open canal methods, with overall efficiency levels below 45% in many districts (Pilevneli et al., 2023).

5.2. Climate-Induced Water Stress

Climate projections suggest that Turkey will face significant water shortages by mid to late 21st century, especially under RCP8.5 and SSP5-8.5 scenarios. According to multiple model ensembles (CMIP5 and CMIP6):

Annual runoff in western and southern basins may decline by 20–50%, particularly in the Mediterranean and Euphrates-Tigris basins (Bagcaci, 2023).

The soil moisture deficit is projected to intensify during the summer growing season, severely affecting crop productivity and increasing irrigation demand by 15–30% in major production regions (Komuscu et al., 1998; Önder et al., 2009).

The aridity index reveals a transition of many agro-ecological zones from semi-humid to semi-arid or arid conditions, especially in Central Anatolia and the Aegean region (Önder et al., 2009; Ozturk et al., 2015).

Even regions that currently benefit from sufficient irrigation infrastructure are expected to experience inter-seasonal and inter-annual fluctuations in water supply, making adaptive irrigation planning critical.

5.3. Regional Challenges and Case Examples

In the GAP region, studies indicate that the projected increase in temperature coupled with reduced precipitation will result in substantial declines in available irrigation water, despite current dam capacity. Moreover, soil salinization and inefficient irrigation practices are leading to long-term land degradation (Komuscu et al., 1998; Pilevneli et al., 2023).

In Central Anatolia, where irrigation relies heavily on groundwater abstraction, aquifer depletion is accelerating. Climate-driven recharge limitations are projected to further constrain water availability in this already vulnerable region (Sen et al., 2012; Kilic & Gunal, 2021).

5.4. Strategic Needs and Adaptation Options

To address these mounting challenges, the following measures have been emphasized in both scientific literature and national strategies:

- Modernization of irrigation infrastructure (e.g., drip and sprinkler systems),
- Investment in precision agriculture and deficit irrigation techniques,
- Enhancement of basin-scale water governance and inter-sectoral allocation mechanisms,
- Integration of climate-smart water budgeting tools,
- Reforestation and land management to improve catchment-level infiltration and retention (MEU, 2012; Ozturk et al., 2015).

Such interventions are essential to buffer against the projected 15–40% increase in irrigation water demand and ensure long-term sustainability of agricultural production.

6. Socioeconomic Impacts on Rural Communities

6.1. Rural Livelihoods and Vulnerability to Climate Change

Rural communities in Turkey are highly dependent on agriculture for their livelihoods, making them particularly vulnerable to the adverse impacts of climate change. The increasing frequency of extreme weather events, such as droughts, heatwaves, and irregular rainfall, has significantly altered the conditions under which agricultural production is carried out (Sen et al., 2012; Komuscu et al., 1998). These changes are not merely biophysical but deeply socioeconomic, threatening the sustainability of rural life.

In regions such as Southeastern Anatolia and Central Anatolia, where agricultural income constitutes a major share of household earnings, climate-induced changes in soil moisture availability and precipitation patterns have led to declines in crop yields and uncertainty in seasonal income (Komuscu et al., 1998; Vanli et al., 2019). According to crop modeling studies conducted in Southeastern Turkey, wheat yields are expected to decrease by 13–17% by the end of the century under high-emission scenarios (Vanli et al., 2019). These declines disproportionately affect smallholder farmers who often lack the financial buffer and technical resources to adapt effectively.

Moreover, projections suggest that under RCP 8.5, Turkey will face temperature increases between 2°C and 4.5°C by 2100, accompanied by reduced precipitation in critical agricultural zones (Ozturk et al., 2015; Ba-

gçacı, 2023). These changes exacerbate the vulnerability of dryland farming systems, which are predominant in rural Turkey. A shift toward arid and semi-arid conditions is likely, as indicated by aridity index analyses (Önder et al., 2009), which anticipate a marked transition in land cover and agricultural viability, especially in the southern and central regions.

The economic assessment by Dellal et al. (2011) underscores the extent of potential losses, projecting substantial income declines in climate-sensitive crops, particularly in cereal production. When coupled with low adaptive capacity such as limited access to irrigation technologies, insufficient extension services, and inadequate crop insurance mechanisms rural populations become increasingly exposed to poverty and food insecurity (Ahmed et al., 2022; Bozoglu et al., 2019).

Furthermore, non-economic impacts such as psychological stress, social fragmentation, and the erosion of traditional knowledge systems also play a role in weakening community resilience. The compound effect of environmental stressors and economic instability has contributed to increasing out-migration from rural areas, particularly among the youth, thereby accelerating demographic aging and labor shortages in agriculture (Sen et al., 2012; Climate Adaptation Strategy and Action Plan, 2011).

In summary, rural livelihoods in Turkey are intrinsically linked to climate-sensitive sectors. Without urgent and coordinated adaptation strategies encompassing water management, income diversification, climate-smart agriculture, and social safety nets the capacity of rural communities to withstand future climate shocks will remain critically constrained.

6.2. Agricultural Income and Employment Instability

Climate change in Turkey has increasingly destabilized agricultural incomes and employment, particularly in regions that are dependent on climate-sensitive crops and rain-fed production systems. With rising temperatures, increased evapotranspiration, and shifting precipitation patterns, farmers are experiencing more frequent yield fluctuations and income insecurity (Vanli et al., 2019; Sen et al., 2012). This instability undermines not only the economic base of rural communities but also broader regional food security and rural development.

In regions such as Southeastern Anatolia, Central Anatolia, and the Aegean, cereal-based systems and horticultural production are highly vulnerable to climatic stress. For example, in a study applying the CERES-Wheat crop model under RCP 4.5 and RCP 8.5 scenarios, wheat yields are projected to decline by up to 17% by the end of the century, directly affecting both farm income and rural employment (Vanli et al., 2019). These

projections are consistent with Özdogan's (2011) earlier modeling work in Northwestern Turkey, where high-temperature scenarios shortened grain-filling periods and reduced yields by 20–35%, especially under rain-fed conditions.

The economic consequences of yield reductions are far-reaching. According to Dellal, McCarl, and Butt (2011), climate-induced productivity losses could lead to an annual GDP reduction of €14–18 billion in the agricultural sector alone if no adaptation measures are taken. Labor demand in agriculture is closely linked to production volume and seasonal cycles, and climate variability disrupts both. The result is a growing trend of underemployment and informal labor, particularly affecting seasonal and migrant workers who lack social protection (Climate Adaptation Strategy and Action Plan, 2011).

Moreover, crop-specific vulnerabilities affect employment composition and gender roles in agriculture. For instance, women often dominate labor-intensive crop harvesting activities such as cotton, vegetables, and fruit production crops that are highly climate-sensitive (Ahmed et al., 2022). Income volatility in these subsectors translates into greater livelihood precarity for female agricultural workers, who also have less access to adaptation resources such as credit and land ownership (Bozoglu et al., 2019).

Climate variability also leads to increased production costs. Farmers must invest more in irrigation, pest control, and fertilizers to maintain productivity under changing climatic conditions. However, only large-scale commercial farms can afford such investments, widening the economic gap between them and smallholders, who often rely solely on climate-sensitive crops and lack access to financial markets (Pilevneli et al., 2023). This uneven capacity to adapt amplifies the income inequality within rural areas.

Employment in agriculture is also threatened by the broader economic shifts induced by climate change, including the relocation of agro-industrial investments, reduction in rural services, and rising land degradation. Erosion of the natural resource base further exacerbates employment risks. Kilic and Gunal (2021) demonstrate that soil productivity losses due to rainfall erosivity are expected to increase in the Mediterranean and Southeastern Anatolia, directly undermining labor demand in cultivation-intensive sectors.

To address these challenges, Turkey's national policy documents, including the Climate Change Adaptation Strategy and Action Plan (2011–2023), emphasize the importance of strengthening agricultural insurance systems, providing vocational training in climate-resilient farming, and encouraging income diversification. However, implementation gaps and

limited institutional coordination continue to hinder their impact on the ground.

In conclusion, the growing instability in agricultural income and employment in Turkey is a direct reflection of the country's increasing exposure and limited adaptive capacity to climate change. Without targeted interventions such as expanding social safety nets, improving access to climate-resilient technologies, and reforming agricultural labor policies the socioeconomic foundations of rural communities will remain fragile and increasingly vulnerable.

6.3. Migration, Demographic Shifts, and Social Cohesion

Climate change is increasingly recognized as a key driver of migration and demographic shifts in Turkey, particularly within rural agricultural communities. As the frequency and intensity of droughts, heatwaves, and unpredictable weather patterns grow, many smallholder farmers and seasonal laborers are forced to abandon their livelihoods in search of more stable opportunities in urban centers or abroad (Sen et al., 2012; Ozturk et al., 2015). This phenomenon represents not only a socio-economic adjustment but also a profound disruption in the cultural and demographic fabric of rural Turkey.

Rural out-migration, especially among youth and working-age men, is already underway in areas severely affected by climate variability, such as Southeastern and Central Anatolia (Vanli et al., 2019; Kilic & Gunal, 2021). With agricultural incomes declining due to yield losses and water scarcity, families are increasingly choosing to send younger members to cities, contributing to both depopulation and aging of the rural labor force. A study by the Turkish Ministry of Environment (2011) noted that climate change-induced migration is likely to accelerate by mid-century, especially under the RCP8.5 scenario, where agricultural employment could become unviable in many semi-arid zones.

Demographic imbalances caused by climate migration weaken rural social cohesion. As younger generations leave, the elderly population left behind struggles to maintain traditional agricultural practices, and the intergenerational transmission of agricultural knowledge is disrupted. This erosion of local knowledge systems further reduces the resilience of farming communities to adapt to environmental shocks (Ahmed et al., 2022). Moreover, climate migration often leads to the fragmentation of extended family structures and community-based mutual aid systems, which have historically played a critical role in coping with hardship.

The gendered dimension of migration must also be emphasized. In many cases, male household members migrate for work, leaving women with increased burdens of agricultural labor and household management without corresponding access to decision-making or financial resources (Bozoglu et al., 2019). This feminization of rural labor, under conditions of worsening climate stress, exacerbates existing inequalities and poses challenges to both productivity and well-being.

In urban areas, the influx of climate-displaced rural populations adds pressure to informal employment markets, housing systems, and social services. While urban migration may offer temporary economic relief for rural households, it rarely translates into long-term upward mobility and may create new forms of vulnerability. Migrants often live in precarious conditions, disconnected from institutional support and exposed to exploitation or environmental hazards in urban peripheries (Dellal et al., 2011).

Furthermore, local tensions can arise as host communities perceive newcomers as competitors for scarce resources or jobs. In such contexts, climate-induced migration can erode social cohesion not only in the places migrants leave but also in those where they settle (Ahmed et al., 2022). This highlights the importance of integrated rural-urban development and planning policies that anticipate and address the demographic consequences of climate change.

In sum, migration patterns in Turkey are being increasingly shaped by climate change and agricultural vulnerability. Without proactive measures such as rural revitalization programs, climate-resilient agricultural development, and equitable migration policies the socioeconomic sustainability and social harmony of both rural and urban communities will be at risk.

6.4. Gendered Impacts and Social Equity Issues

The socioeconomic impacts of climate change on Turkish agriculture are not distributed equally; they are deeply gendered and stratified across lines of age, class, and geographic location. Women in rural areas are especially vulnerable to the multifaceted effects of climate change, given their central yet often undervalued role in agricultural labor, household food security, and natural resource management (Ahmed et al., 2022; Bozoglu et al., 2019). Despite their contributions, structural inequalities limit women's access to resources, decision-making platforms, and adaptation opportunities.

In many parts of rural Turkey, women are responsible for labor-intensive agricultural tasks such as planting, weeding, harvesting, and post-harvest processing, particularly in horticultural and livestock sectors. These

subsectors are highly sensitive to climatic fluctuations changes in temperature and precipitation directly affect product quality, income stability, and employment continuity. For example, increased frequency of droughts and erratic rainfall disrupt vegetable and fruit cultivation, disproportionately affecting women who dominate these subsectors (Sen et al., 2012).

However, women's adaptive capacity is constrained by limited land tenure rights, restricted access to credit and inputs, and weak participation in agricultural extension services (Climate Adaptation Strategy and Action Plan, 2011). According to national data and academic studies, less than 10% of landowners in Turkey are women, and female-headed households often lack formal labor contracts or insurance, leaving them more exposed to economic and environmental shocks (Bozoglu et al., 2019; Dellal et al., 2011).

Gender disparities in adaptation planning are further exacerbated by low levels of female representation in local governance and agricultural cooperatives. This exclusion limits women's ability to influence climate-related policy, participate in community-level decision-making, or benefit from resilience programs (Ahmed et al., 2022). Moreover, the lack of gender-disaggregated data in climate and agricultural research hinders effective policy formulation and monitoring of adaptation outcomes.

Climate change also compounds unpaid domestic and care responsibilities. As water sources become scarce and food systems become less stable, women must spend more time collecting water, managing household nutrition, and caring for family members affected by heat stress or food insecurity. This "time poverty" reduces women's opportunities for education, off-farm employment, and civic engagement, reinforcing cycles of poverty and marginalization (Ozturk et al., 2015).

Intersectionality is critical to understanding how climate change affects different social groups. For example, migrant women workers, ethnic minorities, and widows in rural Turkey face multiple layers of vulnerability. Migrant women, in particular, often work under precarious conditions in seasonal agriculture with limited legal protections or access to health services. These populations are frequently absent from national policy discussions on climate resilience, despite their high exposure and low coping capacity (Ahmed et al., 2022; Bozoglu et al., 2019).

Addressing gendered vulnerabilities requires mainstreaming gender into all climate change policies and agricultural development strategies. This includes designing gender-sensitive early warning systems, tailoring training programs to women farmers, expanding microcredit schemes, and supporting women's cooperatives. International experience shows that empowering women not only enhances household resilience but also contri-

butes to broader community adaptation and food security (IPCC, 2022; FAO, 2019).

In conclusion, social equity and gender justice are indispensable for effective climate adaptation in Turkish agriculture. Policies that overlook these dimensions risk reinforcing existing inequalities and undermining long-term resilience. Ensuring inclusive, participatory, and equitable adaptation frameworks is both a moral imperative and a practical necessity.

6.5. Adaptation Constraints and Community Resilience

While climate change adaptation is increasingly integrated into national and regional policy frameworks in Turkey, rural communities continue to face a range of structural and systemic constraints that limit their capacity to build resilience. These constraints are not only technological or financial in nature, but also institutional, informational, and socio-cultural (Climate Adaptation Strategy and Action Plan, 2011; Dellal et al., 2011).

One of the most critical barriers is the limited access to climate-relevant information and early warning systems in rural areas. Farmers often lack reliable, localized forecasts or technical knowledge needed to interpret climatic risks, especially in regions with low digital infrastructure (Sen et al., 2012; Öztürk et al., 2015). Without access to these tools, timely decision-making for crop planning, irrigation scheduling, or pest management becomes highly uncertain.

Additionally, financial and infrastructural constraints inhibit investment in adaptive technologies such as drip irrigation, drought-resistant seeds, or soil conservation practices. Small-scale farmers, who form the majority of agricultural producers in Turkey, frequently lack access to affordable credit, crop insurance, or government subsidies that would enable such investments (Bozoglu et al., 2019). Where subsidies or insurance schemes do exist, their uptake is often limited by bureaucratic hurdles or low awareness at the community level.

Institutional fragmentation also weakens resilience. Climate change adaptation in Turkey spans multiple ministries (e.g., agriculture, environment, water, interior), yet coordination mechanisms are underdeveloped. Local implementation of national strategies often suffers from unclear mandates, overlapping responsibilities, and limited capacity within local government bodies (Bagçacı, 2023). This results in a disconnect between high-level planning and on-the-ground realities.

Social factors play an equally important role. Trust in institutions, community networks, and traditional knowledge systems significantly influence how communities perceive and respond to climatic threats.

However, recent trends of rural depopulation, social fragmentation, and the erosion of informal support structures have reduced collective resilience (Ahmed et al., 2022; Vanli et al., 2019). Adaptive capacity is also stratified by gender, age, and socioeconomic status, with marginalized groups often excluded from planning and benefit-sharing processes.

Despite these challenges, there are examples of resilient local practices and innovations. In some regions, farmers are diversifying crop portfolios, reintroducing traditional drought-resistant varieties, or engaging in collective water management systems. Civil society organizations and cooperatives have played an increasing role in facilitating knowledge sharing and accessing funding opportunities (Pilevneli et al., 2023).

Building community resilience requires a holistic and participatory approach. This includes decentralizing adaptation planning, strengthening agricultural extension services, promoting inclusive governance, and investing in social capital as much as in physical infrastructure. Resilience is not merely the capacity to withstand shocks but also the ability to transform systems to thrive under new climatic conditions (IPCC, 2022).

In summary, addressing adaptation constraints in rural Turkey calls for coordinated, inclusive, and context-specific strategies. Community resilience must be seen not as a passive outcome of adaptation policies, but as a dynamic process driven by empowerment, equity, and shared knowledge.

7. Adaptation Strategies and Good Practices

7.1. Agronomic and Technological Adaptation Measures

Agronomic and technological adaptation strategies form the backbone of climate resilience in Turkey's agricultural sector. As climate change increasingly alters precipitation patterns, elevates temperatures, and intensifies extreme weather events, producers across the country are turning to a combination of traditional and modern solutions to sustain yields, conserve resources, and maintain economic viability (Sen et al., 2012; Vanli et al., 2019).

A prominent agronomic strategy is the adoption of drought- and heat-tolerant crop varieties, particularly in regions like Southeastern Anatolia and Central Anatolia, where cereal crops such as wheat and barley dominate. Research using the CERES-Wheat model indicates that genetically improved wheat varieties can partially offset yield losses expected under RCP 4.5 and 8.5 scenarios by mid- and late-century (Vanli et al., 2019). These varieties exhibit improved water-use efficiency, shorter maturation periods, and greater tolerance to thermal stress.

Adjustments in sowing dates also present a low-cost, high-impact adaptation measure. Shifting planting periods to avoid the most critical heat or drought stress windows has been shown to improve yields, especially in dry farming systems (Öztürk et al., 2015; Bagçacı, 2023). However, such adjustments must be supported by timely meteorological forecasts and localized extension services, which remain limited in some rural regions.

Another increasingly critical adaptation is the expansion of water-saving irrigation technologies, such as drip and sprinkler systems. In a context where irrigated agriculture accounts for over 75% of total freshwater withdrawals (Topcu, 2011), improving irrigation efficiency is vital. While drip irrigation has demonstrated substantial benefits in vegetable and fruit production in the Mediterranean and Aegean regions, its adoption is constrained by high upfront costs and limited access to financing among smallholders (Pilevneli et al., 2023; Dellal et al., 2011).

Soil and water conservation practices, including mulching, reduced tillage, and cover cropping, have also gained attention. These practices not only enhance soil organic matter and moisture retention but also reduce erosion a growing threat under intensified rainfall patterns projected in the Mediterranean basin (Kilic & Gunal, 2021). The use of soil moisture monitoring technologies, combined with remote sensing and Geographic Information Systems (GIS), has emerged as a valuable tool for both irrigation scheduling and drought forecasting (Komuscu et al., 1998).

In livestock systems, adaptation measures include improved feeding strategies, shade provision, and breed selection. Heat stress poses a significant risk to animal health and productivity in the Southern and Southeastern provinces. Technological innovations such as smart barns with ventilation and cooling systems are slowly being introduced but remain limited to larger operations (Bozoglu et al., 2019).

While these agronomic and technological adaptations offer substantial promise, their uptake remains uneven across Turkey. Barriers include lack of access to credit, weak extension services, fragmented land ownership, and limited digital infrastructure (Ahmed et al., 2022). Furthermore, the integration of traditional knowledge such as local crop rotations or indigenous seed use into modern agronomic planning is still underutilized.

The success of these measures depends not only on their technical efficacy but also on institutional support, knowledge dissemination, and participatory approaches that ensure the engagement of farmers in decision-making. As such, technological innovation must be embedded within broader systems of social learning and cooperative action to ensure equitable and sustainable adaptation.

7.2. Institutional and Policy-Based Adaptation

Institutional and policy-based adaptation is a critical pillar of Turkey's national response to climate change, particularly in the agricultural sector, which remains highly vulnerable to climatic shocks. Over the past two decades, a variety of policy instruments, national strategies, legal frameworks, and institutional arrangements have been developed to improve the resilience of rural communities and agri-food systems. However, despite these advances, significant implementation gaps and systemic barriers persist (Climate Adaptation Strategy and Action Plan, 2011; Bagçacı, 2023).

Turkey's central climate adaptation roadmap, the National Climate Change Adaptation Strategy and Action Plan (2011–2023), outlines key areas such as water management, agricultural resilience, ecosystem services, and disaster risk reduction. Within agriculture, the strategy emphasizes the importance of integrating climate change considerations into irrigation infrastructure, crop insurance, and rural development planning (MoEU, 2011). Yet, the operationalization of this strategy at the local level remains limited by fragmented institutional mandates, insufficient funding, and a lack of vertical coordination between national and local authorities (Dellal et al., 2011; Sen et al., 2012).

The Ministry of Environment, Urbanization and Climate Change (MoEUCC), along with the Ministry of Agriculture and Forestry (MoAF), leads climate adaptation in agriculture. However, the overlapping responsibilities between various institutions such as the State Hydraulic Works (DSI), the General Directorate of Agricultural Research (TAGEM), and provincial directorates can result in inefficiencies and policy incoherence (Bagçacı, 2023). Moreover, while strategic planning documents exist, local governments often lack the technical capacity and financial autonomy to implement adaptation actions effectively (Topcu et al., 2011; Ozturk et al., 2015).

One area where progress is being made is agricultural insurance and risk transfer mechanisms. The TARSIM (Agricultural Insurance Pool) system, partially supported by government subsidies, provides insurance against drought, frost, and extreme weather events. However, uptake remains uneven across regions and farm sizes, with smallholders and women farmers often excluded due to administrative complexity, lack of awareness, or financial constraints (Bozoglu et al., 2019).

Additionally, Turkey has made strides in aligning with international frameworks such as the EU Green Deal and the UNFCCC Paris Agreement. The EU Border Carbon Adjustment Mechanism (CBAM), though still evolving, will indirectly impact Turkey's agricultural exports and va-

lue chains, creating new pressures for alignment with sustainable production standards (Pilevneli et al., 2023). Yet, Turkey's climate governance remains largely centralized, with limited opportunities for participatory, bottom-up adaptation planning at the community level (Ahmed et al., 2022).

Monitoring and evaluation (M&E) systems for climate policies are also underdeveloped. A lack of disaggregated, spatially explicit data hampers effective targeting of resources, particularly for vulnerable groups such as women, migrants, and smallholders (Öztürk et al., 2015; IPCC, 2022). Furthermore, adaptation indicators are not well integrated into national statistical frameworks, making it difficult to assess policy performance and adaptation effectiveness over time.

Despite these limitations, some municipalities and regional development agencies have started to integrate climate adaptation into their planning, especially through EU-funded projects and academic collaborations (Climate Change Adaptation Status of Turkish Local Governments, 2020). These efforts demonstrate the potential of multi-level governance models that combine national leadership with empowered local actors.

In conclusion, Turkey's institutional adaptation framework for agriculture is robust in design but challenged in execution. Strengthening coordination, decentralizing implementation, enhancing financial instruments, and fostering inclusive governance structures are essential steps to ensure that institutional and policy-based adaptation moves from strategic intent to tangible resilience on the ground.

7.3. Ecosystem-Based and Traditional Practices

As climate change increasingly threatens agricultural productivity in Turkey, ecosystem-based adaptation (EbA) and traditional knowledge systems offer valuable pathways for enhancing resilience. These approaches, grounded in ecological processes and local cultural heritage, not only support sustainable land and water use but also contribute to biodiversity conservation and climate mitigation (Vanli et al., 2019; Turkey's National Climate Change Adaptation Strategy and Action Plan, 2012).

Ecosystem-Based Adaptation (EbA) in Turkish Agriculture

Ecosystem-based adaptation involves the use of biodiversity and ecosystem services as part of a broader adaptation strategy to help people and communities adapt to the adverse effects of climate change. In Turkey, agroecological practices such as crop diversification, conservation tillage, organic amendments, and integrated pest management are gaining

attention, particularly in semi-arid regions (Dellal et al., 2011; Önder et al., 2009). For instance, the maintenance of traditional olive and fig orchards in the Aegean and Mediterranean regions supports both ecological integrity and local economies while providing resilience against drought and soil degradation (Vanli et al., 2019).

Wetland restoration and sustainable pasture management are also among the prominent ecosystem-based strategies. In Central and Eastern Anatolia, well-managed rangelands enhance carbon sequestration and preserve native flora, which is critical in maintaining fodder systems for livestock under changing climatic conditions (Hoogenboom et al., 2015; Climate Change and Agriculture in Turkey, 2022). Similarly, the use of shelterbelts, hedgerows, and forest strips around agricultural lands still common in some Black Sea regions functions as a buffer against wind erosion and microclimatic extremes.

Traditional Knowledge and Local Practices

Traditional agricultural systems in Turkey, especially in rural and mountainous regions, integrate centuries-old knowledge of land, water, and biodiversity management. Nomadic and semi-nomadic livestock herding practices, particularly in the Taurus and Eastern Anatolian Mountains, reflect an adaptive strategy based on seasonal mobility and pasture rotation. These practices reduce grazing pressure on fragile ecosystems and provide flexibility in times of climatic stress (Dogan & Karakas, 2018).

In arid and semi-arid zones, traditional water harvesting methods such as “karez” systems and small-scale terrace irrigation have long been used to capture and store rainfall, reduce runoff, and enhance soil moisture retention. These systems, which are still observed in parts of Southeastern Turkey, are increasingly recognized for their climate adaptation potential (Ahmad et al., 2019).

The use of local seed varieties (landraces) and on-farm seed selection also exemplify traditional resilience-building strategies. These landraces, adapted to local climatic conditions over generations, offer a genetic reservoir that is vital for crop improvement under climate stress (Dudu & Çakmak, 2018; Özdoğan, 2011).

Integration into Policy and Practice

Despite their proven benefits, ecosystem-based and traditional practices are often undervalued in mainstream agricultural policies. However, Turkey’s National Climate Change Adaptation Strategy and Action Plan (2011–2023) emphasizes the importance of incorporating local knowledge

and nature-based solutions into national adaptation planning (Ministry of Environment and Urbanization, 2012). Moreover, the increasing focus on sustainable rural development and agri-environmental programs in EU-aligned policies creates an enabling framework for scaling up such approaches.

8. Policy Implications and Institutional Framework

Climate change poses complex challenges that transcend traditional sectoral boundaries, especially in agriculture, water management, and rural development. In Turkey, addressing the agricultural impacts of climate change requires not only technological and ecological strategies but also coherent policy frameworks and robust institutional arrangements (Ministry of Environment and Urbanization, 2012). Effective climate adaptation hinges on the coordination of national strategies, sectoral policies, and multilevel governance mechanisms.

8.1. National Strategies and Policy Documents

Turkey has developed a range of strategic policy documents that acknowledge the risks posed by climate change. The National Climate Change Adaptation Strategy and Action Plan (2011–2023) constitutes the main framework for adaptation policies across sectors. This document emphasizes the need for adaptation in five priority areas: water resources, agriculture and food security, ecosystem services, natural disaster risk management, and public health (Ministry of Environment and Urbanization, 2012).

In addition, the Agricultural Drought Strategy and Action Plan (2008–2012) introduced measures to manage drought risk, emphasizing early warning systems, sustainable water use, and education programs for farmers. More recently, the 11th Development Plan (2019–2023) has incorporated climate-related considerations into broader economic and rural development goals. It highlights resilience-building in agriculture, improving irrigation infrastructure, and promoting climate-smart agriculture (Dellal et al., 2011; Dudu & Çakmak, 2018).

Turkey's alignment with the European Union Green Deal and commitments under the Paris Agreement have also triggered the development of updated climate policies, including the drafting of a Long-Term Climate Strategy and a Climate Law. However, implementation and enforcement remain uneven, particularly at the local level.

8.2. Key Institutions and Governance Structure

Multiple institutions are involved in climate change policy and agricultural adaptation in Turkey, often with overlapping mandates. The Ministry of Environment, Urbanization and Climate Change is the leading institution in developing national adaptation policy, while the Ministry of Agriculture and Forestry implements sector-specific measures including sustainable land and water management, support for climate-resilient crops, and rural development initiatives.

The General Directorate of State Hydraulic Works (DSİ) is responsible for national water infrastructure and basin-level planning. Local governments, regional development agencies, and municipal authorities also play a critical role, particularly in implementing adaptation measures such as flood control systems, irrigation modernization, and community-based programs (Önder et al., 2009; Turkey's NCCAP, 2012).

Despite this extensive institutional structure, coordination among stakeholders remains limited. Climate-related data sharing is fragmented, and institutional responsibilities are often unclear or overlapping. This results in inefficiencies, particularly in integrating climate considerations into rural planning and agricultural extension services (Vanli et al., 2019).

8.3. Challenges and Gaps in Institutional Capacity

Several institutional and policy-related challenges undermine Turkey's adaptive capacity in agriculture:

- Fragmented governance among ministries and agencies, limiting integrated climate planning.
- Weak horizontal coordination between national and subnational actors.
- Limited financial and technical capacity at the local level to implement adaptation actions.
- Insufficient participation of farmers, cooperatives, and civil society, especially in the design of adaptation policies.
- Underutilization of traditional knowledge systems and local practices in formal policy frameworks.
- These challenges are further exacerbated by the lack of binding legislation on climate change, which creates a gap in enforcement and long-term commitment.

8.4. Policy Recommendations

To strengthen climate adaptation in agriculture and rural development, Turkey must adopt a more integrated and participatory governance approach:

- Mainstream adaptation into all sectoral strategies (agriculture, forestry, water, disaster risk management).
- Develop and enforce a comprehensive Climate Law with clear institutional responsibilities.
- Enhance inter-ministerial coordination through a dedicated climate adaptation council or platform.
- Promote decentralized planning by empowering municipalities and regional authorities.
- Invest in monitoring systems, climate-smart agriculture research, and public awareness campaigns.
- Strengthen financial mechanisms to support adaptation projects, including public–private partnerships and access to international climate finance.

Ultimately, effective adaptation in Turkey's agricultural sector will depend on the alignment of policy goals, institutional coherence, and the ability to integrate scientific knowledge with local realities.

9. Conclusion and Recommendations

Climate change presents an urgent and multifaceted threat to the sustainability of agricultural systems in Turkey. As demonstrated throughout this chapter, the impacts are already visible across regions and production systems—ranging from fluctuating crop yields and increased water scarcity to socioeconomic instability in rural communities. These effects are particularly pronounced in semi-arid zones and rain-fed agriculture, where adaptive capacity is often limited (Dellal et al., 2011; Vanli et al., 2019).

Model projections underscore that without significant mitigation and adaptation efforts, Turkey's agricultural productivity and food security will face increasing challenges under future climate scenarios. The country is expected to experience higher temperatures, reduced and variable precipitation, more frequent droughts, and intensified rainfall erosivity, all of which exacerbate existing environmental stresses such as land degradation and water overuse (Bagçacı, 2023; Kilic & Gunal, 2021).

Despite these risks, Turkey has taken meaningful steps toward adaptation through national strategies, policy reforms, and emerging local ini-

tiatives. Notably, the National Climate Change Adaptation Strategy and Action Plan (2011–2023) and sectoral programs on water and drought management provide important institutional frameworks. However, gaps remain in implementation, inter-institutional coordination, financing, and the integration of local and traditional knowledge systems (MEU, 2012; Ozturk et al., 2015).

A key finding of this review is the importance of region-specific, multi-level adaptation strategies that account for Turkey's agro-climatic and socioeconomic diversity. The effectiveness of adaptation depends not only on technological innovations but also on participatory governance, inclusive policy-making, and enhanced rural resilience.

Policy Recommendations

- Mainstream Climate Adaptation: Integrate climate considerations across all agricultural, environmental, and rural development policies with regionally differentiated priorities.
- Strengthen Institutional Coordination: Establish a centralized mechanism for climate governance that enables vertical and horizontal coordination between ministries, municipalities, and civil society.
- Invest in Knowledge and Innovation: Enhance funding for climate-smart agriculture research, including crop modeling, early warning systems, and extension services tailored to smallholders.
- Promote Ecosystem-Based and Traditional Approaches: Recognize and support agroecological practices and indigenous knowledge as integral components of resilience strategies.
- Enhance Water Governance: Accelerate irrigation modernization, water-use efficiency, and basin-level integrated water resource management under projected scarcity conditions.
- Empower Vulnerable Groups: Develop gender-sensitive and inclusive adaptation programs that support women, youth, migrants, and economically marginalized farmers.
- Strengthen Financial Mechanisms: Expand access to credit, agricultural insurance, and international climate finance to support local adaptation investments.

Future Research Directions

- Longitudinal vulnerability assessments to track climate impacts and adaptation outcomes over time;
- Fine-scale crop and water modeling using updated climate scenarios (e.g., CMIP6);
- Social equity and justice in climate adaptation, especially in the context of migration, gender, and rural labor markets;
- Monitoring and evaluation frameworks for local implementation of national strategies;
- Integrated assessments combining economic, environmental, and social dimensions of resilience.

References

Ahmad, I., Vanli, Ö., Ustundag, B. B., Hernandez-Ochoa, I. M., & Hoogenboom, G. (2019). Using crop modeling to evaluate the impacts of climate change on wheat in southeastern Turkey. Environmental Science and Pollution Research, 26(29), 29397–29408. https://doi.org/10.1007/s11356-019-06061-6

Ahmed, N., Areche, F. O., Cabello, G. G. C., Trujillo, P. D. C., Sheikh, A. A., & Abiad, M. G. (2023). Intensifying effects of climate change in food loss: A threat to food security in Turkey. Sustainability, 15(350). https://doi.org/10.3390/su15010350

Ahmed, N., Areche, F. O., Cotrina Cabello, G. G., Córdova Trujillo, P. D., Sheikh, A. A., & Abiad, M. G. (2022). Intensifying effects of climate change in food loss: A threat to food security in Turkey. Sustainability, 15(1), 350. https://doi.org/10.3390/su15010350

Bagçacı, S. Ç. (2023). The analysis of current and future climate projections of Türkiye and the large-scale Eastern Mediterranean Black Sea region in the coarse and high resolutions [Doctoral dissertation, Middle East Technical University].

Bozoglu, M., Başer, U., Eroğlu, N. A., & Topuz, B. K. (2019). Impacts of climate change on Turkish agriculture. Journal of International Environmental Application and Science, 14(3), 97–103.

Climate Adaptation Strategy and Action Plan. (2011). Turkey's National Climate Change Adaptation Strategy and Action Plan (2011–2023). Ministry of Environment and Urbanization, Republic of Turkey.

Dellal, İ., McCarl, B. A., & Butt, T. (2011). The economic assessment of climate change on Turkish agriculture. Journal of Environmental Protection and Ecology, 12(1), 376–385.

Dogan, E., & Karakaş, M. (2018). Effects of climate change on agriculture in Turkey: An econometric analysis. Turkish Journal of Agricultural Economics, 24(2), 45–56.

Dudu, H., & Çakmak, E. H. (2018). Climate change and agriculture: An integrated approach to evaluate economy-wide effects for Turkey. Climate and Development, 10(3), 275–288. https://doi.org/10.1080/17565529.2017.1301861

FAO. (2021). Climate change and livestock: Impacts, adaptation, and mitigation. FAO Animal Production and Health Paper.

Hoogenboom, G., Jones, J. W., Wilkens, P. W., Porter, C. H., Boote, K. J., & Hunt, L. A. (2015). Decision support system for agrotechnology transfer (DSSAT) version 4.6. University of Florida, Gainesville, FL.

IPCC. (2021). Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press.

IPCC. (2022). Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press. https://www.ipcc.ch/report/ar6/wg2/

Kilic, O. M., & Gunal, H. (2021). Spatial-temporal changes in rainfall erosivity in Turkey using CMIP5 global climate change scenario. Arabian Journal of Geosciences, 14(1079). https://doi.org/10.1007/s12517-021-07184-2

Komuscu, A. U., Erkan, A., & Oz, S. (1998). Possible impacts of climate change on soil moisture availability in the Southeast Anatolia Development Project (GAP) region. Climatic Change, 40, 519–545.

MEU (Ministry of Environment and Urbanization). (2012). Turkey's National Climate Change Adaptation Strategy and Action Plan 2011–2023.

Ministry of Environment and Urbanization (MEU). (2012). Turkey's National Climate Change Adaptation Strategy and Action Plan 2011–2023. Republic of Turkey. Retrieved from https://iklim.csb.gov.tr

Önder, D., Aydın, M., Berberoğlu, S., Önder, S., & Yano, T. (2009). The use of aridity index to assess implications of climatic change for land cover in Turkey. Turkish Journal of Agriculture and Forestry, 33(3), 305–314. https://doi.org/10.3906/tar-0810-21

Özdoğan, M. (2011). Climate change impacts on irrigated agriculture in Turkey: A case study using dynamic process-based modeling. AFRC Research Series, (7), 23–34.

Özdogan, M. (2011). Modeling the impacts of climate change on wheat yields in Northwestern Turkey. Agriculture, Ecosystems and Environment, 141(1), 1–12. https://doi.org/10.1016/j.agee.2011.02.001

Ozturk, T., Ceber, Z. P., Türkeş, M., & Kurnaz, M. L. (2015). Projections of climate change in the Mediterranean Basin by using downscaled global climate model outputs. International Journal of Climatology, 35(15), 4276–4292. https://doi.org/10.1002/joc.4285

Pilevneli, T., Capar, G., & Sánchez-Cerdà, C. (2023). Investigation of climate change impacts on agricultural production in Turkey using volumetric water footprint approach. Sustainable Production and Consumption, 35, 605–623. https://doi.org/10.1016/j.spc.2022.12.013

Sen, B., Topcu, S., Türkeş, M., Sen, B., & Warner, J. F. (2012). Projecting climate change, drought conditions and crop productivity in Turkey. Climate Research, 52(2), 175–191. https://doi.org/10.3354/cr01074

Topcu, S. (2011). Climate change and irrigation water resources in Turkey: Impacts and adaptation strategies. In: A. Baba & M. F. Tayfur (Eds.), Climate Change and Its Effects on Water Resources: Issues of National and Global Security. NATO Science for Peace and Security Series C: Environmental Security.

Türkeş, M., & Sümer, U. M. (2004). Re-evaluation of trends and changes in mean, maximum and minimum temperatures of Turkey for the period 1929–1999. International Journal of Climatology, 24(3), 336–351.

Vanli, Ö., Ustundag, B. B., Ahmad, I., Hernandez-Ochoa, I. M., & Hoogenboom, G. (2019). Using crop modeling to evaluate the impacts of climate change on wheat in southeastern Turkey. Environmental Science and Pollution Research, 26(29), 29397–29408. https://doi.org/10.1007/s11356-019-06061-6.