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Kekik (*Thymus eigii* M. Zohary et P.H. Davis) Jalas Türünün Uçucu Yağının Karakterizasyonu ve *in silico* Modelleme Perspektifi

Sezgin SANCAKTAROĞLU[1] Bünyamin YILDIRIM[1] Kamil EKİCİ[2] Fatih DEMİREL[3]

[1] *Iğdır University, Faculty of Agriculture, Department of Field Crops, Iğdır, Türkiye.*

[2] *Van Yüzüncü Yıl University, Faculty of Veterinary Medicine, Department of Nutrition/Food Hygiene and Technology, Van, Türkiye.*

[3] *Iğdır University, Faculty of Agriculture, Department of Agricultural Biotechnology, Iğdır, Türkiye.*

**Sorumlu Yazar/Corresponding Author: Fatih DEMİREL, e-mail: drfdemirel@gmail.com*

Özet: Son yıllarda, aromatik bitkilerin ve tedavi edici özellikleri için kullanılan bitkilerin kullanımını içeren bitkisel ilaçların kullanımında bir artış olmuştur. Her geçen gün artan bu talebi karşılayabilmek için tıbbi bitkilerden elde edilen aktif bileşiklerin miktarının belirlenmesine önemli bir ihtiyaç duyulmaktadır. Bu araştırma için Hatay ili Amanos Dağı'ndan kekik (*Thymus eigii* M. Zohary et P.H. Davis) bitki örnekleri toplanmıştır. Bitkinin yer üstü kısmından uçucu yağı çıkarmak için hidrodistilasyon yöntemi kullanıldı ve uçucu yağın bileşenlerini analiz etmek için bir Gaz kromatografisi-kütle spektrometresi (GC-MS) kullanılmıştır. Yapılan analizler sonucunda 21 adet uçucu yağ bileşeni tespit edilmiştir. En yüksekler arasından ana bileşenler olarak Gamma-terpinene (%27.49), Carvacrol (%27.38) ve P-cymene (%14.40) belirlenmiştir. *Fusarium oxysporum* kütinaz yapısı ile H-bağlı etkileşimleri ortaya çıkaran başlıca monoterpenlerin etki mekanizması moleküler modelleme teknikleri kullanılarak araştırılmış ve bu yöntemler kullanılarak da en düşük bağlanma enerjileri hesaplanmıştır. Verilen bulguların, yaygın kekik bitkilerinden fitoterapötik bileşikler oluşturmaya yönelik gelecekteki araştırmaların yolunu açması olasıdır.

Anahtar kelimeler: Uçucu yağ bileşeni, tıbbi bitki, moleküler modelleme, moleküler bağlanma, patojen

Characterization of essential oil and *in silico* modelling perspectives of thyme (*Thymus eigii* M. Zohary et P.H. Davis) jalas species

Abstract: In recent years, the use of herbal medicines has increased, including the use of aromatic plants and plants used for their therapeutic properties. To meet this ever-increasing demand, the quantity of active compounds extracted from medicinal plants must be significantly determined. For this study, plant samples of thyme (*Thymus eigii* M. Zohary et P.H. Davis) were collected from Amanos Mountain in the province of Hatay. Hydrodistillation was utilized to extract the essential oil from the aboveground portion of the plant, and Gas chromatography-mass spectrometry (GC-MS) was utilized to analyze the essential oil's constituents. As a consequence of the analysis, twenty-one components of essential oils were identified. The principal components were determined as Gamma-terpinene (27.49%), Carvacrol (27.38%), and P-cymene (14.40%). The mechanism of action of the major monoterpenes that reveal H-bonded interactions with the structure of *Fusarium oxysporum* cutinase was investigated using molecular modeling techniques, and the lowest binding energies were calculated using these techniques. The presented findings are likely to pave the way for future research on phytotherapeutic compounds derived from common thyme plants.

Keywords: Essential oil component, medicinal plant, molecular modelling, molecular docking, pathogen

INTRODUCTION

Thymus eigii, also known as *T. syriacus* subsp. *eigii*, belongs to the *Lamiaceae* family and is indigenous to regions in southern Europe and Asia. It is classified under the *Thymus* genus, which has over 300 species of resilient perennial herbaceous plants and subshrubs (Könemann, 1999). *T. eigii*, similar to other species such as *Thymus*, *Coriandrum*, *Thymbra*, *Coridothymus*, and *Satureja* found in the Turkish flora, is often referred to as "kekik." This particular plant has a limited distribution in the southern Anatolia region (Davis, 1982; Kocabas and Karaman, 2001; Barut et al., 2021). The plant exhibits natural growth at elevations ranging from 500 to 915 meters in the regions of Lebanon, Syria, and Turkey (Barut et al., 2021).

The use of botanical resources for medicinal purposes is extensively practiced on a global scale. Active compounds present in plants are naturally occurring molecules that elicit physiological responses in both people and animals, while posing no damage to the environment. The chemical composition, therapeutic properties, and industrial applications of *Thymus* L. (thyme) species have been extensively studied on a global scale (Baser et al., 1996; Maharramov and Hüseynova, 2017; Barut et al., 2021).

Thyme, a botanical herb often used as a culinary seasoning, has a diverse array of applications including medicinal, pharmaceutical, and agricultural domains, encompassing both plant and animal cultivation. Thyme has been extensively used within the medical domain for an extended period, specifically for the therapeutic management of several ailments (Altundağ and Aslım, 2005). Previous research has shown that thyme juice has regulatory properties, as it alleviates spasms in the stomach and intestines, aids in digestion, and exhibits analgesic effects (Başer, 2001). Carvacrol, chemically known as 2-methyl-5-(1-methylethyl), is a phenolic monoterpenoid that exists in a liquid state and is often found in the essential oil of thyme. The substance has antibacterial, antioxidant, and anticancer effects. The induction of apoptosis by Carvacrol has been seen in both in vivo and in vitro investigations, whereby it exerts its effects on many genes and apoptotic pathways (Sharifi-Rad et al., 2018). In a research conducted by Koçak and Boyraz (2006), an evaluation was carried out to assess the antifungal properties of thyme oil in comparison to several other plant extracts. The impact of thyme oil on plant pathogenic fungus, including *Alternaria mali*, *Fusarium oxysporum*, *Botrytis cinerea*, *Sclerotinia sclerotiorum*, and *Colletotrichum circinans*, has been examined by researchers. The findings of their study, which included a comparative analysis of the antifungal activities of thyme oil and many other plant extracts, indicate that thyme oil exhibited efficacy against fungi at elevated doses (10 µl and 50 µl).

The fungus known as *Fusarium oxysporum* is transmitted via the soil. (Gordon and Martyn, 1997). In addition, *Fusarium oxysporum* is a huge species complex that includes plant infections. These pathogens target their attacks on a wide variety of species in a way that is host-specific (Fourie et al., 2011). In certain soils, referred to as favorable soils, soil-borne pathogens like *Fusarium oxysporum* are able to flourish and cause serious illnesses. On the other hand, in other soils, referred to as suppressive soils, these pathogens are able to flourish considerably less and produce much less severe diseases (Smith, 2007). The species contains a broad variety of strains that cause wilts or rots on numerous plant species (Dean et al., 2012). Also, there is evidence that *Fusarium oxysporum* is responsible for the illness that affects a wide variety of plants, including cotton, potato, and ornamental plants (Peters et al., 2008; Lecomte et al., 2016; Halpern et al., 2018). Researchers investigated how essential oils extracted from plants fared against the fungus *Fusarium oxysporum* (Barrera-Necha et al., 2009; Sharma et al., 2017). Essential oils have been shown to be effective against *Fusarium* wilt

disease in both a preventative and therapeutic capacity, thanks to the fact that the primary components of essential oils are able to break the cell membrane and produce a significant shift in the permeability of the cell (Gill and Holley, 2006; Sharma et al., 2017).

Cutin is one of the most prevalent polymers in nature and is made up of β-1,4 N-acetyl glucosamine units. Cutinases are hydrolytic enzymes that break down glycosidic bonds in chitin. Cutinase is found in the cell walls of fungus organisms (Tharanathan and Kittur, 2003). Extracellular cutinases are a kind of serine esterase that are used by the majority of plant diseases and saprophytes in order to break down cutin (Purdy and Kolattukudy, 1975). A cutinase that was produced by *Fusarium oxysporum* was analyzed for its biochemical and structural properties by Dimarogona et al. (2015).

This study was carried out to determine the essential oil ratios and components of Thyme (*Thymus eigii* M. Zohary et P.H. Davis) Jalas species, which grow naturally in Amanos Mountain in Hatay province and are widely found in the flora. In addition, in light of the information presented above, an estimation of the interaction was determined by using the primary components of *Thymus eigii* essential oils in order to reveal the enzymatic mechanism of action against the target enzyme, which was *Fusarium oxysporum* cutinase. This was done through the use of *in silico* methods.

MATERIAL AND METHOD

Material

The plants were collected from Amanos Mountain in Hatay, Türkiye. The plants were sampled by recording their locations using a GPS device each time they were inspected for field research.

Method

Obtaining the Essential Oil

The samples taken were dried in the shade after taxonomic identification, and were grouped according to the species names and localities from which they were taken. The 100 g of shade-dried plant samples were treated to a 3-hour hydrodistillation using a Clevenger equipment. The oils were extracted with dH_2O and kept in a sealed vial under N_2 pressure until usage at 20 °C. After taking enough samples, essential oil was obtained from these samples by steam distillation method with the Clevenger apparatus.

Determination of essential oil components and GS-MS

The acquired essential oil was extracted into a solvent (N-hexane) from water, and after dilution, the essential oil components were analyzed using the GC-MS (Gas Chromatography-Mass Spectrometry) instrument at Erciş Vocational School of Van Yuzuncuyil University. As a preliminary investigation, the essential oil components of several previously collected plant species were identified, and the following program was selected to be the GC-MS temperature program that yielded the best results for essential oils in the tests. All samples were run with the same software. For analysis of GS-MS, it was used the same procedures that Yildirim et al. (2016) describe.

In silico prediction of molecular docking studies

The term "*in silico* analysis" pertains to the practice of conducting scientific investigations via the use of computer simulations, modeling, and analysis, as opposed to empirical experimentation (Korkmaz et al., 2022). This methodology has the potential to save expenses, optimize time use, and sometimes provide a viable substitute in situations when doing trials is arduous or hazardous (Cairns et al., 2016; Usta et al., 2023). Silico molecular coupling simulations were applied to investigate the interaction of naturally sourced bioactive compounds (components of thyme) with the crystal structure

of *Fusarium oxysporum* cutinase (https://www.rcsb.org/structure/5AJH). We made use of this method to study whether or not it interacts with the structures of alpha-pinene, beta-pinene, and beta-phellandrene, which are the three primary compounds found in the essential oil derived from thyme. Chimera (version 1.16) tools were used in order to produce protein structures ready to use as docking targets (Butt et al., 2020).

RESULTS and DISCUSSION

Essential oil components isolated using GC-MS for the investigated thyme are presented in Table 1 along with their retention index and relative rates. The discovery of twenty-one components represented 100% of the plant's total essential oil, according to the data. The primary constituents of the *T. eigii* plant were Gamma-terpinene (27.49%), Carvacrol (27.38%), and P-cymene (14.40%) (Table 1).

Table 1. Essential oil constituents of thyme (*Thymus eigii* M. Zohary et P.H. Davis) Jalas

Peak	Component	Retention Index	Rate (%)	Peak	Component	Retention Index	Rate (%)
1	Alpha-pinene	3.054	3.12	12	3-octenol	8.872	0.26
2	Camphene	3.506	0.20	13	Trans sabinene hydrate	9.118	0.24
3	Beta-pinene	3.995	0.35	14	Linalool	10.231	0.66
4	3-carene	4.525	0.16	15	Trans-caryophyllene	11.064	3.09
5	Beta-Myrcene	4.713	5.44	16	Aromadendrene	11.194	0.45
6	Alpha- terpinene	4.969	7.20	17	Thymol acetate	14.399	0.25
7	Limonene	5.232	0.81	18	Caryophyllene oxide	15.826	0.37
8	Beta-phellandrene	5.378	0.58	19	Spathulenol	17.204	0.47
9	Gamma-terpinene	5.998	27.49	20	Thyme camphor	17.679	6.76
10	P-cymene	6.346	14.40	21	Carvacrol	18.027	27.38
11	Terpinolene	6.491	0.32				

Can Başer (2008) documented that the genera *Origanum*, *Thymus*, *Coridothymus*, *Thymbra satureja*, and *Lippia exhibit* a high concentration of carvacrol, which is notably associated with many biological activities. The investigator's finding also provides evidence for the presence of carvacrol as the primary component in the present investigation. Tümen et al. (1995) conducted an analysis to identify the constituents of the essential oils in several thyme species. According to the paper, carvacrol is identified as the primary constituent of *Thymus eigii*, with concentrations ranging from 30% to 65%. In the present investigation, the proportion of carvacrol, a prominent constituent, was found to be 27.38%. This observation aligns with the results reported by the researcher. Baser et al. (1996), in their study, detected carvacrol (64.61%) as the main component in the essential oil of the *Thymus eigii* species. In this study, carvacrol was identified as one of the main components and its rate was found to be low. There is a partial similarity with the findings of the researchers. In their study, Tepe et al. (2004) discovered that the essential oil content derived from different aerial portions of the *Thymus eigii* species consisted mostly of 30.6% thymol, 26.1% carvacrol, and 13% P-cymen. The primary components identified in the present investigation were carvacrol, gamma-terpinene, and p-cymene. While the carvacrol to p-cymene ratio exhibits a notable similarity, the present study incorporates gamma-terpinene as another principal constituent. The researcher's findings also indicate the presence of thymol as distinct components, yielding somewhat comparable outcomes. According to the research conducted by Göze et al. (2009), carvacrol was shown to be the predominant compound in *Thymus fallax*, similar to other species of thyme, with a composition of 46.15%. The findings align with the observation that carvacrol is the primary component investigated in the present investigation.

According to a study conducted by Zehra Küçükbay et al. (2003), three distinct varieties of *Thymus kotschyanus* were examined. The essential oils of two of these varieties were found to mostly consist of geraniol and geranyl acetate, whilst the third variety exhibited a significant presence of monoterpene chemicals, particularly carvacrol and p-cymene. The research conducted by Barut et al. (2021) examined *Thymus eigii*, a perennial shrub from the Lamiaceae family that is often found in the Adana and Hatay regions of Turkey. The primary objective of the study was to determine the most favorable period for harvesting in order to achieve the highest possible essential oil production and overall plant attributes. The results indicated that the full-flowering stage was associated with the greatest plant height, diameter, fresh herb and flower output, as well as dried herb and flower yield. Regarding the composition of essential oils, they were observed that carvacrol constituted the primary constituent, exhibiting fluctuations in its content throughout different phases of development. As a result, the findings of our study were similar to the studies summarized above.

There has been a significant uptick in the usage of *in silico* research in recent years for the purpose of predicting the interaction of essential oils with bacteria, virus, and fungus (Jianu et al., 2021; Kundu et al., 2021; Santana de Oliveira et al., 2021). In this work, we used *in silico* methods to investigate the link between the primary components of *Thymus eigii* essential oil and the structure of *Fusarium oxysporum* cutinase. Important essential oils found in plants have been shown to be capable of causing a considerable alteration in the permeability of cell membranes as well as degrading the membranes of fungus (Gill and Holley, 2006; Sharma et al., 2017).

Chimera software was used for *in silico* prediction (Usta et al., 2023). For assessing the quality of each redocking posture, both the root means square deviation (RMSD) values and docking scores were taken into consideration. The research that has been done indicates that the root means square deviation (RMSD) values between the redocked protein and the crystallographic ligand should be fewer than 2Å (angström) (Silva et al., 2019). As a result of this study, the RMSD that we calculated came out to be lower than 2 for carvacrol, gamma-terpinene, and p-cymene. It was found that carvacrol had the highest docking score, and this information was compared with the predicted binding score for the other three compounds (-6.8 for carvacrol, -5.4 for p-cymene, and -5.2 for gamma-terpinene). The formation of stable protein-ligand complexes is measured by the low docking scores (Kundu et al., 2021). As a consequence of this, present research involving molecular docking placed carvacrol in the top position in terms of docking scores. Figure 2 depicts the carvacrol molecule in the optimal binding position, which involves placing amino acid (Serine: SER and asparagine: ASN) residues in specific binding pockets of the enzyme. Also, gamma-terpinene was attached to the amino acid SER (Serine) and ARG (Arginine) (Figure 2), whereas P-cymene was bound to the LEU (Leucine) amino acid (Figure 3).

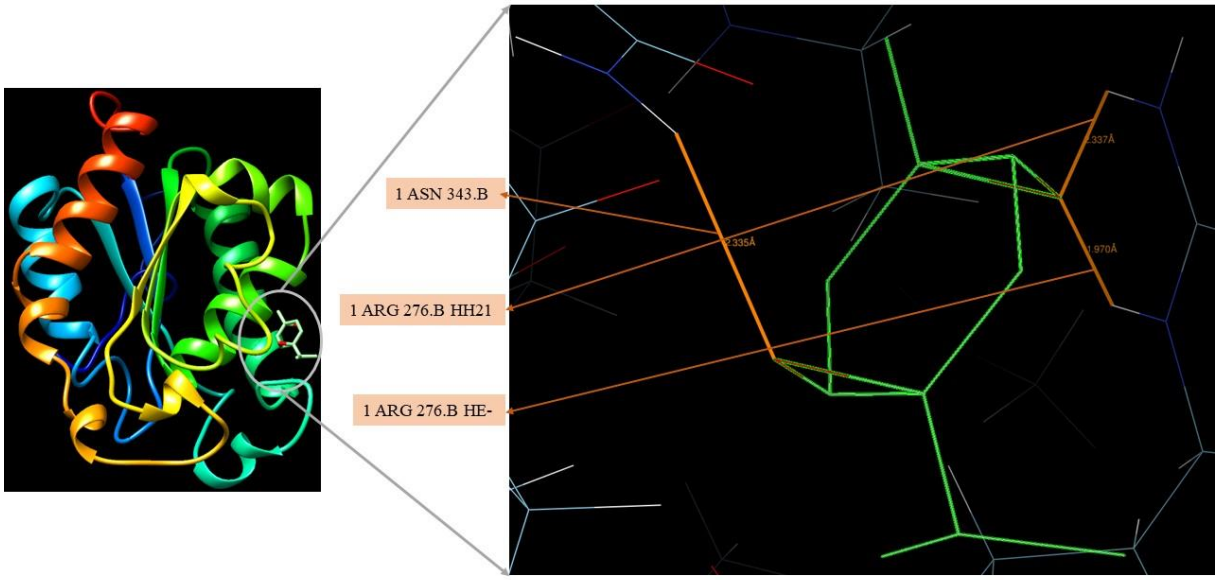

Figure 1. Docking structre of Gamma-terpinene and 5AJH

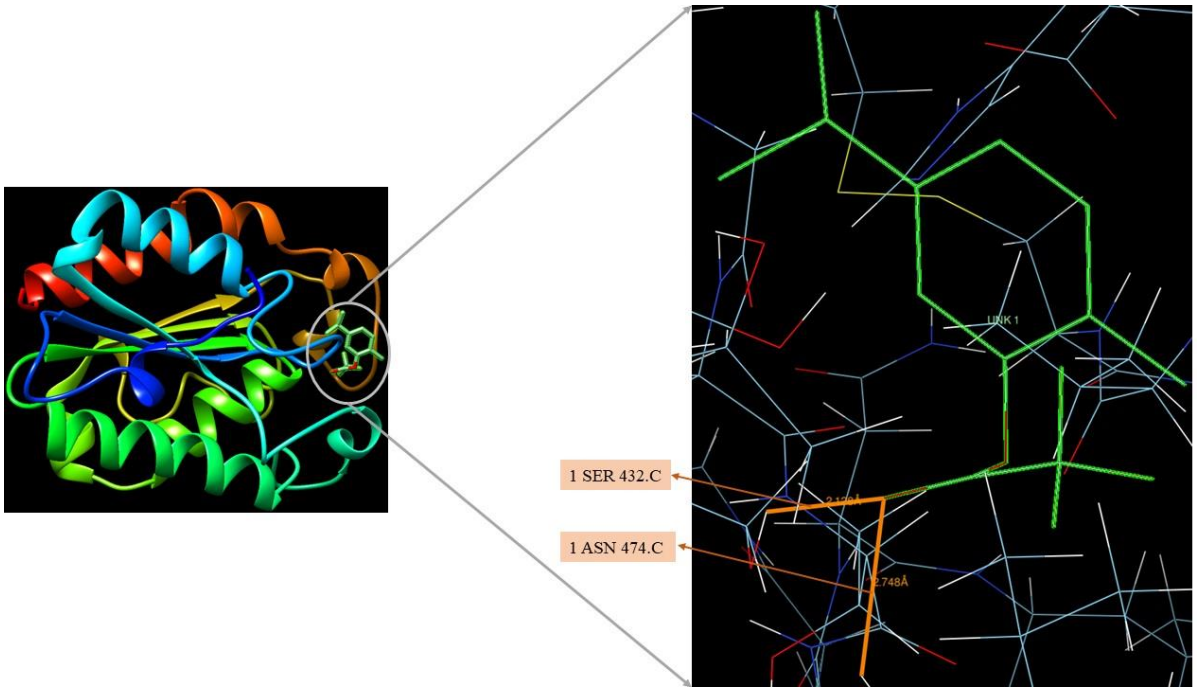

Figure 2. Docking structre of Carvacrol and 5AJH

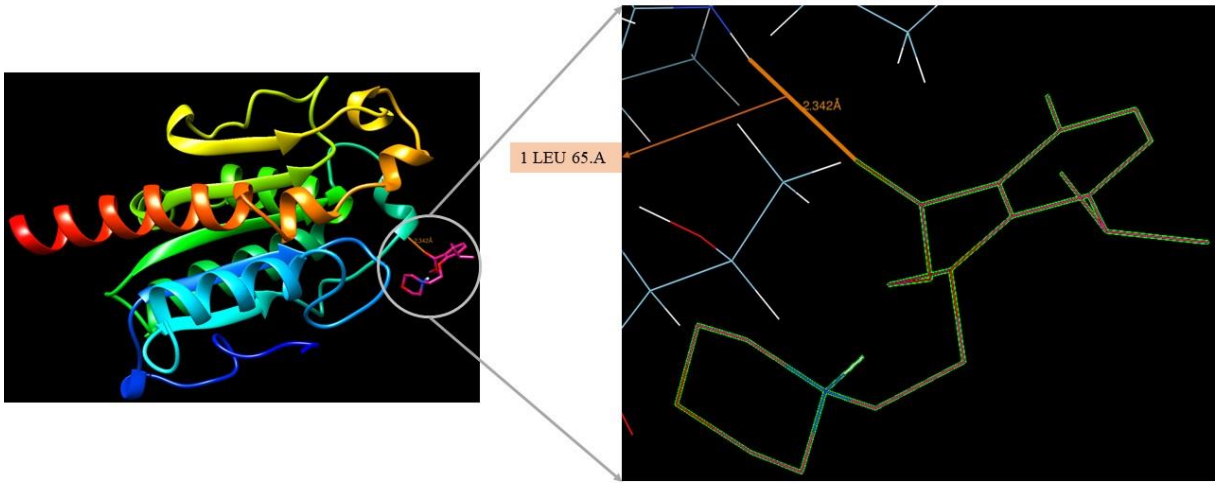

Figure 3. Docking structre of P-cymene and 5AJH

CONCLUSION

Aromatherapy, antimicrobial benefits, and the relief of cold and flu symptoms are just some of the numerous uses for essential oils with therapeutic effects, which are extensively employed in many public and private settings. *Thymus eigii* may be of importance for human health, as shown by the attention it has received due to its essential oils. The development of these naturally occurring bioactive molecules has the potential to assist in mitigating a number of unfavorable consequences of synthetic antibiotics, including residue, resistance, and environmental harm. As a consequence of these observations, perhaps new paths might be opened for the development of novel phytotherapeutic medicines derived from this plant. The analysis of the components of essential oils showed that carvacrol, gamma-terpinene, and P-cymene were present in high concentrations. Detailed knowledge of the relationships between ligands and target proteins was detected; specifically, it was discovered that three key components bind firmly to residues of the enzymatic pocket of *Fusarium oxysporum* cutinase synthase. To have a better understanding of the mechanism behind the actions of *Thymus eigii*'s essential oils, further study is needed.

REFERENCES

Altundağ Ş, Aslım B, 2005. Kekiğin Bazı Bitki Patojeni Bakteriler Üzerine Antimikrobiyal Etkisi. Orlab On-Line Mikrobiyoloji Dergisi, 3 (7): 12-14.

Barrera-Necha LL, Garduno-Pizana C, Garcia-Barrera LJ, 2009. In vitro Antifungal Activity Of Essential Oils And Their Compounds On Mycelial Growth of *Fusarium oxysporum* f. sp. gladioli (Massey) Snyder and Hansen. Plant Pathology Journal (Faisalabad), 8 (1): 17-21.

Barut M, Tansı S, Karaman Ş, 2021. Yield and Essential Oil Composition of *Thymus eigii* (M. Zohary & PH Davis) Jalas Leaves and Flowers at Various Growth Stages in the Mediterranean Region. Avrupa Bilim ve Teknoloji Dergisi, (31): 523-530.

Baser KHC, Kürkçüoglu M, Tümen G, Sezik E, 1996. Composition of the Essential oil of *Thymus eigii* (M. Zohary et PH Davis) Jalas from Turkey. Journal of Essential Oil Research, 8 (1): 85-86.

Başer KHC, 2001. Her Derde Deva Bir Bitki Kekik. Bilim ve Teknik Dergisi, 402 (26): 74-77.

Butt SS, Badshah Y, Shabbir M, Rafiq M, 2020. Molecular Docking Using Chimera And Autodock Vina Software For Nonbioinformaticians. JMIR Bioinformatics and Biotechnology, 1 (1): e14232.

Cairns TC, Studholme DJ, Talbot NJ, Haynes K, 2016. New and Improved Techniques for the Study of Pathogenic Fungi. Trends in Microbiology, 24 (1): 35-50.

Can Baser KH, 2008. Biological and Pharmacological Activities of Carvacrol and Carvacrol Bearing Essential Oils. Current Pharmaceutical Design, 14 (29): 3106-3119.

Davis PH, 1970. Flora of Turkey and the East Aegean Islands. Vol. 3. Flora of Turkey and the East Aegean Islands. University Press: Edinburgh, Scotland, Vol. 7, 349-382.

Dean R, Van Kan JA, Pretorius ZA, Hammond-Kosack KE, Di Pietro A, Spanu PD, Foster GD, 2012. The Top 10 Fungal Pathogens in Molecular Plant Pathology. Molecular Plant Pathology, 13 (4): 414-430.

Dimarogona M, Nikolaivits E, Kanelli M, Christakopoulos P, Sandgren M, Topakas E, 2015. Structural and Functional Studies of a *Fusarium oxysporum* Cutinase with Polyethylene Terephthalate Modification Potential. Biochimica et Biophysica Acta (BBA)-General Subjects, 1850 (11): 2308-2317.

Fourie G, Steenkamp ET, Ploetz RC, Gordon TR, Viljoen A, 2011. Current Status of the Taxonomic Position of *Fusarium oxysporum* Formae Specialis Cubense Within the *Fusarium oxysporum* Complex. Infection, Genetics and Evolution, 11 (3): 533-542.

Gill AO, Holley RA, 2006. Inhibition of Membrane Bound ATPases of *Escherichia coli* and *Listeria monocytogenes* by Plant Oil Aromatics. International journal of food microbiology, 111 (2): 170-174.

Gordon TR, Martyn RD, 1997. The Evolutionary Biology of *Fusarium oxysporum*. Annual review of phytopathology, 35 (1): 111-128.

Goze I, Alim A, Cetinus SA, Durmus N, Vural N, Goze HM, 2009. Chemical Composition and Antioxidant, Antimicrobial, Antispasmodic Activities of the Essential oil of *Thymus fallax* Fisch, Mey. J Med Plants Res, 3 (3): 174-178.

Halpern HC, Bell AA, Wagner TA, Liu J, Nichols RL, Olvey J, Brewer MT, 2018. First Report of *Fusarium wilt* of Cotton Caused by *Fusarium oxysporum* f. sp. *vasinfectum* race 4 in Texas, USA. Plant disease, 102 (2): 446-446.

Jianu C, Stoin D, Cocan I, David I, Pop G, Lukinich-Gruia AT, Horhat DI, 2021. *In silico* and in vitro Evaluation of the Antimicrobial and Antioxidant Potential of *Mentha× smithiana* R. GRAHAM Essential Oil from Western Romania. Foods, 10 (4): 815.

Kocabas YZ, Karaman S, 2001. Essential Oils of Lamiaceae Family From South East Mediterranean Region (Turkey). Pakistan Journal of Biological Sciences, 4 (10): 1221-1223.

Koçak R, Boyraz N, 2006. Bazı Bitki Uçucu Yağlarının Fungisidal ve Fungistatik Etkileri. Selcuk Journal of Agriculture and Food Sciences, 20 (38): 76-81.

Korkmaz G, Usta M, Demirel S, 2022. Potato virus S (PVS)-Bitlis İzolatının Kılıf Proteinin *in silico* Karakterizasyonu ve Konak Proteini ile Docking analizi. Journal of Agriculture 5 (1): 57-67.

Könemann B, 1999. The İllustrated AZ of Over 10,000 Garden Plants and How to Cultivate Them. Hong Kong: Gordon Cheers Publication, 51-3.

Kundu A, Dutta A, Mandal A, Negi L, Malik M, Puramchatwad R, Singh PK, 2021. A Comprehensive *in vitro* and *in silico* Analysis of Nematicidal Action of Essential Oils. Frontiers in Plant Science, 11: 614143.

Küçükbay FZ, Kuyumcu E, Çelen S, Azaz AD, Arabaci T, Yildiz B, 2013. Chemical Composition and Antimicrobial and Antioxidant Activities of Three Turkish Thyme Essential Oils. Journal of Essential Oil Bearing Plants, 16 (5): 661-671.

Lecomte C, Alabouvette C, Edel-Hermann V, Robert F, Steinberg C, 2016. Biological Control of Ornamental Plant Diseases Caused by *Fusarium oxysporum*: a Review. Biological control, 101: 17-30.

Maharramov S, Hüseynova A, 2017. Bazı Kekik Türlerinin (*Thymus kotschyanus* ve *Thymus collinus*) Gastrointestinal Parazitlere Karşı Antelmentik Etkisinin Araştırılması. 2018 24 1 January-February, 961.

Peters RD, MacLeod C, Seifert KA, Martin RA, Hale LR, Grau CR, MacInnis S, 2008. Pathogenicity to Potato Tubers of *Fusarium* spp. Isolated From Potato, Cereal and Forage Crops. American Journal of Potato Research, 85: 367-374.

Purdy RE, Kolattukudy PE, 1975. Hydrolysis of Plant Cuticle by Plant Pathogens. Properties of cutinase I, cutinase II, and a nonspecific esterase isolated from *Fusarium solani* pisi. Biochemistry, 14 (13): 2832-2840.

Santana de Oliveira M, Pereira da Silva VM, Cantao Freitas L, Gomes Silva S, Nevez Cruz J, de Aguiar Andrade EH, 2021. Extraction Yield, Chemical Composition, Preliminary Toxicity of Bignonia Nocturna (bignoniaceae) Essential Oil and *in silico* Evaluation of the Interaction. Chemistry & Biodiversity, 18 (4): e2000982.

Sharifi-Rad M, Varoni EM, Iriti M, Martorell M, Setzer WN, del Mar Contreras M, Sharifi-Rad J, 2018. Carvacrol and Human Health: A Comprehensive Re view. Phytotherapy Research, 32 (9): 1675-1687.

Sharma A, Rajendran S, Srivastava A, Sharma S, Kundu B, 2017. Antifungal Activities of Selected Essential Oils Against *Fusarium oxysporum* f. sp. *lycopersici* 1322, with Emphasis on *Syzygium aromaticum* Essential Oil. Journal of Bioscience and Bioengineering, 123 (3): 308-313.

Silva SG, da Costa RA, de Oliveira MS, da Cruz JN, Figueiredo PLB, Brasil DDSB, Andrade EHDA, 2019. Chemical Profile of *Lippia thymoides*, Evaluation of the Acetylcholinesterase Inhibitory Activity of its Essential Oil, and Molecular Docking and Molecular Dynamics Simulations. PLoS One, 14 (3): e0213393.

Smith SN, 2007. An Overview of Ecological and Habitat Aspects in the Genus *Fusarium* with Special Emphasis on the Soil-borne Pathogenic Forms. Plant Pathol Bull, 16: 97-120.

Tepe B, Daferera D, Sökmen M, Polissiou M, Sökmen A, 2004. In vitro Antimicrobial and Antioxidant Activities of the Essential Oils and Various Extracts of *Thymus eigii* M. Zohary et PH Davis. Journal of Agricultural and Food Chemistry, 52 (5): 1132-1137.

Tharanathan RN, Kittur FS, 2003. Chitin—the Undisputed Biomolecule of Great Potential. Crit. Rev. Food Sci. Nutr., 43: 63-86.

Tümen GN, Kırımer KHC, Başer C, 1995. Composition of the Essential Oils of *Thymus* species Growing in Turkey. Chemistry of Natural Compounds, 3 (1): 42-45.

Usta M, Guller A, Demirel S, Korkmaz G, Kurt Z, 2023. New insights into tomato spotted wilt orthotospovirus (TSWV) infections in Türkiye: Molecular detection, phylogenetic analysis, and *in silico* docking study. Notulae Botanicae Horti Agrobotanici Cluj-Napoca, 51 (3):13245.

Yildirim B, Kumlay AM, Rezaeieh KAP, 2016. Chemical Composition of Bioactive Volatile Oils from *Silene vulgaris* L. International Scientific Researches Journal, 72: 213.