

CHAPTER 2

SWEET FENNEL (*Foeniculum vulgare* MILL. var. *dulce*): CULTIVATION AND INDUSTRIAL USE

Prof. Dr. Belgin COŞGE ŞENKAL¹
Assist. Prof. Dr. Tansu USKUTOĞLU²

DOI: <https://dx.doi.org/10.5281/zenodo.10003482>

¹Yozgat Bozok University, Faculty of Agriculture, Department of Field Crops, Yozgat, Türkiye, ORCID ID: 0000-0001-7330-8098 e-mail: belgin.senkal@yobu.edu.tr,

²Pamukkale University, Faculty of Agriculture, Department of Field Crops, Denizli, Türkiye. ORCID ID: 0000-0001-6631-1723, e-mail: tuskutoglu@pau.edu.tr

INTRODUCTION

Fennel (*Foeniculum vulgare* Mill.) is a valuable essential oil and spice plant from the Apiaceae family. Fennel, which is thought to be endemic in the Mediterranean region, originated from these regions and spread to a wide geography extending to Asia, Africa, Europe and Oceania (Chatzopoulou et al., 2006; Grover et al., 2013; Diao et al., 2014; Abdellaoui et al., 2017; Jadid et al., 2023). World fennel production data is not given alone, but cumulatively presented with some medicinal and aromatic plants such as anise, fennel and coriander. For this reason, official data about its production cannot be reached around the world, and information about its production is obtained with the own reports of local governments. It is known that the country with the highest production in the world is India with 90,000 ha. It is produced in significant quantities in India and Turkey, Syria, Egypt, Germany, Spain and Pakistan (Rahman et al., 2020) (Figure 1).

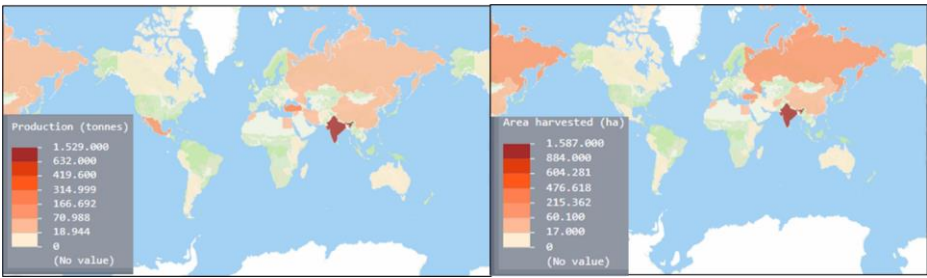


Figure 1: World fennel production (<https://data.apps.fao.org/> accessed date: 29.05.2023)

According to 2022 production data in Turkey, a total of 2323 thousand tons of production was made with an average yield of 196 kg

da⁻¹ on an area of 11.875 decares (TUIK, 2023). Production data of the last 10 years in Türkiye are presented in Figure 2 and Figure 3. Burdur is the province with the highest production in Türkiye, followed by Antalya and Konya. Apart from these 3 provinces, a small amount of fennel is produced in Ankara, Afyonkarahisar and Manisa (TUIK, 2023).

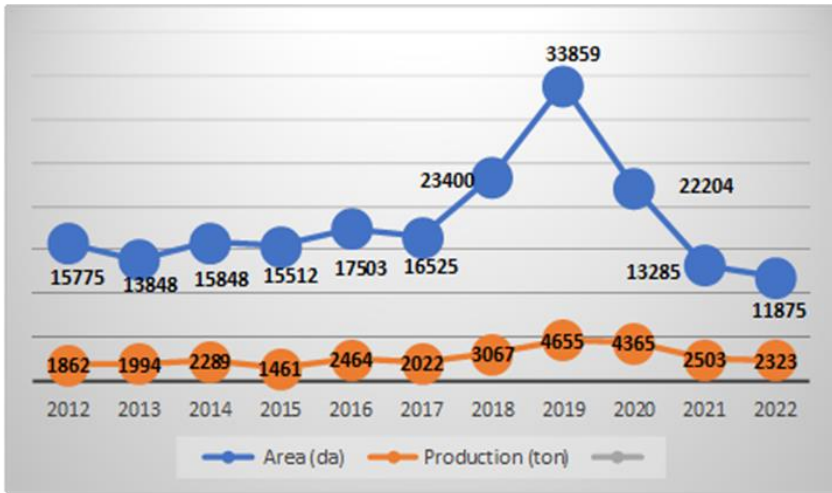


Figure 2: Fennel cultivation area and production amount for the last 10 years in Türkiye (TUIK, 2023).

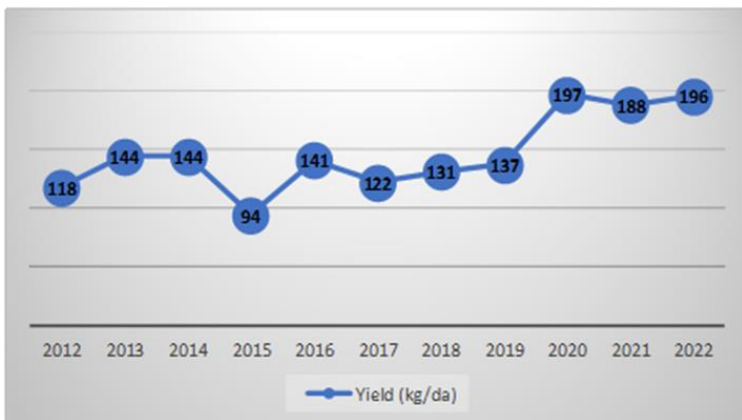


Figure 3: Fennel yield for the last 10 years in Türkiye (TUIK, 2023).

1. TAXONOMY AND PLANT CHARACTERISTICS

The taxonomy of the fennel plant is given in Table 1.

Table 1: Taxonomy of Fennel Plant (Menemen, 2012)

Regnum	: Plantae
Divisio	: Magnoliophyta
Subclassis	: Magnoliidae
Familia	: Apiaceae
Genus	: <i>Foeniculum</i>
Species	: <i>Foeniculum vulgare</i> Mill.

Fennel is an aromatic herb that can be grown as an annual, biennial or perennial (Mishra et al., 2016; Singh, 2017). There are varieties between wild and cultivated fennel that differ in size, odor and taste of the fruit. There are two subspecies of this species, "piperitum" (growing wild in the Mediterranean region) and "capillaceum" (widely cultivated), which are widespread throughout the world. There are three varieties of the Capillaceum subspecies. These:

1-*Foeniculum vulgare* var. *azoricum*

It is one-year. It has the ability to form bumps. It is consumed as a vegetable (Figure 4).



Figure 4: *Foeniculum vulgare* var. *azoricum*

(<https://www.floragard.de/de-de/pflanzeninfothek/pflanze/gemuese/foeniculum-vulgare-var-azoricum>) (Accessed date:17.06.2023)

2-*Foeniculum vulgare* var. *vulgare*

Bitter fennel. It is perennial. It is rich in fenchone. It is used in industry because of its aromatic bitterness and sharp aroma (Figure 5).



Figure 5: *Foeniculum vulgare* var. *vulgare*

(https://www.richters.com/Web_store/web_store.cgi?product=X2423&show=&prodclass=Herb_Seeds&cart_id=111.100) (Access date:17.06.2023)

3-*Foeniculum vulgare* var. *dulce*

Sweet fennel. It is usually an annual, sometimes biennial. It is grown for its aromatic fruits and essential oil (Figure 6).

Sweet fennel is foreign fertilized and the number of chromosomes in its somatic cells is $2n=22$ (Malhotra, 2012). The stem of the plant is hollow and green in color. It grows upright and can grow up to 2.5 m in length (Dheebisha and Vishwanath, 2020). It has bisexual yellow oval and umbrella-shaped flowers (Rafieian et al., 2023) (Figure 6).



Figure 6: Sweet fennel flowers (left) and fruits (right) (Yozgat Bozok University Trial Area)

The fruits of the plant contain 9.5% protein, 10% fat, 42.3% carbohydrates, 18.5% fiber and various minerals and vitamins (C, E, B6, thiamine, riboflavin and niacin) (Abdellaoui et al., 2017). The stem, fruit and leaves of the plant are widely used in many culinary traditions (Nourimand et al., 2012; Abdellaoui et al., 2017).

The pale green, pale yellowish-brown fruits of sweet fennel contain volatile oils ranging from 1.0% to 6.0% (Cosge et al., 2008; Saharkhiz et al., 2011; Malhotra, 2012; Avci, 2013; Salami et al., 2016). Sweet fennel essential oil contains an average of 70-90% trans-anethole (Cosge et al., 2008; Saharkhiz et al., 2011; Salami et al., 2016; Borotová et al., 2021). Other important components in the essential oil were recorded as estragole (2.5-6.4%), limonene (2.18-7.12%), and α -fenchone (0.97-13.0%) (Cosge et al., 2008; Saharkhiz et al., 2011; Malhotra, 2012; Avci, 2013; Salami et al., 2016, Borotová

et al., 2021). A maximum of 7.5% fenchone and 10% estragole is allowed in the essential oil obtained from sweet fennel fruits (Salami et al., 2016). However, there are types that do not contain any fenchone.

It is emphasized that the amount and chemical composition of essential oil obtained from fennel fruits are affected by many factors such as geographical origin, genotype, phenology, cultural practices, ecological conditions, extraction method (Cosge et al., 2008; Sahahat et al., 2012).

Trans-Anethole: Anethole is an aromatic compound commonly found in essential oils in nature (Figure 7). It is a clear, colorless or amber liquid, sparingly soluble in water but highly soluble in ethanol. It has a sweet aroma. It is 13 times sweeter than sugar (Marinov and Valcheva-Kuzmanova, 2015). Trans-anethole is the main component of essential oil obtained from fennel fruits and is used in different industrial areas (Table 2).

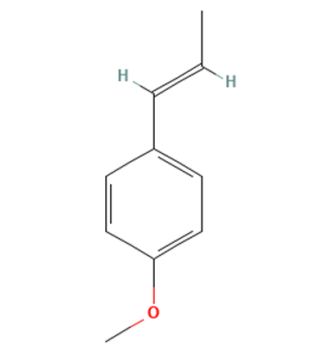


Figure 7: Chemical structure of *trans*-anethole
(<https://pubchem.ncbi.nlm.nih.gov/compound/637563#section=Structures>)
(Accessed date:12.06.2023)

Table 2. Some Chemical Properties and Uses of Trans-Anethole¹

Molecular Formula	C ₁₀ H ₁₂ O
Molecular weight	148.20 g/mol
Chemical Classes	Other aromatic compounds (A natural product)
Pharmacological Classification	Flavoring agent (substances added to foods and drugs to improve taste)
USES	
1-Cleaning and home care products	Household air fresheners, including scented candles
2- Flavoring	
3- Fragrance	
4- Fragrance component	
5- Personal care	
a- Dental care	Toothpastes and teeth cleaning products
b-Fragrance	Fragrances, colognes and perfumes
6-Vehicle-Car interior	
a-Automatic air freshener	Products to mask odors or add fragrance to cabin air

¹ <https://pubchem.ncbi.nlm.nih.gov/compound/637563> (Accessed date: 11.06.2023).

Anethole;

-It is added to alcoholic beverages (like Turkish raki).

It has the feature of covering unpleasant odors. Due to this feature, it is considered as a masking agent in many products (toothpastes, mouthwashes, toilet soaps, etc.) (=MAIN USAGE AREA).

- It is used as flavoring and fragrance in some food industry products (bakery products, candies, etc.).
- It is included in chewing gum and cigarettes for both aroma and fragrance (Marinov and Valcheva-Kuzmanova, 2015).

2. USES OF THE FENNEL PLANT

Food: Fennel is grown mainly for its fruits, which have a pleasant smell and aromatic taste. It is widely used in various Indian dishes to season soups, sauces, pastries, confectionery, breads, liqueurs, meat dishes and pickles. Its essential oil is used as a flavoring agent in various foodstuffs, pickles, perfumes, soaps, liqueurs and liqueur ice candies. It is used in the production of herbal tea (Saber and Eshra, 2019).

Medical: Fennel contains anethole, which, along with other pharmacologically active substances, is antispasmodic. It is reported to be effective in the treatment of diseases of bacterial, viral and fungal origin (Noreena et al., 2023). It has a wide range of biological activity (Kwon et al., 2002; de Marino et al., 2007; Badgujar et al., 2014) (Figure 8). It has carminative, expectorant and spasmolytic activity, especially at the respiratory and digestive level. It also shows estrogenic activity. It is also used externally; in which case it acts as an anti-inflammatory. Fennel is also beneficial in amenorrhea and dysmenorrhea (Mahboub, 2019). It is traditionally used in medicines to treat tremors and stomach problems (Raghavan, 2007).

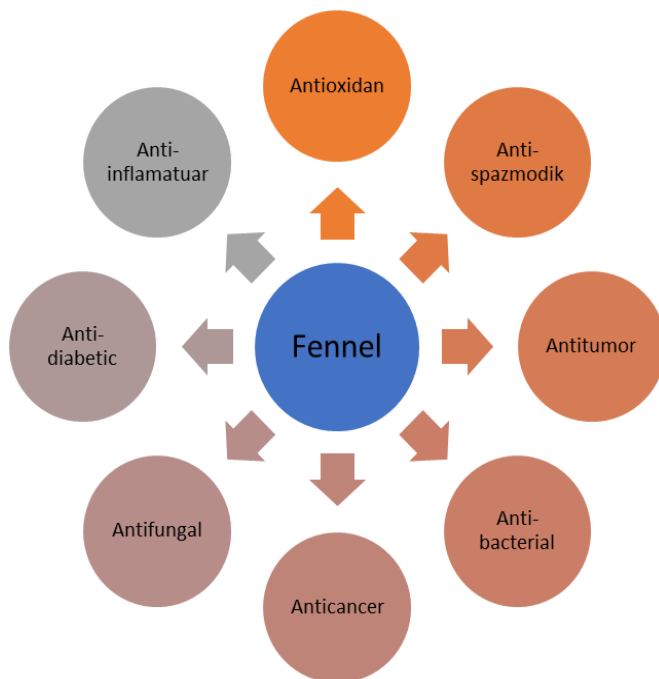


Figure 8: Biological activity of fennel plant

Its fruits are aromatic, act as a stimulant and are carminative. It is used in diseases such as cholera, bile, nervous disorders, cough and cold, constipation, dysentery and diarrhea, as well as diseases affecting the chest, lungs, spleen and kidneys (Saber and Eshra, 2019). In folk medicine, a hot infusion of the fruit is used to increase milk secretion. Its essential oil is used in cough lozenges. Fennel is used as a sweetener in natural toothpastes (Badgujar et al., 2014; Noreena et al., 2023, Kim et al., 2023).

Perfume-Cosmetics: Its essential oil is used in perfumes and soaps. Due to its antimicrobial properties, it is used in cosmetic creams, body lotions and moisturizers. The bulb, leaves, and seeds of the fennel plant are used in different ways in cuisines around the

world (Stefanini et al., 2006). Fennel pollen has very strong antioxidant properties.

Fennel fruits contain 12-15% fatty oil and 80-85% of the oil is petroselinic acid ($C_{18}H_{34}O_2$, unsaturated fatty acid). It can be used in the edible oil and biodiesel industry with its high melting points. It can also be evaluated in the food and perfumery industry due to its antimicrobial effect (Baydar, 2016).

To Feed Animal: The residue remaining after distillation of the essential oil from the fruit is used as a rich cattle feed.

3. CULTIVATION

Fennel is grown in warm and temperate climatic regions where the Mediterranean climate is dominant (Jaitawat, 2007). The soil selectivity of the fennel plant is low. It can be grown in all kinds of soils, only the cultivated areas should not be affected by excessive salinity and flooding (Grover et al., 2013). It generally grows well in lime-rich, humus, sandy, sandy-loam soils with a pH between 4.8-8.3. It is also reported that it can grow in sodic soils. It has been reported that fennel can take part in the improvement of sodic soils because it accumulates a large amount of sodium in its own structure and removes a large amount of sodium from the soil (Garg, et al. 2004).

Fennel seeds can be planted directly in the field, or it can be produced by planting the seedlings formed in the nursery. The yield is higher when planted as a seedling (Jaitawat, 2007). The optimum temperature should be 15-20°C during the development phase of the

plant. During the seed setting stage, dry and cool air increases seed yield and product quality (Dheebisha and Vishwanath, 2020).

In fennel cultivation, fertilization can be made with 4 kg N and 6 kg P₂O₅ per decare. The planting norm of fennel should be 60 x 2-3 cm, with 1.5 kg of seeds per decare. Sowing time is autumn or early spring (Baydar, 2020). It can be irrigated 1-3 times according to the sprinkler or drip method, especially at the beginning of flowering and during the seed setting period. Irrigation increases yield. With the increase of weed density with irrigation, it is struggled by hand hoeing or mechanized.

Fennel fruits are harvested by mowing or removing at a time when they are just starting to turn brown. Harvest time usually coincides with August. Harvested plants are blended after drying for a few weeks (Baydar, 2020) (Figure 9).



A



B



C

Figure 9: The beginning of flowering (A), full flowering (B), and seed maturity (C) stages in sweet fennel (Yozgat Bozok University-2022)

REFERENCES

- Abdellaoui, M., Bouhlali, E. D. T., Kasrati, A., & El Rhaffari, L. (2017). The effect of domestication on seed yield, essential oil yield and antioxidant activities of fennel seed (*Foeniculum vulgare* Mill) grown in Moroccan oasis. Journal of the Association of Arab Universities for Basic and Applied Sciences, 24: 107-114.
- Avci, A. B. (2013). Effect of seeding rate on yield and quality of non-chemical fennel (*Foeniculum vulgare* Mill.) cultivation. Turkish Journal of Field Crops, 18: 27-33.
- Badgajar, S. B., Patel, V. V., & Bandivdekar, A. H. (2014). *Foeniculum vulgare* Mill: A review of its botany phytochemistry, pharmacology, contemporary application, and toxicology. BioMed Research International, Article ID 842674.
- Baydar, H. (2016). Tıbbi ve Aromatik Bitkiler Bilimi ve Teknolojisi (Geniştirilmiş 5. Baskı). Süleyman Demirel Üniversitesi Yayın No: 51 (ISBN: 975-7929-79-4).
- Baydar, H. (2020). Tıbbi ve Aromatik Bitkiler Bilimi ve Teknolojisi. Nobel Yayınları. Yayın No:2328.
- Borotová, P., Galovičová, L., Valková, V., Ďuranová, H., Vuković, N., Vukić, M., Babošová, M., & Kačániová, M. (2021). Biological activity of essential oil from *Foeniculum vulgare*. Acta Hort Regiotec, 24(2):148-152.
- Chatzopoulou, P. S., Koutsos, T. V., & Katsiotis, S. T. (2006). Study of nitrogen fertilization rate on fennel cultivars for essential oil yield and composition. Journal of Vegetable Science, 12: 85-93.
- Cosge, B., Gurbuz, B., Kendir, H., & Ipek, A. 2008. Composition of essential oil in sweet fennel (*Foeniculum vulgare* Mill. var. *dulce*) lines originated from Turkey. Asian Journal of Chemistry, 20: 1137-1142.
- de Marino, S., Gala, F., Borbone N., Zollo, F., Vitalini, S., Visioli, F., & Lorizzi, M. (2007). Phenolic glycosides from *Foeniculum vulgare* fruit and evaluation of antioxidative activity. Phytochemistry, 68: 1805-1812.
- Dheebisha, C., & Vishwanath, Y. C. (2020). Advances in cultivation of fennel. Journal of Pharmacognosy and Phytochemistry, 9:1295-1300.
- Diao, W. R., Hu, Q. P., Zhang, H., & Xu, J. G. (2014). Chemical composition, antibacterial activity and mechanism of action of essential oil from seeds of fennel (*Foeniculum vulgare* Mill.). Food Control, 35:109-116.

- Garg V. K., Singh P. K., & Katiyar R. S. (2004). Yield, mineral composition and quality of coriander (*Coriandrum sativum*) and fennel (*Foeniculum vulgare*) grown in sodic soil Indian Journal of Agricultural Science, 74: 221-223.
- Grover, S., Malik, C. P., Hora, A., & Kushwaha, H. B. (2013). Botany, cultivation, chemical constituents and genetic diversity in fennel (*Foeniculum vulgare* Mill): a review. LS - An International Journal of Life Sciences, 2: 128-139.
- Jadid, N., Widodo, A.F., Ermavitalini, D., Saadah, N.N., Gunawan, S., & Nisa, C. (2023). The medicinal Umbelliferae plant fennel (*Foeniculum vulgare* Mill.): Cultivation, traditional uses, phytopharmacological properties, and application in animal husbandry. Arabian Journal of Chemistry, 16: 104541.
- Jaitawat, G. S., Sisodia, S. S., & Bhimawat, B. S. (2007). Constraints in adoption of improved fennel cultivation technology. Indian Research of Journal Extension Education, 7(2): 52-54.
- Kim, S., Chen, J., Cheng, T., Gindulyte, A., He, J., He, S., Li, Q., Shoemaker, B. A., Thiessen, P. A., Yu, B., Zaslavsky, L., Zhang, J., & Bolton, E. E. (2023). PubChem 2023 update. Nucleic Acids Research, 51(D1), D1373–D1380. <https://doi.org/10.1093/nar/gkac956>
- Kwon, Y. S., Choi W. G., Kim, W. J., Kim, W. K., Kim, M. J., Kang, W. H., & Kim, C. M. (2002). Antimicrobial constituents of *Foeniculum vulgare*. Archives of Pharmacal Research, 25:154-157.
- Mahboubi M. (2019). *Foeniculum vulgare* as Valuable Plant in Management of Women's Health. J Menopausal Med. 2019 Apr;25(1):1-14. doi: 10.6118/jmm.2019.25.1.1. Epub 2019 Apr 25. PMID: 31080784; PMCID: PMC6487283.
- Malhotra, S. K. (2012). Fennel and fennel seed. In Handbook of herbs and spices (pp. 275-302). Woodhead Publishing.
- Marinov, V., & Valcheva-Kuzmanova, S. (2015). Review on the pharmacological activities of anethole. Scripta Scientifica Pharmaceutica, 2:14-19.
- Menemen, Y. (2012). *Foeniculum*.: Bizimbitkiler (2013). (<http://www.bizimbitkiler.org.tr>) (Accessed date: 12.06.2023).
- Mishra, B. K., Meena, K. K., Dubey, P. N., Aishwath, O. P., Kant, K., Sorty, A. M., & Bitla, U. (2016). Influence on yield and quality of fennel (*Foeniculum vulgare* Mill.) grown under semi-arid saline soil, due to application of native phosphate solubilizing rhizobacterial isolates. Ecological Engineering, 97: 327-333.

- Noreena, S., Tufaila, T., Ul Aina, H.B., & Awuchi, C.G. (2023). Pharmacological, nutraceutical, functional and therapeutic properties of fennel (*Foeniculum vulgare*). International Journal of Food Properties. 26:915-927.
- Nourimand, M., Mohsenzadeh, S., & Teixeira Da Silva, J. A. (2012). Physiological responses of fennel seedling to four environmental stresses. Iranian Journal of Science and Technology (Sciences), 36(1): 37-46.
- Rafieian, F., Amani, R., Rezaei, A., Karaca, A. C., & Jafari, S. M. (2023). Exploring fennel (*Foeniculum vulgare*): Composition, functional properties, potential health benefits, and safety. Critical Reviews in Food Science and Nutrition, 1-18.
- Raghavan, S. (2007). Handbook of Spices, Seasonings, and Flavorings. CRC Press Taylor & Francis Group, 322 p.
- Rahman, A., Akbar, D., Timilsina, S., Trotter, T., Thomson, M., & Bhattarai, S. (2020). Market analysis of of fennel seed: A.2.1819045 - Spicing up Northern Australia with high-value condiment crops. (<https://crcna.com.au/resources/publications/market-analysis-fennel-seed>)
- Saber, J. I., & Eshra, G. H. (2019). Using fennel and its oil as a preservative and functional food to produce food and drink products to be used to alleviate cough symptoms. Alexandria Science Exchange Journal, 40(4):406-414.
- Saharkhiz, M. J., & Tarakeme, A. 2011. Essential oil content and composition of fennel (*Foeniculum vulgare* L.) fruits at different stages of development. Journal of Essential Oil Bearing Plants, 14: 605-609.
- Salami, M., Rahimmalek, M., Ehtemam, M.H., Szumny, A., Fabian, S., & Matkowski, A. (2016). Essential oil composition, antimicrobial activity and anatomical characteristics of *Foeniculum vulgare* Mill. fruits from regions of Iran. TEOP, 19:1614-1626.
- Shahat, A. A., Hammouda, F. M., Shams, K. A., & Saleh, M. A. (2012). Comparative chemical analysis of the essential oil of wild and cultivated fennel (*Foeniculum vulgare* Mill.). Journal of Essential Oil Bearing Plants, 15: 314-319.
- Singh, D. (2017). On-farm assessment of technological innovation of fennel (*Foeniculum vulgare* Mill.) cultivation. International Journal of Current Microbiology and Applied Sciences, 6(7): 1504-1509.
- Stefanini, M.B.1, Ming, L.C., Marques, M.O.M., Facanali, R., Meireles, M.A.A., Moura, L.S., Marchese, J.A., & Sousa, L.A. (2006). Essential oil constituents

of different organs of fennel (*Foeniculum vulgare* var. *vulgare*). Revista Brasileira de Plantas Medicinais, 8:193-198.

TUIK. (2023). Crop Production Statistics. (<https://data.tuik.gov.tr/Kategori/GetKategori?p=tarim-111&dil=1>.) (Accessed date: 10.06.2023.)