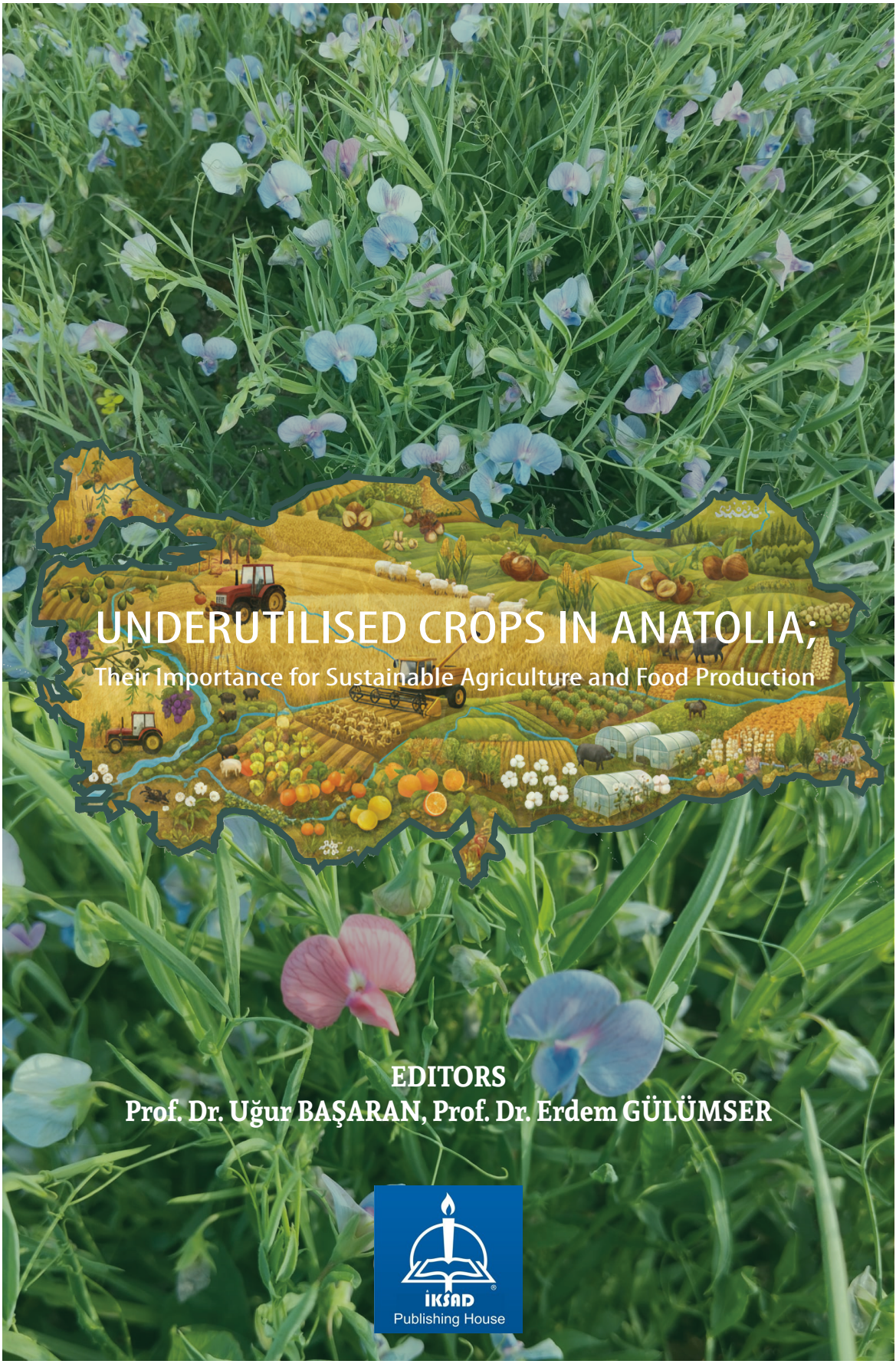


UNDERUTILISED CROPS IN ANATOLIA;

Their Importance for Sustainable Agriculture and Food Production

EDITORS
Prof. Dr. Uğur BAŞARAN, Prof. Dr. Erdem GÜLÜMSER

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(The Licence Number of Publicator: 2014/31220)
TÜRKİYE TR: +90 342 606 06 75
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Iksad Publications – 2025©

ISBN: 978-625-378-362-4
Cover Design: İbrahim KAYA
October / 2025
Ankara / Türkiye
Size: 16x24cm

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FOREWORD

Agricultural systems are multi-component and highly dynamic environments, and ecological and anthropogenic factors can alter crop diversity in the long or short term, globally or regionally. The cultivation and consumption of some crops may change over time, decline significantly, or even disappear entirely. Such crops, which are planted less than in the past, are called neglected and underutilized crops (NUS) and sometimes orphan crops. Many factors can be cited as the reasons for the neglect of plants, such as agronomic developments and widespread mechanization in agriculture, social and economic developments, consumer preferences, etc. NUS include cereals, legumes, fruits, vegetables and root crops, often adapted to local conditions and cultural preferences. Nevertheless, NUS has been still used to some extent at local, national and international levels but the dominance of more productive crops in agricultural systems makes their presence in the field more difficult and leads to their increasing neglect. Not only are NUS ignored by farmers or their production reduced, they are also overlooked by researchers, extension services and policy makers. Modern agri-food systems, breeding programs, consumer preferences, and the promotion of high-yielding varieties have marginalized NUS, which play a minor role in current farming and food systems. This has led to farmers planting them less frequently, reduced access to high-quality seeds of NUS and, perhaps most importantly, the loss of traditional knowledge. However with the increasing focus on adaptation to climate change and the increasing demand for plant-based protein diets, NUS have begun to receive renewed and increasing attention worldwide in recent years.

Compared to staple crops, NUS are generally more resistant to environmental stresses such as drought, salinity and extreme temperatures, have a richer nutrient composition and require less input. NUS have the potential to contribute more to agriculture and human nutrition than they currently do, especially by helping to enrich our diets with certain nutrients (essential amino acids, vitamins fiber, proteins) and to increase diversity in food production. Where common and basic crops fail to provide sufficient yields, the cultivation of NUS are the most prudent strategies for reducing hunger. NUS offer immense opportunities to fight poverty, hunger, and malnutrition and so, their incorporation into farming systems can contribute to

nutrient-dense, climate-resilient, and sustainable production. NUS are vital for enhancing food security, promoting biodiversity and supporting sustainable agricultural practices. These crops can therefore improve the resilience, sustainability and inclusiveness of existing agricultural systems, and support local development and food security strategies. The effective use of neglected, nutrient-dense species can be considered a promising solution to combat climate change, nutrition and hunger problems. Food security remains a major challenge for all humanity, especially in developing countries. While the world population and food demand are constantly increasing, agricultural production opportunities and resources are significantly decreasing. Current agricultural and food systems have limited production diversity, leading to unbalanced nutrition and, consequently, undernourishment for many people worldwide. Protein-energy malnutrition, vitamin A deficiency, and iron deficiency are the most common problems worldwide. Nutrients in the human diet, thanks to their generally high mineral, vitamin, and carotenoid content, can significantly contribute to improving the micronutrient content of the human diet.

Sustainable agriculture requires diversification of production resources for effective production in different ecological conditions and combating increasing stressors and climatic risks. Throughout history, 250.000 species have been identified, and humanity has used 7000 of these in agriculture. Today species diversity in agriculture has narrowed considerably and food production is limited to a few common species. According to FAO records, 75% of global food production comes from just 12 plant and 5 animal species, and 60% of total calorie input comes from just three plants: rice, wheat, and corn. NUS are important elements to overcome this restriction and increase biodiversity in agriculture. NUS are generally low-input crops and tolerate various stresses, so can be grown on marginal land, intercropped or rotated with staple crops, and easily fit with integrated practices. Therefore, they are vital crops for enhancing food security, promoting biodiversity and supporting sustainable agricultural practices. They also make important contributions to the soil fertility and biota by recycling nutrients and strengthening the food chain for soil organisms. Therefore, they are suitable for all types of land and operating conditions, making them insurance plants.

Cultivated plants not only provide food security to people worldwide, but are also fundamental elements of livelihood, social and economic development, both directly and indirectly. In this regard, NUS are poorly known, small-scale and local crops have various uses such as food, fuel, medicine, energy and economic gain. Such crops help preserve local biodiversity, provide economic, social benefits and contribute to the healthy diet of local populations, as well as increasing the climate resilience of communities in many aspects. Despite the numerous advantages, several barriers, including limited awareness among farmers and consumers, inadequate research and development, policies that prioritize staple foods, and economic reasons, hinder the widespread adoption of NUS in mainstream agriculture. Overcoming these barriers requires improved research, extension services and supportive policies, and promotional efforts. Recognizing the multifaceted importance of these crops, identifying the reasons for their cultivation and reduction in consumption, and developing strategies for their reintroduction into agricultural production and consumption are crucial for sustainability and food security.

Due to their highly localized character, underutilized crops have a wide range of distinct and regional consumption patterns. Unlike common varieties, underutilized crops have a rich variety of uses and are an important component of local culture and cuisine. Therefore, the disappearance of underutilized crops could mean the loss of not only a food source but also a diverse cultural knowledge, which is a different and crucial reason for their protection and development.

This book “Underutilized Crops in Anatolia; Their Importance for Sustainable Agriculture and Food production” aims to draw attention to neglected species in Türkiye. This book is designed to provide researchers, students, and producers with in-depth information about botanical and agricultural characteristics, uses, nutritional values and economic values of underutilized crops. Thus, in line with the priorities of the international community, we aim to contribute to and raise awareness on "ensuring food security" and "zero hunger" within the scope of Sustainable Development Goals in Türkiye. The book covers 21 species including cereals, pulses, forages, and industrial crops whose production have decreased over time and with various reasons in Anatolia, and so can be considered as neglected or

underutilized crop for Türkiye. Among the crops, those that are in constant decline are also discussed, along with those that are on a declining trend. Therefore, the content also includes species that still hold high economic value today but pose a risk to the future. Also the factors limiting their cultivation of these crops are discussed, and their potential for ensuring food security and sustainable production in the future is explored. Each chapter is designed to increase public knowledge and awareness about the crops by supporting visual contents besides technical information. Therefore, the book serves not only as a reference source for academics and students but also as a guide for farmers.

Prof. Dr. Uğur BAŞARAN

This book is attributed to today's one of the most neglected communities, the peasants, especially the wise and noble Anatolian peasants: they are the strongest guarantees of agricultural sustainability. Because, despite many difficulties they are continue to produce, and protect their own seeds and soil. Moreover, they not only protected them; they kept them alive, just like their own children.

Chapter 1

BITTER VETCH (*Vicia ervilia* (L.) Willd)

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DOI: https://dx.doi.org/10.5281/zenodo.17453221

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1. General Characteristics of the Bitter Vetch

Bitter vetch (*Vicia ervilia* (L.) Willd) is a species belonging to the legume family (Fabaceae). The most common English name for this plant is “bitter vetch,” while it is also referred to as “ervil” and “lentil vetch”. It is also known by its Persian name “gavdaneh”, Arabic name “kersannah”, Spanish name “yero”, Greek name “rovi”, and Turkish name “burçak” (Salehi et al., 2020). In Türkiye, it is commonly known as "burçak", but it is also called "küşne" in some regions.

As the effects of global warming become increasingly pronounced, the sustainability of crop production in arid and semi-arid regions has reached a critical level. Under these conditions, bitter vetch stands out as a significant alternative crop due to its relatively stable grain yield, even on marginal lands. Adapted to the Mediterranean climate, it exhibits high drought tolerance and moderate cold tolerance, permitting spring cultivation in areas with harsh winters. Its modest requirements enable cultivation on otherwise unproductive lands, including those that are calcareous-deficient, stony, or sloped, where growing other crops is uneconomical.

Despite its short stature and relatively low biomass yield, it provides a good grain yield under arid conditions, a characteristic that enhances its value as a forage crop. Furthermore, its ability to fix atmospheric nitrogen in the soil through symbiotic Rhizobium bacteria in its roots, thereby improving soil fertility, is another crucial trait that makes it valuable for crop rotation systems. In terms of nutritional content, bitter vetch grain is rich, containing 22.3% crude protein and 19.1% digestible protein. However, due to the presence of bitter compounds in the seeds, it is not suitable for feeding horses, mules, and pigs; it is primarily used in the nutrition of cattle, sheep, and goats (Akyıldız, 1986).

In recent years, the primary reasons for the decline in bitter vetch production include the decreasing number of draft animals fed with bitter vetch, the necessity for largely manual harvesting due to the plant's short stature, the predominance of low-yielding local landraces, the lack of high-yielding improved cultivars, the presence of anti-nutritional factors in its seeds, and its cultivation being typically confined to infertile, arid lands. The average grain yield of the currently cultivated populations is around 1000 kg

ha^{-1}, this low productivity is attributed to both the limited genetic potential and the inadequacy of appropriate agronomic practices.

In conclusion, it is anticipated that through the breeding of new bitter vetch cultivars and the contribution of modern agricultural practices, the economic and sustainable production of this ancient crop may become feasible.

1.1. Center of origin and domestication

Bitter vetch is one of the most ancient legume species, utilized both as animal feed and human food since prehistoric times. The origin and domestication of this crop are being understood with increasing clarity through archaeobotanical findings and genetic studies. The Mediterranean Basin is considered the primary center of origin for *Vicia ervilia*, while the Near East is regarded as a secondary center of diversity (Mikić et al., 2015). Seed remnants of bitter vetch, dating back to 9000–8000 BC and belonging to its natural distribution in Central Anatolia, have been encountered at the Aşıklı Höyük settlement (Zohary and Hopf, 1993; Van Zeist and De Roller, 1995). Furthermore, remains dated to 6600–6200 BC in Çatalhöyük demonstrate that this species was domesticated during the Neolithic period and cultivated as an important pulse crop by early civilizations (Fairbairn et al., 2007). Excavations at the Tell El-Kerkh (Syria) settlement reveal that bitter vetch seeds date back 10.000 years, indicating that this species was present at the very beginning the agricultural revolution (Tanno and Willcox, 2006). The domestication process involved morphological changes such as an increase in seed size, smoothness of the seed coat, and non-shattering pods. All this evidence reveals that bitter vetch was first domesticated in Anatolia and its surroundings (Zeist, 1988), from where it spread to the interior of Europe, particularly along the Danube route (Mikić et al., 2015).

1.2. Taxonomy

Family: *Fabaceae* (*Leguminosae*)

Genus: *Vicia*

Species: *Vicia ervilia*

Bitter vetch (*Vicia ervilia*) is a species belonging to the genus *Vicia* within the legume family (*Fabaceae*). It has historically been classified under various taxonomic names and Latin nomenclatures in older literature, such as

Ervum ervilia L., *Lens pygmaea* Grossh., and *Ervilia sativa* Link (Harris, 1967; Кучер, 2016; Ellis et al., 2024). However, it is now exclusively classified as *Vicia ervilia* within the genus *Vicia*.

Bitter vetch is a diploid species, with a somatic chromosome number of 2n = 14 (Raina and Rees, 1983; Sevimay and Sancak, 1997). It exhibits a high degree of self-pollination (Zohary et al., 2012). Self-pollination typically occurs while the flowers are still closed, a phenomenon known as cleistogamy.

1.3. Morphological characteristics

Bitter vetch is an annual, herbaceous plant. The root system is a thin, branched taproot that does not penetrate deeply into the soil (Ekiz, 2009). The roots bear nodules formed by Rhizobium spp. bacteria.

The general appearance of the plant is presented in Figure 1. Bitter vetch has a slender, weakly developed stem and branches, growing in an erect or semi-prostrate form. It is a short-statured plant, with an average height ranging between 20 and 60 cm (Ekiz and Özkaynak, 1984; Al, 2000; Özköse, 2003). Plant height is shorter under arid conditions, while it can grow taller in rainy or irrigated conditions. Plant height also varies significantly depending on the genotype (Ekiz and Özkaynak, 1984). The stem branches from the base, and the number of primary branches can reach up to 10 (Ekiz and Özkaynak, 1984). The height of the first pod varies between 2 and 21 cm (Ekiz and Özkaynak, 1984; Özköse and Ekiz, 2005). The plant can be entirely glabrous (hairless) or sparsely pubescent (hairy) (Elçi, 2006).

The leaves are opposite and compound (Fig.2). The leaf rachis terminates in a very short tendril. The number of leaflets per leaf is greater compared to other vetch species (Elçi, 2006). A single leaf comprises 8 to 15 pairs of leaflets (Ekiz, 2009). The leaflets are small, oblong-elliptic in shape, 1.0-1.5 cm long and 0.2-0.5 cm wide (Elçi, 2006). The stipules are small, crescent-shaped, and typically have four notches (Soya et al., 1997).

In bitter vetch, flowers emerge from the leaf axils (Fig.3). The inflorescence type is a raceme. Each raceme bears 1 to 6 flowers (Ekiz, 1983). The flowers are small, and the petals are cream-colored. The pedicel is 0.6-2.8 mm long (Ekiz, 1983).

The pods (fruits) of bitter vetch are distinctly constricted between the seeds (Fig.4). Pod length ranges between 5 and 28 mm, and pod width is between 4 and 5 mm (Ekiz, 1983). A pod typically contains 2 to 4 seeds.

Bitter vetch seeds are pyramidal in shape, plain-colored or speckled, and are 2.5 - 5.5 mm in length (Ekiz, 1983) (Fig.5). The 1000-seed weight ranges from 25 to 50 g. Seedling emergence is hypogeal.



Figure 1. Morphology of bitter vetch (*Vicia ervilia*) (Sturm et al., 1901).



Figure 2. The leaves and branches of bitter vetch (*Vicia ervilia*) (GBIF, 2025a).



Figure 3. The flowers of bitter vetch (*Vicia ervilia*) (GBIF, 2025b).



Figure 4. The pods of bitter vetch (*Vicia ervilia*) (GBIF, 2025c).



Figure 5. The flowers of bitter vetch (*Vicia ervilia*) (USDA, 2025.

1.4. Adaptation

The primary center of origin for the bitter vetch is the Mediterranean Basin. As a typical Mediterranean species, it grows well in arid and semi-arid regions (Ekiz, 1991). Although it is highly drought-tolerant, precipitation during its growth period significantly increases its yield.

In general, bitter vetch is a highly low-input crop. It can be cultivated in low-rainfall, stony, and sloping lands where other crops are not economically viable to grow. It is grown for both its grain and forage. However, due to its short stature, its forage yield is limited, and it is therefore primarily cultivated for its grain.

Bitter vetch is an undemanding plant in terms of soil requirements and can grow in various soil types. The soil must contain sufficient lime. Due to the Rhizobium sp. bacteria in its roots, it has a low requirement for nitrogen fertilization. As a legume, bitter vetch is a desirable crop in rotation systems because it enhances soil fertility.

Bitter vetch is a forage crop with excellent drought tolerance but limited winter hardiness. It is generally reported to suffer damage at temperatures of -7 to -8 °C and lower. However, in a study conducted by Ekiz (1995) in Ankara, selected bitter vetch lines were observed to withstand

temperatures as low as -14.2 °C without snow cover. This indicates that bitter vetch possesses potential for improving cold tolerance through breeding.

1.5. Cultivation

In bitter vetch agriculture, obtaining registered cultivars is quite challenging (Ekiz, 1988). Seeds classified as local populations or landraces are typically used. Seeds from the previous year should be cleaned using a seed selector to remove shriveled grains, broken seeds, weed seeds, etc., before sowing.

In Mediterranean climates with harsh winters, it can be sown in early spring. Depending on the region, sowing should be done between February and April. For instance, in a study conducted under Ankara conditions, Özköse (2003) recommended late March to early April as the optimal sowing time. The primary consideration for determining the sowing time is to allow the plant to complete its vegetation cycle before the hot and dry summer period, ensuring that damaging frosts have passed and that the plant can utilize winter and spring rainfall effectively.

Bitter vetch should be sown in rows using a drill seeder. The row spacing should be between 15 and 20 cm, depending on the seeder used (Ev and Ekiz, 1994). For grain production, the seeding rate should be 80–100 kg per hectare, adjusted according to the region's rainfall and soil conditions (Tosun, 1975). The sowing depth varies between 2 and 4 cm, depending on soil structure and seed size (Tosun, 1974).

Fertilization is not extensively practiced in bitter vetch cultivation. As a legume, it meets its nitrogen requirements through biological nitrogen fixation facilitated by Rhizobium bacteria in its roots. Applying 100–150 kg ha^{-1} of diammonium phosphate (DAP: 18-46) fertilizer at sowing will supply the plant's phosphorus needs and support its initial nitrogen requirements during germination.

The yield of the plant increases under cool and rainy conditions. Since bitter vetch is typically cultivated in areas without irrigation facilities, it relies entirely on natural rainfall. Therefore, it is essential to develop agricultural techniques that maximize the utilization of available precipitation. This includes optimizing sowing time, determining the appropriate seeding rate, implementing weed control, adopting conservation tillage to preserve soil

moisture, practicing reduced tillage or direct seeding where possible, and increasing soil organic matter to enhance water retention in the root zone.

Weed control should primarily be achieved through cultural methods such as using clean seeds, crop rotation and tillage. Herbicides should only be applied if necessary. These measures will help conserve the limited moisture and nutrients in the soils where bitter vetch is grown. Bitter vetch can be affected by pests commonly found in other vetch species, such as Bruchus spp. and aphids. When pest populations exceed the economic injury threshold, appropriate insecticides should be applied.

Due to its short stature and low-hanging pods, bitter vetch is not well suited for mechanical combine harvesting. For this reason, the common practice is to harvest and thresh separately. This is also due to the fact that the plant is generally grown in marginal areas. Harvesting should be carried out when the plants have turned yellow and the pods have matured. The plants are first harvested by hand and then threshed using a thresher to separate the grain from the straw. Grain yield can range from 500 to 3000 kg ha^{-1}, depending on the region and climatic conditions. In arid regions, yield typically range from 500 to 1500 kg ha^{-1}, while improved lines or cultivars under favorable rainfall and good management conditions can yield between 2500 and 3000 kg ha^{-1}. Indeed, in a study by Ev and Ekiz (1994) investigating plant density in bitter vetch, using an improved single-plant line and a planting density of 15 x 9 cm (row spacing x intra-row spacing), the seed yield reached up to 3090 kg ha^{-1}. Similarly, in a study conducted by Özköse (2003) under Ankara conditions using improved bitter vetch lines, the crop received adequate rainfall during the trial period (total precipitation from March to June = 191.8 mm), resulting in a grain yield of 2978.6 kg ha^{-1} (Fig.6,7).



Figure 6. A close-up view of a bitter vetch trial plot (Original).



Figure 7. A bitter vetch trial plot (Original).

2. Cultivation Purposes and Nutritional Value of Bitter Vetch

A significant portion of agricultural land in Türkiye is located in arid and semi-arid regions. In recent years, both in Türkiye and globally, the extent of arid and semi-arid areas has been increasing due to global warming. In these regions, the quantity of forage produced by grasslands and pastures is very low, and the number of forage plant species that can thrive is also limited (Özköse, 2023). In these areas where cereal farming is predominant, plants with grain forage characteristics hold great importance within crop rotation systems. Grain forage crops are preferred over other forage plants due to their use as concentrated winter feed, superior nutritional value, and easier transportation, storage, and preservation. One of the grain forage plants that has been cultivated for years in the Mediterranean Basin and adapted to the environment is bitter vetch. Although bitter vetch is a short-statured plant with relatively low biomass yield, it provides quite good grain yield under arid climates, thereby gaining value as a forage crop in such regions.

Bitter vetch is one of the oldest legume species, utilized both as animal feed and human food since prehistoric times. While its use as human food is less common in modern history, it has been primarily employed as grain-based animal feed. In Türkiye, bitter vetch had extensive cultivation areas until the 1950s and was mainly used to feed draft animals. After the 1950s, the widespread adoption of tractors reduced the reliance on animal labor, leading to a consequent decline in bitter vetch cultivation areas. In Türkiye, the cultivation area of bitter vetch decreased from 109,900 hectares in 1963 to approximately 1.235 hectares in 2024 (Table 1).

Table 1. Cultivation Area of Bitter Vetch in Türkiye by Year*

Years	Cultivation Area (ha)	Production (tons)	Yield (kg ha^{-1})
1963	109900	110000	1001
1970	75000	72000	960
1975	60000	60000	1000
1980	31000	30000	968
1985	18000	19000	1060
1990	11000	11000	1000
1995	9200	9200	1000
2000	3550	3600	1010
2005	2000	2300	1150
2010	10079	12100	1200
2015	3590	3765	1050
2020	1424	2162	1520
2024	1235	1978	1600

* 1963: Tosun (1974); 1970 – 1980: Ekiz (1983) 1985- 2000: Fırıncıoğlu (2006); 2005-2024: TÜİK (2025)

2.1. Uses of bitter vetch grain as feed and its nutritional content

Bitter vetch grain is a notable feed source due to its high protein content, nutritional value, and mineral composition. According to research findings, the nutrient and mineral matter content of bitter vetch grain varies within the following ranges: dry matter content 90.3–94.85%, crude protein 21–28.5%, crude fat 4.06–7.70%, crude ash 3.00–5.45%, carbohydrate content 58.86–63.64%, ADF 9.10–12.28%, NDF 9.70–14.20%, Ca 0.16–0.71 g/100g, P 0.29–0.31 g/100g, K 2.2–3.22 g/100g, Na 0.61–17.63 g/100g, Mg 0.010–0.110 g/100g, Cu 6.91–46.7 ppm, Mn 10.55–36.7 ppm, Fe 57.8–340.0 ppm, Zn 35.0–154.9 ppm, and Mo 0.35–6.24 ppm (Table 2). These variations may be attributed to differences in the genotypes studied, climatic and soil conditions, and agricultural practices, either individually or in combination. However, these differences also indicate that better genotypes can be selected and improved in terms of nutritional value and elemental content, and that better results can be achieved by optimizing cultivation conditions.

Table 2. Nutrient composition of bitter vetch grain

Parameters	Minimum	Maximum
Dry Matter, %	90.3 (Aletor et al.,1994)	94.85 (Arabi, 1997)
Crude protein, %	21.00 (López Bellido, 1994)	28.52 (Farran et al., 2001)
Crude fat, %	4.06 (Farran et al., 2001)	7.70 (Tabatabaei et al., 2000)
Crude ash, %	3.00 (López Bellido, 1994)	5.45 (Arabi, 1997)
Carbohydrate content, %	58.86 (Sadeghi et al., 2009b)	63.64 (Tabatabaei et al., 2000)
ADF %	9.10 (Ayaşan, 2010)	12.28 (Sadeghi et al., 2009b)
NDF %	9.70 (Ayaşan, 2010)	14.20 (Sadeghi et al., 2009b)
Ca (g/100g)	0.16 (Sadeghi et al., 2009b)	0.71 (Sayar, 2016)
P (g/100g)	0.29 (Sayar, 2016)	0.31(Sayar, 2016)
K (g/100g)	2.2 (Sadeghi et al., 2009b)	3.22 (Sayar, 2016)
Na (g/100g)	0.61 (Sadeghi et al., 2009b)	17.63 (Kaplan et al., 2014)
Mg (g/100g)	0.010 (Kaplan et al., 2014)	0.110 (Sadeghi et al., 2009b)
Cu (ppm)	6.91 (Kaplan et al., 2014)	46.7 (Sadeghi et al., 2009b)
Mn (ppm)	10.55 (Kaplan et al., 2014)	36.7 (Sadeghi et al., 2009b)
Fe (ppm)	57.8 (Kaplan et al., 2014)	340.0 (Sadeghi et al., 2009b)
Zn (ppm)	35.0 (Sadeghi et al., 2009b)	154.9 (Kaplan et al., 2014)
Mo (ppm)	0.35 Kaplan et al., 2014)	6.24 (Kaplan et al., 2014)

The amino acid composition of bitter vetch and soybean is presented in Table 3. As can be seen in Table 3, the amino acid content of bitter vetch is comparable to that of soybean.

The primary concern regarding the use of bitter vetch grain as feed is the presence of anti-nutritional substances in the seeds, which can negatively affect the performance and health of consuming animals. The anti-nutritional factors in bitter vetch include canavanine, protease (trypsin and chymotrypsin) inhibitors, lectins, and tannins (Sadeghi et al., 2009a; Ayaşan, 2010). Researchers have reported the following concentrations of anti-nutritional substances in bitter vetch grains: canavanine 0.05 mg/kg (Angeles-Garcia et al., 1992) – 1.7 mg/kg (Brenes et al., 1993), proteinase (trypsin and chymotrypsin) inhibitors 3.46 g/kg (Aletor et al., 1994) – 10.33 g/kg (Berger et al., 2003), tannins 0.80 mg/kg (Berger et al., 2003) – 6.70 mg/kg (Sadeghi et al., 2009b), and lectin 0.75 mg/kg (Fornestedt and Porath, 1975).

Table 3. Comparative amino acid composition (g/100 g CP) and total nitrogen content (g/100 g DM) of bitter vetch and soybean grains*

Amino Acid	Bitter vetch	Soybean
Total nitrogen	3.98	6.67
Alanine	4.73	4.80
Arginine	4.51	6.86
Aspartic acid	11.13	11.90
Phenylalanine	4.04	4.58
Glycine	4.16	3.72
Glutamic acid	17.35	20.23
Histidine	3.43	2.40
Isoleucine	3.28	4.22
Leucine	6.46	7.07
Lysine	7.48	6.04
Methionine	0.49	1.25
Proline	5.31	4.58
Serine	5.19	5.18
Cystine	<0.01	1.29
Threonine	3.51	3.79
Tyrosine	1.36	3.36
Valine	3.55	4.20
Total amino acids	85.98	95.47

*: (Kaya and Yalçın, 1999)

Numerous studies have reported that the use of bitter vetch in broiler production negatively affects feed intake, live weight gain, and growth (Ayaşan, 2010). D'Mello and Devendra (1995) observed reduced feed intake in broilers fed bitter vetch, while Ocio et al. (1980) reported not only decreased feed consumption but also slower weight gains and a significant increase in pancreas weight, with these effects being more pronounced in animals fed higher levels of bitter vetch. Similarly, Sadeghi et al. (2004) found that increasing levels of bitter vetch (15%, 30%, and 40%) in compound feed reduced live weight and feed intake, while increasing the feed conversion ratio and mortality rate. Comparable results have been observed in layer hens. In ruminant nutrition, anti-nutritional factors also limit the use of bitter vetch. To eliminate these anti-nutritional substances in bitter vetch

seeds, heating or soaking in water has long been known and practiced in Anatolia. Another method is the addition of acetic acid.

In this regard, various detoxification methods for legume seeds—such as soaking in water, acetic acid, sodium bicarbonate solutions, potassium bicarbonate, boiling in solution, autoclaving, urea treatment, alkaline extraction, and extrusion—have been studied by different researchers. However, it has been noted that these methods are sometimes insufficient when applied alone and may require combined (physical and chemical) application for effective detoxification (Sadeghi et al., 2004). Additionally, keeping the proportion of bitter vetch low in compound feed is another preventive measure that can be taken.

2.2. Uses of bitter vetch hay

Bitter vetch hay is also used in animal nutrition. Since the plant's green forage and dry hay yield per hectare is low, the remaining straw after grain harvest is primarily utilized for animal feed. In a study conducted by Larbi et al. (2011), bitter vetch was harvested for forage at the 50% flowering stage and for grain when the pods matured. The study reported an average dry hay yield of 3085 kg ha^{-1} DM, a straw yield of 3696 kg ha^{-1} DM for grain-harvested plots, and a grain yield of 1719 kg ha^{-1} DM. The crude protein content was 16.2% in hay, 9.1% in straw, and 28% in grain. By multiplying the dry matter yields with their respective crude protein percentages, the crude protein yield per hectare was calculated as 499.77 kg ha^{-1} for hay (3085 × 0.162) and 817.6 kg ha^{-1} for grain-harvested plots (straw: 3696 × 0.091 = 336.3; grain: 1719 × 0.28 = 481.3). These results indicate that higher crude protein per hectare is achieved when bitter vetch is cultivated for grain production. Thus, producing bitter vetch for grain and utilizing its grain and straw separately appears more advantageous.

2.3. Uses of bitter vetch grain in food and traditional medicine

Bitter vetch was historically used as human food. It is reported that boiling the whole seeds multiple times in hot water significantly reduces their bitterness, resulting in a product with a pleasant texture and an enjoyable nutty flavor (Miller and Enneking, 2014).

Bitter vetch seeds also have medicinal applications. Bitter vetch has been traditionally used in Anatolia (Türkiye) to treat various ailments (Salehi

et al., 2021). The seeds are mashed into a poultice and applied to fractures, where they are believed to aid in healing bruises and injuries. Literature also suggests potential anticarcinogenic properties. Yeşilada et al. (1995) reported that in the inner Taurus Mountains of Southern Anatolia, roasted bitter vetch seeds are ground and used for diabetes treatment by local communities. In Northwestern Anatolia, it is known that a decoction is consumed for its hypoglycemic effects and to treat rheumatic pains; the leaves are dried over fire and applied to limbs or boiled, and the water is used in baths while still warm (Yeşilada et al., 1999). In Spain (Pallars region), bitter vetch seeds are swallowed directly and used as a relaxant, aphrodisiac, and health tonic (Agelet and Vallès, 2003). In Eastern Morocco, bitter vetch is employed for treating digestive system disorders and allergies, as well as for addressing strength-related issues and general weakness (Salehi et al., 2021). Okba et al. (2017) found that the ethanolic extract (70%) of bitter vetch seeds exhibits significant anti-inflammatory, analgesic, anti-ulcerogenic, antihyperglycemic, and antiviral activities.

Vioque et al. (2020) concluded that bitter vetch, a historically neglected and underutilized plant, holds potential for revaluation and increased use due to its high-quality protein content and functional components such as antioxidant and antiproliferative properties that may offer health benefits.

3. Contribution of the Bitter Vetch to Sustainable Agriculture and Food Supply Security

Sustainable agriculture aims to meet the needs of current and future generations while conserving natural resources and maintaining productivity and profitability. In this context, bitter vetch emerges as a promising candidate crop. It is a versatile legume well-suited for low-input production systems, particularly in arid and semi-arid regions under Mediterranean climates. As a legume adapted to marginal soils, bitter vetch has been primarily used for animal feed. Today, its former cultivation area, production, and usage have significantly declined, largely replaced by soybean meal, feed peas, and other vetch species. However, within the framework of sustainable economic development, expanding bitter vetch cultivation in marginal areas could be highly beneficial. The contributions of bitter vetch to sustainable agriculture can be summarized under several key points:

3.1. Nitrogen fixation and soil fertility

As a legume, bitter vetch performs symbiotic nitrogen fixation through Rhizobium bacteria in its roots. This allows it to meet its own nitrogen requirements while also enriching the soil with nitrogen-rich root and plant residues, thereby increasing soil organic matter. Consequently, subsequent cereal crops such as wheat or barley exhibit yield improvements with reduced mineral fertilizer needs. Researchers have reported that bitter vetch can fix up to 110 kg of nitrogen per hectare per year through its rhizobial associations (Özköse, 2024). Some studies indicate that bitter vetch demonstrates higher biological nitrogen fixation compared to other vetch species, with significant variation among genotypes, suggesting potential for further enhancement through breeding (El Moneim and Saxena, 2015).

3.2. Reduced tillage

Bitter vetch seeds are relatively large, and the plant exhibits vigorous emergence. It does not require finely pulverized, heavily worked, or compacted soil preparation for sowing. In areas without significant weed pressure, it can be cultivated through direct seeding into stubble or with minimum tillage practices. This reduces input costs, preserves soil structure, and minimizes negative environmental impacts.

3.3. Adaptation to arid regions

Bitter vetch has the potential to grow in arid marginal lands without requiring intensive inputs such as fertilization. Its relatively short vegetative period is another advantage. The plant's ability to tolerate cold temperatures down to -8 °C allows for early spring sowing, enabling it to make better use of spring rainfall. These characteristics make bitter vetch a promising crop in the face of increasing drought risks due to climate change. Furthermore, existing populations and genotypes can be utilized to develop more stress-tolerant cultivars. In a study by Petrova et al. (2025), significant variation was observed among local bitter vetch genotypes for the traits examined, suggesting that future breeding efforts could develop cultivars with enhanced tolerance to abiotic stresses such as drought and salinity.

3.4. Diversification of Crop

Diseases and pests affecting many currently cultivated crops are increasingly prevalent. Reducing these pathogens and pests or introducing new resistant species into rotation systems is essential. In this context, bitter vetch can serve as an alternative rotation crop. Notably, its genetic diversity highlights the potential for developing more resilient and higher-yielding bitter vetch varieties through breeding efforts.

3.5. Alternative protein source in animal nutrition

The growing global population and increasing per capita consumption of animal protein necessitate higher animal production. However, expanding livestock production with existing resources and reducing unit production costs remain challenging. Therefore, cultivating bitter vetch in marginal areas where other crops are unviable or costly can contribute to agricultural output, produce protein-rich grain feed, and support livestock production. Bitter vetch grains can be ground and directly incorporated into poultry, small ruminant, and cattle rations without exceeding certain inclusion thresholds. If desired, thermal processing, soaking, or other methods can be applied to eliminate anti-nutritional factors, allowing for higher inclusion rates in animal diets.

3.6. Potential for use as human food

Bitter vetch seeds are rich in protein, carbohydrates, and minerals. However, the presence of anti-nutritional factors limits their use for human consumption. Through household processing methods such as soaking, boiling, pressure cooking, and sprouting, these anti-nutritional compounds can be reduced, making the seeds suitable for human diets. In regions where climate change threatens conventional grain production, bitter vetch could contribute to dietary diversity and food security as a resilient alternative source of protein and carbohydrates.

4. Factors limiting the Cultivation and Use of Bitter Vetch

4.1. Lack of mechanization

The bitter vetch plant has a relatively short stature, and its pod clearance height—a critical factor for mechanization—is notably low. Additionally, bitter vetch is typically cultivated in stony, sloping, and small-scale fields. These characteristics make harvesting with conventional

agricultural machinery challenging. Traditional harvesting methods (manual labor) are both labor-intensive and costly, representing one of the major barriers to large-scale commercial production.

To address these limitations, breeding programs should focus on developing new bitter vetch cultivars with taller stems and higher pod clearance. Furthermore, agricultural fields designated for bitter vetch cultivation should be cleared of stones, and soil preparation practices must be optimized. The development of combine harvesters specifically adapted to bitter vetch harvesting is also essential.

4.2. Anti-nutritional factors and toxicity

The seeds of the plant contain various compounds such as vicine, convicine, tannins, and trypsin inhibitors that can be harmful to animals and humans if left unprocessed. These components prevent the direct use of the plant as a safe feed or food. To neutralize the toxic and anti-nutritional factors, the seeds must undergo processing methods such as crushing, boiling, and prolonged soaking, or roasting. These processes incur additional time, energy, and labor costs. Moreover, small-scale farmers may lack the infrastructure to perform such treatments. Large-scale feed mills also prefer raw materials like soybean or canola meal, which offer easier and more consistent processability. This limits demand and, consequently, bitter vetch production.

To address these challenges, breeding programs should focus on developing new bitter vetch varieties with reduced or eliminated anti-nutritional factors and toxicity. Additionally, mechanized solutions for processing methods such as soaking, boiling, roasting, or additive-assisted elimination of anti-nutritional compounds must be developed to resolve these issues efficiently and cost-effectively.

4.3. Insufficiency of breeding studies

Current varieties predominantly consist of local landraces. Compared to widely cultivated commercial crops such as wheat, barley, corn, or soybean, breeding and research efforts focused on bitter vetch remain limited. There is a lack of sufficiently developed and commercialized cultivars along with their certified seeds suitable for large-scale cultivation.

There is a critical need to develop varieties with high yield, increased plant height and pod clearance, reduced anti-nutritional factors, synchronous maturity, and resistance to pod shattering.

4.4. Inadequate knowledge of agricultural production techniques

Currently, bitter vetch cultivation primarily relies on traditional production methods, with limited adoption of modern agricultural techniques. This hinders the realization of the full yield potential of existing varieties or populations.

Implementing appropriate agricultural practices—such as optimal sowing time, seeding rate, row spacing, fertilization, and reduced tillage in a timely and accurate manner can significantly enhance the yield performance of available varieties or populations.

4.5. Other limiting factors

The yield and economic returns of bitter vetch cannot currently compete with those of widely cultivated crops. The development of high-yielding varieties and low-cost production methods is essential. At present, bitter vetch is primarily produced for animal feed. However, its economic value would increase significantly if utilized as a functional food or medicinal resource for humans. In other words, the seeds could be valued as a high-economic-value functional food or pharmaceutical raw material rather than a low-value feed. Recent scientific studies highlight that bitter vetch seeds, with their high-quality protein content, antioxidant, anti-inflammatory, and various biological activities, possess broad potential applications from functional foods to medicinal and wellness practices.

Low recognition and farmers' lack of knowledge about cultivating this plant are additional factors currently limiting bitter vetch production.

The inability to guarantee a consistent, high-quality, and large-volume supply further prevents industrial feed producers from incorporating it into ration formulations.

5. Conclusion and Recommendations

Bitter vetch (*Vicia ervilia* (L.) Willd), with its ancient historical background, high adaptability to arid and semi-arid regions, and low-input

requirements as a legume species, holds significant potential for sustainable agriculture and livestock production. Its ability to enhance soil fertility through nitrogen fixation, suitability for low-input cultivation, high nutritional value as feed grain, and capacity to thrive even in marginal lands underscore its promise for future utilization. However, the current limitations in agricultural production are closely tied to challenges such as lack of mechanization, use of low-yielding local landraces, scarcity of improved cultivars, and presence of anti-nutritional factors. Additionally, low awareness among producers and underdeveloped market chains have contributed to the progressive decline in bitter vetch cultivation areas.

Research on bitter vetch demonstrates its potential as an alternative protein source in animal nutrition, as well as its suitability for human food and functional products. By reducing anti-nutritional factors through processing techniques, developing low-toxin varieties via breeding programs, and implementing modern agricultural practices, bitter vetch can be transformed into a high-economic-value crop. Furthermore, considering the impacts of climate change and the rising global demand for food and feed, reintegrating bitter vetch into agricultural systems as a strategic crop is of critical importance for sustainability.

In this context, the following recommendations stand out:

Breeding Studies: Priority should be given to developing new varieties with high yield, low anti-nutritional factors, suitability for mechanized harvesting, and resilience to stress conditions.

Advancement of Mechanization: Harvesting machinery and production technologies tailored to overcome the challenges of short plant height and low pod clearance should be developed.

Dissemination of Agricultural Practices: Modern sowing techniques, fertilization, crop rotation, and tillage methods should be communicated to farmers to enhance production efficiency.

Reduction of Anti-Nutritional Factors: Research on seed processing methods (soaking, boiling, roasting, chemical, and biotechnological applications) should be conducted, and suitable methods made accessible to farmers.

Investigation of Functional Food and Medicinal Application Potential: Bitter vetch should be re-evaluated not only as animal feed but also as a raw

material for functional foods and medicinal products, leveraging its high protein and bioactive compounds.

Policy and Incentives: Agricultural support and incentives targeting bitter vetch production should be implemented to promote the use of marginal lands, support small-scale farmers, and enhance crop diversity.

In summary, bitter vetch is not only historically significant as a forage and food crop but also represents a species worthy of consideration for the future of sustainable agriculture and food security. Supported by research, breeding, and extension activities, it holds the potential to regain its status as a strategic legume in Türkiye and other regions within arid climate zones.

In conclusion, bitter vetch should be regarded not only as an important feed and food crop of the past, but also as a species that deserves attention for the future of sustainable agriculture and food security today. With sufficient support through research, breeding, and extension activities, bitter vetch has the potential to regain importance as a strategic legume, both in our country and in other regions of the arid climate zone.

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Chapter 2

BUCKWHEAT (*Fagopyrum esculentum* Moench)

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DOI: https://dx.doi.org/10.5281/zenodo.17453232

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1. General Characteristics of Buckwheat (*Fagopyrum* sp.)

Buckwheat belongs to the genus *Fagopyrum* (Polygonaceae) and has been used as a cereal and medicinal plant for many years. There are a total of 21 species in the genus Fagopyrum, two of which are cultivated (*Fagopyrum esculentum* Moench. and *Fagopyrum tataricum* (L.) Gaertn). (Tang et al., 2019; Wen et al., 2021) (Table 1).

Table 1. The species of genus *Fagopyrum*

Number	Scientific Name	Number	Scientific Name
Wild species		**Wild species**	
1	*Fagopyrum cymosum* (Trevir.) Meisn	12	*Fagopyrum urophyllum* (Bureau & Franch.) H. Gross
2	*Fagopyrum hailuogouense* J.R. Shao, M.L. Zhou & Qian Zhang	13	*Fagopyrum lineare* (Sam.) Haraldson
3	*Fagopyrum macrocarpum* Ohsako & Ohnishi	14	*Fagopyrum gracilipedoides* Ohsako & Ohnishi
4	*Fagopyrum qiangcai* D.Q. Bai	15	*Fagopyrum statice* Gross
5	*Fagopyrum capillatum* Ohnishi	16	*Fagopyrum crispatifolium* J.L. Liu
6	*Fagopyrum gracilipes* (Hemsl.) Dammer	17	*Fagopyrum caudatum* (Sam.) A.J.Li
7	*Fagopyrum pugense* T. Yu	18	*Fagopyrum gilesii* (Hemsl.) Hedberg
8	*Fagopyrum homotropicum* Ohnishi	19	*Fagopyrum jinshaense* Ohsako & Ohnishi
9	*Fagopyrum leptopodum* (Diels) Hedberg	**Cultivated species**	
10	*Fagopyrum luojishanense* J.R. Shao	20	*Fagopyrum esculentum* Moench
11	*Fagopyrum rubifolium* Ohsako & Ohnishi	21	*Fagopyrum tataricum* (L.) Gaertn



Figure 1. General views of buckwheat

Buckwheat (*Fagopyrum esculentum* Moench) is a significant crop that is botanically not a true cereal (Figure 1) but is utilized similarly to cereals in human diet. For this reason, it is classified as a "pseudocereal." One of the mainstructural differences that distinguishing buckwheat from cereals is that it is a dicotyledonous plant (Dizlek et al., 2009). Furthermore, it exhibits strong adaptability to develop within a short period at high altitudes (Kan, 2011). In recent years, buckwheat has gained increasing attention both for its nutritional value and its role in sustainable agricultural systems. It has emerged as a

functional food due to its gluten-free nature, high-quality protein content and richness in antioxidant compounds.

1.1. Origin and spread

The genetic and cultural origin of buckwheat is believed to be centered in southwestern China, particularly Yunnan Province, and the Himalayan region. This origin overlaps with the natural distribution areas of wild relatives such as *Fagopyrum cymosum* and *Fagopyrum tataricum* (Ohnishi, 1998; Fesenko et al., 2019).

Domesticated buckwheat is thought to have been first cultivated around 4000 years ago in the vicinity of the Yunnan and Tibetan Plateaus (Campbell, 1997). These regions correspond with the "East Asian Center of Origin"- one of the eight plant gene centers identified by Vavilov (Figure 2). The domestication of buckwheat from wild types naturally growing in mountainous areas has led to the development of resilient and fast-maturing cultivars.

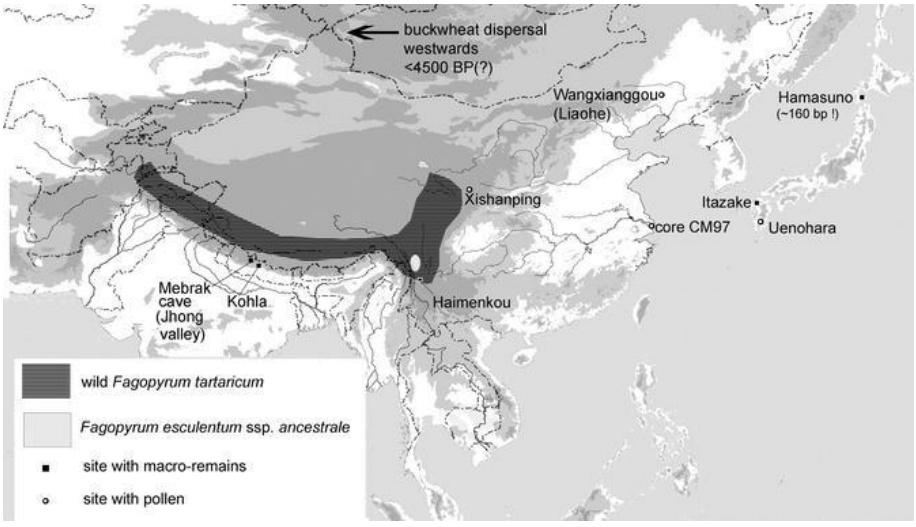


Figure 2. Origin and spread of buckwheat (Anonymous, 2025a)

From China, buckwheat spread westward to the Central Asian steppes, eventually reaching Iran and the Caucasus, and then into Anatolia. The Black Sea basin served as a critical transition zone during this westward movement. The Mongol invasions and Silk Road trade routes played substantial roles in

the rapid dissemination of buckwheat across Eurasia (Li and Zhang, 2001). It is believed that buckwheat was introduced into Europe during the 13th century through Mongol incursions and became widely cultivated in Western Europe by the 14th and 15th centuries (Campbell, 1997). In Slavic countries such as Russia, Poland, and Ukraine, where it is known as "grechka," buckwheat has become a staple in traditional diets.

Although the exact date of buckwheat's arrival in Anatolia is unknown, it is presumed to have been introduced during the Ottoman period either via the Caucasus or the Balkans. Having been grown in limited areas across various ecological regions of Anatolia, buckwheat nearly faded into obscurity by the latter half of the 20th century. However, due to its gluten-free nature and recognized health benefits, it has recently regained interest in Türkiye.

1.2. Current cultivation and in the world, Türkiye

Thanks to its short growing period, low input requirements, and wide adaptability, buckwheat is now considered a strategic crop in modern agriculture, particularly in contexts focused on drought mitigation, organic farming, and diversification of alternative crops. Today, buckwheat is cultivated under very diverse climatic and soil conditions across the world. China and Russia are the leading countries in terms of both cultivated area and production. China accounts for approximately 34% of global buckwheat production. Russia, with a sown area of about 712.000 hectares, holds the largest cultivation area globally. Other major producing countries include Kazakhstan, Ukraine, Poland, Japan, and the United States. In some European countries such as France and Slovenia, high-yielding and high-quality cultivars are grown.

Globally, the total area under buckwheat cultivation is approximately 3.5 million hectares, with an estimated total production of around 2 million tons (TUIK, 2024). France has recorded the highest yield with 369.7 kg da^{-1}, followed by the Czech Republic with 250 kg da^{-1}. The global average yield stands at about 116.1 kg da^{-1}.

In Türkiye, buckwheat is cultivated in limited areas, primarily in regions such as Yozgat, Erzurum, Konya, Karaman, Bolu, Kars, and Ardahan. It is increasingly valued both for its relevance in the health sector and its suitability for organic farming practices (Güler and Akın, 2020). Türkiye has

suitable climate and soil conditions for buckwheat cultivation. Production activities are increasing, especially in the Central Anatolia, Thrace, and Aegean regions. Since 2021, the Turkish Statistical Institute (TUIK) has started recording data on buckwheat production. In 2021, the cultivated area was 9.603 decares, with a total production of 1.413 tons and an average yield of 154 kg da^{-1}. By 2024, the cultivated area grew to 21.229 decares, production reached 2.856 tons, but the yield decreased to 135 kg da^{-1}. Although production has increased, it is still not at sufficient levels (TUIK, 2024). According to 2024 trade data, Türkiye imported 1,058 tons of buckwheat at a cost of $346.000, while exporting only 85 tons for $83.000. These low figures show that Türkiye is mainly an importer and that buckwheat is still a relatively new crop for the country.

Currently, most cultivation in Türkiye is still in the trial stage and limited to specific regions. In 2024, the leading provinces in buckwheat production were Gümüşhane (3.310 decares, 333 tons) and Afyonkarahisar (3.010 decares, 449 tons). Other important areas include Eskişehir, Ankara, Çankırı, Yozgat (1.318 decares, 159 tons), and Kastamonu. However, production varies by year and region, and buckwheat is mainly grown as an alternative crop. Both public institutions and private organizations in Türkiye are conducting research and development on buckwheat. Due to declining water resources and increasing soil salinity, buckwheat is being considered as a promising crop for crop rotation with cereals, legumes, and industrial crops. It is sensitive to cold, so it is more suitable for summer cultivation in colder regions.

1.3. Morphological characteristics

Buckwheat is an annual herbaceous crop. Although it is not classified as a true cereal in botanical terms, it is referred to as a "pseudocereal" in agricultural literature due to its triangular-shaped fruits (achenes), which are harvested and consumed similarly to cereals. Typically reaching heights of 80–120 cm, the plant has a short and intense vegetation period, usually lasting 10–12 weeks. The morphological structure, root system, stem, leaves, flowers and fruit-seed components of buckwheat in parallel with its life cycle are explained in detail below (Figure 3).

Root system: Buckwheat has a fibrous and shallow root system. While roots generally extend to a depth of 30–40 cm, they can remain shallower depending on soil structure. Due to its lack of deep rooting, buckwheat performs better in well-drained, permeable, and light soils with low water retention capacity. However, it is highly sensitive to drought stress; under water scarcity, its growth slows and yield is significantly reduced. Additionally, buckwheat roots contribute positively to microbial activity in the rhizosphere, making the plant valuable as a preceding crop in organic and rotational farming systems (Bjorkman et al. 2008).



Figure 3. The life cycle of buckwheat (Anonymous, 2025b)

Stem and leaves: The stem of buckwheat is hollow, generally cylindrical, and slender. It is light green in its early stages and may turn reddish-purple as it matures, due to anthocyanin accumulation. Stems are typically upright and brittle, making them prone to lodging under strong winds. The leaves are triangular or arrow-shaped, short-petioled, and have smooth margins. They are arranged alternately on the stem. As the main organ for photosynthesis, the leaves are bright green and delicate in young plants.

The prominent veins on the leaf blades indicate the physiological vitality of the plant (Björkman and Shail, 2010).

Flower structure and pollination: Buckwheat produces raceme-type flower clusters. The flowers are small, five-parted, and usually white or light pink in color. Each flower contains three pistils and eight stamens. The plant exhibits heterostyly (different lengths of stamens and styles), which promotes cross-pollination by reducing self-compatibility. Pollination primarily occurs via insects, particularly bees (entomophilous pollination). Therefore, climatic conditions and pollinator presence during the flowering period directly affect seed yield (Crista and Soral-Śmietana, 2008).

Fruit and seed: Buckwheat fruits are triangular-shaped achenes with a hard shell. The seeds are typically 4-7 mm in length, and the 1000-seed weight ranges from 20-30 g. The husk color varies from light brown to dark brown. The endosperm inside the seed is rich in starch, protein, dietary fiber, magnesium, manganese, and antioxidant compounds. As it is gluten-free, buckwheat is a significant dietary alternative for individuals with celiac disease or gluten intolerance. Mature fruits may shatter easily during the drying phase, making the determination of optimal harvest time critical (Wijngaard and Arendt, 2006).

Buckwheat is a short-day plant, which may delay flowering under long-day conditions. It is not highly selective regarding soil type but performs best at pH levels between 5.5 and 6.5. Its fertilizer requirement is low, though it is sensitive to phosphorus and potassium levels. Due to its limited competitiveness, effective weed control is essential.

The morphological features of buckwheat indicate its adaptability to diverse ecological conditions. Its shallow root structure and short growth period make it suitable for cultivation in mountainous, marginal, and low-input agricultural lands. Additionally, its flowers serve as an excellent nectar source for honey production, adding value to beekeeping systems.

2. Cultivation Purposes and Nutritional Value of Buckwheat

Buckwheat (*Fagopyrum esculentum*) is a highly nutritious, gluten-free pseudo-cereal that is increasingly valued for its health benefits and agricultural adaptability. Below is an overview of its uses and importance both globally and in Türkiye. The significance of buckwheat should be

evaluated both in terms of its nutritional benefits and its contribution to agricultural sustainability. Buckwheat not only plays a key role in meeting the nutritional needs of a rapidly growing global human and livestock population, but it is also gaining importance in industrial production (Figure 4).

2.1. Nutritional value of buckwheat

Although buckwheat is not botanically classified as a cereal, it is considered as valuable as, and in some respects even more valuable than, traditional cereals due to its rich nutritional profile. In particular, its gluten-free nature, high-quality protein content, and abundance of antioxidants make it stand out as a functional food. Buckwheat is especially rich in magnesium, manganese, phosphorus, copper, and zinc, and it also contains significant amounts of B vitamins, including thiamine (B1), riboflavin (B2), niacin (B3), and vitamin B6 (Table 2).

Buckwheat is a nutrient-rich food source, particularly high in protein, fiber, minerals (magnesium, zinc, iron), and B vitamins (Figure 4). In addition to its nutritional value, it is considered a functional food, as defined by Erbaş et al. (2008), due to its role in maintaining and improving health and reducing disease risk. The growing consumer interest in functional foods has led to an increase in the availability of such products on the market (Sedej et al., 2011). Buckwheat is widely used in the production of many functional food products worldwide (Zhang, 2001). As a result, buckwheat-based products are considered dual-purpose items with both nutritional and medicinal value, demonstrating notable effects on the human body in the context of chronic diseases (Peng et al., 2012).

Table 2. Nutritional value and chemical contents of buckwheat

Contents	Value	Contents	Value
Energy	343 kcal	Manganese	1.3 mg
Carbohydrate	71.5 g	Phosphorus	347 mg
Fiber	10.0 g	Iron	2.2 mg
Crude protein	13.3 g	Zinc	2.4 mg
Fat	3.4 g	Thiamine (B1)	0.1 mg
Unsaturated fatty acids	2.2 g	Riboflavin (B2)	0.4 mg
Water	10.0 g	Niacin (B3)	7.0 mg
Magnesium	231 mg	Vitamin B6	0.2 mg

USDA Food Data Central, 2024

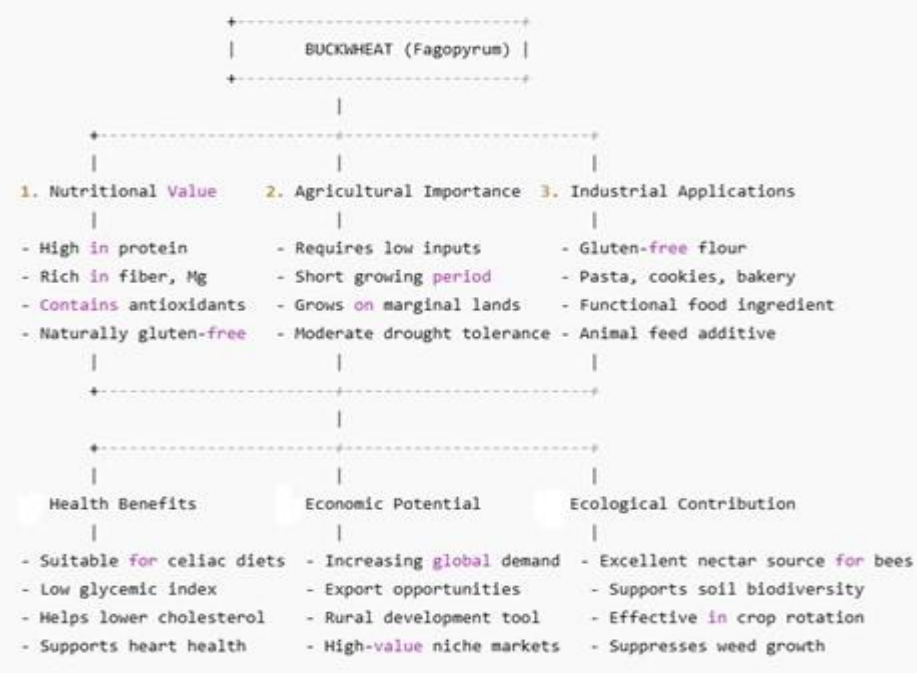


Figure 4. Uses and importance of buckwheat

Particularly due to its antioxidant and flavonoid content, buckwheat exhibits immune-boosting properties. Its low glycemic index also makes it suitable for individuals with diabetes. The flavonoid compound rutin found in buckwheat supports vascular health and may contribute to the prevention of cardiovascular diseases.

Buckwheat protein is not only nutritionally superior to other cereal proteins in terms of amino acid composition but is also one of the best sources of high biological value proteins (Figure 4) (Mariotti et al., 2013). In addition to its similarity to animal-derived proteins, it contains health-promoting components such as flavonoids, fagopyrin, and thiamine-binding proteins (Christa and Soral-Śmietana, 2008). These proteins have cholesterol-lowering and antihypertensive effects (Zhang, 2001). About 73.5% of the buckwheat grain is composed of starch, and 33.5% of this starch is resistant starch. Because it promotes the growth of lactic acid bacteria in the intestines of mice) and has a high resistant starch content, buckwheat is classified as a prebiotic food. In addition to its prebiotic properties, it is a rich source of total and soluble dietary fiber (Christa and Soral-Śmietana, 2008; Mariotti et al.,

2013), making it beneficial in the prevention of coloncancer, obesity, and diabetes.

Furthermore, the lysine content in buckwheat contributes to the prevention of cold sores and excessive sweating (Christa and Soral-Śmietana, 2008). Due to its significant health benefits and nutritional value, buckwheat has taken its place in human diets as an alternative food source in the following areas:

Gluten-free products: Buckwheat is naturally gluten-free, making it a valuable alternative for individuals with celiac disease or gluten intolerance. Its flour is used in the production of gluten-free bread, cakes, and cookies (Figure 5).

Breakfast foods: Buckwheat is used in muesli, granola, and breakfast cereals. It can be consumed in whole grain or flour form, offering a nutritious and satisfying breakfast option (Figure 5).

Noodle and pasta production: "Soba" noodles made from buckwheat flour are common in Asian cuisine. Additionally, buckwheat flour is used in the production of gluten-free pasta and various traditional products such as kasha, porridge, and crumpets in different countries (Figure 5)



Figure 5. Uses of buckwheat (Anonymous, 2025c-f)

Cooked grain dishes and porridge: Buckwheat grains can be boiled and served as pilaf, salad, or porridge. Due to its high fiber content, it promotes satiety.

Desserts and snacks: Buckwheat flour is used in healthy snacks such as cakes, cookies, bars, and energy balls. It is also used in fermented beverages and probiotic food production.

Tea and beverage production: Buckwheat tea (especially made from roasted grains) is traditionally consumed in Asia and is considered a healthy beverage due to its antioxidant content (Figure 5).

Nutritional supplements: Compounds derived from buckwheat (notably rutin and D-chiro-inositol) are used in dietary supplements for their antioxidant, antihypertensive, and antidiabetic effects.

In a study by Bilgiçli (2009), sensory evaluations of noodles made with 20% whole buckwheat flour were positive, and it was observed that the ash content increased, indicating that buckwheat flour could be used to enrich products with minerals. In another study, 20% buckwheat flour noodles were found to be acceptable in sensory properties, except for color (Bilgiçli, 2009). In the production of gluten-free biscuits, a study by Schonbeck and Morse (2003) included 10% buckwheat in the formulation. It was noted that such biscuits tend to be dry and sandy in texture due to the use of pure starch as a base. Manthey and Hall (2007) conducted a study on spaghetti made with buckwheat bran flour to investigate the effects of processing and cooking on ash, mineral, protein content, and amino acid composition. They found that extrusion and drying temperatures did not significantly affect mineral ash or protein content. However, a 31% reduction in lysine content was observed in spaghetti dried at 90°C. During cooking, the ash content decreased by 28%, primarily affecting zinc, copper, and potassium levels, while manganese, magnesium, iron, and calcium remained unaffected.

2.2. Agricultural importance of buckwheat

Buckwheat, although botanically classified as a pseudocereal, holds growing significance in modern agricultural systems due to its ecological advantages, adaptability, and contribution to sustainable farming practices.

Animal nutrition: Buckwheat serves as a valuable alternative feed source in animal nutrition due to its rich protein content, favorable amino acid

profile - especially lysine - and abundance of fiber and essential minerals (Figure 6). It is well-digested and palatable to both monogastric animals and ruminants, and its bioactive compounds like rutin and antioxidants may support immune health and improve feed efficiency. Buckwheat forage can be used for silage, while its grains and by-products are suitable for poultry and livestock feed. Despite the presence of fagopyrin, which may cause photosensitivity in high doses, this risk can be mitigated with proper processing. Moreover, its ability to grow on marginal lands with low input requirements makes buckwheat a sustainable and functional ingredient in animal feeding systems (Kalac and Sanli, 2004; Christa and Soral-Śmietana, 2008; Ikeda et al., 1991; Bonafaccia et al., 2003).

Use of green manure: Buckwheat is increasingly valued as a green manure crop due to its rapid growth, weed suppression ability, and contribution to soil health. When sown as a cover crop or green manure, it produces a substantial amount of biomass in a short period (typically 4–6 weeks), which, when incorporated into the soil, enhances organic matter content and improves soil structure. Its extensive root system mobilizes phosphorus and helps in nutrient cycling, making nutrients more available for subsequent crops. Moreover, buckwheat decomposes quickly, making it ideal for short-term rotations, especially in organic farming systems. Its allelopathic properties and dense canopy also suppress weeds, reducing herbicide needs. Due to these agronomic traits, buckwheat is often used between main crops or in fallow periods to maintain and enrich soil fertility (Bjorkman et al., 2008; Teasdale and Mohler, 2000).

Use of rotation: Buckwheat plays a significant role in crop rotation systems due to its fast growth, short growing season, and ability to suppress weeds and soil-borne pathogens. It is especially useful as a break crop, disrupting pest and disease cycles common in cereals and legumes. Its dense canopy shades the soil, inhibiting weed emergence, while its fibrous root system contributes to improved soil structure and organic matter content. Buckwheat also exhibits allelopathic properties that help reduce the seed bank of some weed species, making it valuable in low-input and organic farming systems. Additionally, it does not host many common pests or diseases, making it an effective tool in integrated pest management strategies. Incorporating buckwheat into crop rotations enhances biodiversity, restores

soil fertility, and increases subsequent crop yields (Björkman and Shail, 2010; Hinneburg et al., 2006).

Use of nectar source: Buckwheat is a highly valuable nectar source for pollinators, especially honeybees (*Apis mellifera*). Its flowers produce abundant nectar with a high sugar content, which makes it particularly attractive to bees and contributes to significant honey yields (Figure 6). Buckwheat blooms quickly—typically within 4–6 weeks of planting and continues flowering over an extended period, making it ideal for supporting bee populations during floral scarcity in midsummer.



Figure 6. Buckwheat as a nectar source (Anonymous, g-h)

The honey produced from buckwheat is dark, rich in antioxidants, and has a strong, distinctive flavor. Its cultivation as a nectar crop not only benefits beekeepers but also improves pollination services for surrounding crops. Consequently, buckwheat plays a dual role in agriculture by enhancing biodiversity and supporting the sustainability of pollinator-dependent ecosystems (Lovett and Jackson, 1980; Bavec and Bavec, 2006).

Ability to grow on marginal lands: Buckwheat thrives in poor, acidic, stony, and low-fertility soils where many other crops fail to grow efficiently. This ability makes it an ideal crop for underutilized or marginal lands, thereby increasing the productivity of areas that would otherwise remain fallow (Myers and Meinke, 1994).

2.3. Industrial applications of buckwheat

Buckwheat is not only valuable in food and agriculture but also holds significant potential in various industrial sectors such as biofuel production, pharmaceuticals, and cosmetics.

Biofuel production: Buckwheat seeds contain approximately 2-3% oil, and the residual biomass is rich in lignocellulosic materials, which can be utilized for bioethanol and biogas production. Its rapid growth and ability to thrive on marginal lands without intensive input make it a promising energy crop. Studies have demonstrated that buckwheat biomass can be effectively fermented to produce bioethanol due to its high carbohydrate content (Smuga-Kogut et al., 2014).

Pharmaceutical uses: Buckwheat is a rich source of flavonoids, particularly rutin, which has well-documented anti-inflammatory, antioxidant, vasoprotective, and anticancer properties. Rutin extracted from buckwheat is used in the formulation of drugs for treating hypertension, venous insufficiency, and capillary fragility (Wieslander et al., 2011). Additionally, D-chiro-inositol, another compound found in buckwheat, is being researched for its role in managing insulin resistance and type 2 diabetes (Yao et al., 2008).

Cosmetic industry: Thanks to its antioxidant and anti-aging properties, buckwheat extracts are also used in cosmetic formulations. Flavonoid-rich extracts help protect skin cells from oxidative stress, making them suitable for use in anti-aging creams and sunscreens (Kim et al., 2010).

Bioplastics and Packaging: Recent studies have explored the use of buckwheat husk and starch as a raw material in biodegradable plastics and eco-friendly packaging. Its starch is being studied as a renewable, low-cost alternative to petroleum-based plastics (Sivaramakrishnan and Ingle, 2014).

Buckwheat stands out for its cost-effectiveness, ease of cultivation, and high market value. Thanks to its added value and ability to generate higher

income per unit area, its attractiveness is steadily increasing. Rich in B vitamins, magnesium, fiber, high-quality protein, and antioxidants, and being naturally gluten-free, buckwheat is among the best alternatives for celiac patients and those on gluten-free diets. In addition to its nutritional benefits, it is a flowering and nectar-producing plant, making it an important source for beekeeping. Furthermore, it is used as animal feed, green manure, soil conditioner, weed suppressant, and medicinal plant.

Buckwheat is becoming an increasingly valuable crop from an economic perspective. Here are some factors contributing to its economic benefits:

- High Market Demand: With the growing number of individuals opting for healthy and gluten-free diets, the demand for buckwheat is on the rise. The popularity of gluten-free products is boosting the trade of buckwheat flour and its derivatives.
- Low-Cost Cultivation: Compared to other cereals, buckwheat requires less maintenance. It has low fertilizer and pesticide requirements, which lowers production costs. Additionally, its short growing cycle allows farmers to harvest it quickly and obtain a fast return on investment.
- Contribution to Farm Cycles: Buckwheat improves soil structure and is compatible with other crops. It is often used as a cover crop or intercrop to enhance soil fertility.
- Versatile Applications: Buckwheat is used not only in food products but also in livestock and cosmetic industries. Its flour, oil, and by-products are utilized industrially, thereby increasing its economic potential.
- High Yield Potential: Buckwheat prevents the accumulation of harmful substances in the soil and supports sustainable farming practices. Farmers can achieve productive harvests by cultivating it once or even twice a year.

3. Contribution of Buckwheat to Sustainable Agriculture and Food Supply Security.

Food security and sustainable agriculture are of major importance in the world. Food security and biodiversity conservation are closely related to achieving sustainable food systems on a large scale. Crop yield is an essential factor to evaluate sustainability. Food security and biodiversity conservation are closely related to achieving sustainable food systems on a large scale (Yue et al., 2017; Crenna et al., 2019).

Buckwheat contributes significantly to sustainable agriculture and food supply security in several ways. It plays a vital role due to its ecological adaptability, nutritional value, and potential in low-input farming systems.

Low input requirements: Buckwheat requires minimal inputs such as fertilizers and pesticides, making it an economical crop choice. Its compatibility with organic farming systems further enhances its value, especially in regions promoting environmentally friendly agriculture. Its adaptability to low-input systems makes it an ideal crop in regions where environmental stress or resource limitations challenge conventional cereal production (Myers and Meinke, 1994; Bavec and Bavec, 2006).

Short growing period: With a short growth cycle (typically 70–90 days), buckwheat allows for double cropping or serves as a rotational or catch crop between major planting seasons. This flexibility contributes to increased annual productivity and better land use efficiency (Schonbeck and Morse, 2006).

Benefits to crop rotation systems: Including buckwheat in crop rotation helps reduce pest and disease pressures, lowers pesticide dependency, and improves soil structure. Its dense canopy suppresses weeds effectively, reducing the need for herbicide applications.

Moderate drought tolerance*:* Although sensitive to water stress during early growth stages, buckwheat generally exhibits moderate drought tolerance. This makes it a viable crop in regions experiencing increasing water scarcity due to climate change (Steadman et al., 2001).

Contribution to rural development: As a high-value niche crop, buckwheat can provide small-scale farmers with alternative income sources. Its adaptability and market potential contribute to rural diversification and economic sustainability

Soil health ımprovement: Buckwheat improves phosphorus availability for subsequent crops, rapid growth, and dense canopy shade out weeds, reducing herbicide use, and biomass can be incorporated into the soil to improve organic matter and nutrient content.

4. Factors Limiting the Cultivation and Use of Buckwheat

Despite its numerous nutritional and agronomic advantages, several factors limit the widespread cultivation and utilization of buckwheat around the world:

Lack of agronomic knowledge and research: Buckwheat has received comparatively less scientific attention than major cereal crops like wheat, rice, or maize. In many regions, there is limited availability of improved cultivars adapted to local climates. There is also insufficient extension support and agronomic training for farmers.

Short growing season and sensitivity to climate: Buckwheat has a relatively short growing period and is highly sensitive to temperature extremes, particularly during flowering. High temperatures and drought can lead to poor pollination and reduced seed set, while excessive rain can delay harvest and damage the crop. It performs best in cool, temperate climates, which limits its suitability in some regions.

Low and variable yields: Compared to other staple crops, buckwheat has relatively low and unstable yields. Its indeterminate flowering habit results in uneven seed maturity making mechanical harvesting challenging. Yield variability is often influenced by weather, soil fertility, and pollinator activity (Zhang, 2001).

Dependence on pollinators: Buckwheat relies heavily on insect pollination, primarily by bees, for good seed production. Declines in pollinator populations or unfavorable pollination conditions can significantly reduce yields.

Limited market infrastructure and demand awareness: In many regions, market structures for buckwheat are under developed. There is a lack of consumer awareness about the nutritional and functional benefits of buckwheat. Limited demand in some areas restricts farmers' incentives to produce it (Wijngaard and Arendt, 2006).

Post-harvest challenges: Buckwheat's triangular seeds are difficult to process, requiring specialized equipment for dehulling and milling. Improper storage can lead to spoilage due to its high fat content, which causes rancidity.

Competition with major cereal crops: Farmers often prefer to grow high-yielding and well-supported cereal crops with established markets. Government subsidies and infrastructure tend to favor staple crops over underutilized ones, such as buckwheat.

5. Conclusion and Recommendations

Agricultural activities have had a major global impact on biodiversity, primarily due to the destruction of natural habitats from land conversion and the widespread use of monoculture farming, which supports very limited biological diversity. Additional contributors to the decline in biodiversity include contamination and the deterioration of soil and water quality resulting from chemical fertilizers and pesticides. By tapping into the potential of lesser-known or underutilized crops, agriculture can become more resilient. This approach encourages greater crop diversity, which can help ensure food and nutritional security amid the challenges posed by climate change and ecological decline.

Buckwheat stands out as an eco-friendly crop with the potential to support both agricultural productivity and biodiversity. It serves effectively as a cover crop, helping to suppress weeds and assist in restoring vegetation in damaged environments. In addition, buckwheat possesses a diverse genetic base, making it valuable for enhancing biodiversity and contributing to improvements in crop quality within the food and biotech sectors. It also promotes greater activity of pollinators within farming systems. With its rich nutritional profile and appealing taste, buckwheat holds strong promise as a component of nutritious and sustainable diets.

In recent years, interest in buckwheat has increased due to its various uses: in human nutrition (particularly for individuals with celiac disease, as both grain and flour), in beekeeping as a nectar plant, in animal feed as roughage or grain and by-products, in medicine (it is one of the richest sources of rutin), and in agriculture as green manure. Therefore, the plant's cultivation needs to be made more widespread. To achieve this, several strategies are needed. These are outlined below.

- Farmers should be informed about buckwheat cultivation, and practical training sessions should be organized
- High-yield, disease-resistant buckwheat varieties should be developed and provided to farmers at affordable prices.
- Buckwheat production should be included in agricultural support programs, and subsidies for fuel, fertilizer, and organic farming should be offered.
- Consumer awareness should be increased, buckwheat-based products should be promoted, and demand should be created in both domestic and international markets.
- Investment should be made in buckwheat flour and other processed products, and producer cooperatives should be supported.
- Buckwheat cultivation should be encouraged in fallow lands, poor soils, and as a second crop after early-harvested products.

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Chapter 3

FORAGE COWPEA (*Vigna unguiculata* L. WALP)

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DOI: https://dx.doi.org/10.5281/zenodo.17453261

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1. General Characteristics of Forage Cowpea

Cowpea (*Vigna sinensis* (L.) Endlicher, synonym for *Vigna unguiculata* (L.) Walp.) is an ancient cultivated plant that has been grown since antiquity. The history of cowpea dates back to 5,000–6,000 years ago in West Africa, coinciding with the period when sorghum (*Sorghum bicolor*) and common millet (*Panicum miliaceum*) began to be cultivated (Davis et al., 1991). Vavilov (1926) was the first to propose a center of domestication for cowpea, identifying Ethiopia as a major center and China and India as minor centers. However, subsequent research demonstrated that the wild relatives of cowpea are confined to Africa, thereby ruling out China and India as primary centers of diversity. Vigna unguiculata ssp. dekindtiana var. spontanea, considered the wild progenitor of cultivated cowpea, is widely distributed across sub-Saharan Africa (Pasquet and Padulosi, 2012). Integrating data derived from genetic analyses, historical texts, and archaeobotanical findings, a comprehensive model of cowpea dispersal from its centers of domestication can be proposed. Evidence indicates that cowpea was domesticated independently in two primary regions: West Africa and Eastern Africa. From the principal domestication center in West Africa, cowpea spread through various routes. The Bantu migrations facilitated its movement southward into the equatorial rainforest and eastward across the Sahelian zone, reaching the regions of present-day Sudan, South Sudan, and Ethiopia. From this Sahelian corridor, three distinct dispersal branches emerged; Southern Africa, South Asia and Southeast Asia.

Southern Africa: One branch extended southward into Southern Africa, where it eventually merged with the cowpea varieties originating from the Eastern African domestication event. Northeast Africa and the Mediterranean: Another branch moved northward, likely following the Nile River, reaching Egypt by approximately 2500 BCE. From Egypt, cowpea spread westward across the Mediterranean Basin, becoming a staple food crop by around 400 BCE. This Mediterranean lineage was later introduced to Spain's colonial territories in the Americas, including the region of the present-day southwestern United States.

South Asia and Southeast Asia: The third branch extended eastward, most plausibly via the "Sabaean lane" through present-day Yemen. By around 1500 BCE, cowpea had reached the west coast of India. From there, it

diffused throughout Southeast Asia, where specialized long-podded cultivars (subspecies sesquipedalis) were eventually developed.

During the 16th century CE, cowpea was introduced to the New World via two primary routes. West African cowpea was transported on transatlantic slave ships, becoming established in colonial slave societies such as those in Brazil, the Caribbean, and the American South. Concurrently, Iberian cowpea, stemming from the Mediterranean lineage, was brought to the southwestern United States and northwestern Mexico by Spanish colonists and explorers. A visual representation of these proposed diffusion pathways are provided in Figure 1. Originating from Africa, cowpea has spread worldwide, although it is still predominantly produced on the African continent. It is believed that the crop was cultivated in South Asia in ancient times and may have been introduced to Greece with the army of Alexander the Great. Although no seeds have been found in excavations of ancient settlements, evidence suggests that it was cultivated during early civilizations. Cowpea was grown in Central Europe in the 16th century; however, its cultivation declined with the spread of bean (*Phaseolus spp*.) varieties (Gençkan, 1983). Today, cowpea is widely cultivated for grain production, animal feed, and vegetable purposes in tropical and subtropical regions between 35°N and 30°S latitudes, including Africa, Latin America, Southeast Asia, the Middle East, and the southern states of the United States (Bilgili, 2009).

Cowpea is an annual, warm-season leguminous plant with an herbaceous growth habit. It belongs to the genus *Vigna* within the tribe *Phaseoleae*. Due to its close resemblance to the genus *Phaseolus* L. it was long believed to be a member of that genus. However, *Vigna* differs from *Phaseolus* primarily in the absence of curvature in the keel petal (Şehirali, 1988). Cowpea possesses a well-developed taproot system (Figure 2). Root lengths have been reported to reach up to 2.4 m within eight weeks after sowing (Barnard, 1969). The roots bear spherical nodules formed by the bacterium *Rhizobium japonicum*. Depending on the main stem growth habit, cowpea exhibits erect, semi-prostrate, prostrate, twining, and climbing forms. The stem may be glabrous or slightly pubescent. In cross-section, the lower portions of the stem are round, while the upper portions are six-angled. The stem is well developed, with hollow internodes. Branching occurs along the entire stem, and in some cases, branches may grow as tall as the main stem.

Plant height varies between 30 and 250 cm, depending on the cultivar and environmental conditions. In terms of growth habit, short and erect types are considered dwarf, while prostrate and climbing types are taller (Thaware et al., 2006).

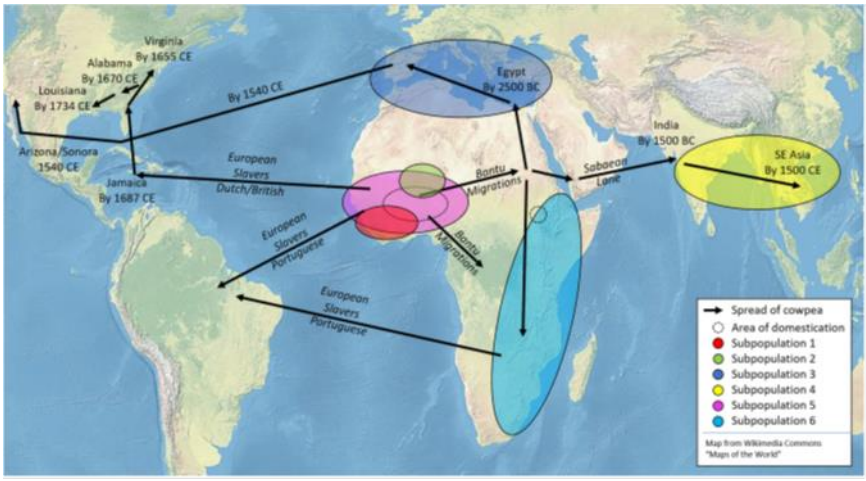


Figure 1. A visual representation of proposed spreading (Herniter et al., 2020)

Generally, cultivars grown for dry grain production are dwarf and erect, whereas those grown for forage purposes are climbing and taller (Ayan et al., 2012). The leaves of cowpea are compound, consisting of three leaflets. In the early stages of plant development, the first leaves are simple in form and arranged oppositely on the stem, whereas the subsequently developed compound leaves exhibit an alternate arrangement. There is no distinct indentation at the point where the cotyledonary leaves attach to the stem. This morphological feature, along with the glabrous surface of the leaves, enables the distinction of cowpea seedlings from common bean (*Phaseolus vulgaris*) at the seedling stage. The petiole length generally ranges from 5 to 25 cm. The leaflets of V. unguiculata display morphological diversity, taking triangular, rhomboid, acuminate, or ovate shapes. Leaves are typically green or dark green in color, with smooth, glabrous, and glossy surfaces. In addition, similar to common bean (*P. vulgaris*), the leaves of cowpea possess a total of six triangular stipules (Figure 2). The flowers emerging from the leaf axils may exhibit various colors, including white, cream, yellow, blue, and purple, and are borne on peduncles 15–30 cm in length. The number of flowers per

inflorescence generally ranges from 8 to 12, and the flowers are attached to the rachis by short pedicels. Although the plant produces a large number of floral buds, only about 10–15% of them develop into mature pods (Çiftçi and Adak, 2009). The remaining buds either abscise before opening or persist as undeveloped pods.



Figure 2. Roots, leaves, flowers, pods, and seeds of cowpea

Cowpea is predominantly a self-pollinating species; however, cross-pollination rates ranging from 0.22% to 12.0% have been reported in the literature (Şehirali, 1988; Can et al., 2021). The fruits (pods) are straight, slender, and measure 10–23 cm in length. Each pod contains 10 to 15 seeds, which are approximately 4–8 mm long and 3–4 mm wide. The seeds are typically kidney-shaped, though in some cases they may be round. Seed coats

may be smooth or wrinkled. Cowpea seeds exhibit wide variation in shape and color, ranging from white, cream, green, pale yellow, red, brown, and black to mottled or speckled patterns (Figure 2). In Türkiye, cowpea is also known by local names such as “Karagöz” or “Karnıkara,” which derive from color differences around the seed hilum (Özdemir, 2002). Furthermore, genotypes with dark-colored flowers and seed coats are more commonly utilized for forage purposes.

2. Cultivation Purposes and Nutritional Value of Forage Cowpea

Cowpea is a versatile plant utilized not only in agricultural production but also across various industrial sectors, including perfumery and cosmetics, paper and furniture manufacturing, pharmaceuticals and healthcare, the dye industry, and ornamental plant production (Marotti et al., 2007; Ekincialp and Şensoy, 2018). Cowpea seeds are rich in protein, vitamins, minerals, carbohydrates, and micronutrients, making them of significant nutritional importance for human consumption. They are particularly noted as a good source of folic acid (Boukar et al., 2011). In African countries, cowpea seeds are used in the preparation of coffee-like beverages, while its leaves are consumed as a vegetable (Çiftçi and Adak, 2009; Can et al., 2021). In Southeast Asia, sprouted cowpea seeds are consumed as a vegetable. Similarly, the use of sprouted legume seeds as vegetables has recently become more common in Turkey. Being a member of the *Fabaceae* family, cowpea has the ability to fix atmospheric nitrogen through symbiotic associations with *Rhizobium spp*. bacteria in root nodules. This process not only satisfies the plant’s nitrogen requirements but also contributes to soil nitrogen accumulation. Literature reports indicate that cowpea can fix approximately 9 kg of nitrogen per hectare (Gülümser, 1986). Consequently, cowpea is widely used as a green manure crop to enhance soil fertility (Singh et al., 2008). Due to its high adaptability to both heat and drought and its association with nitrogen-fixing bacteria, cowpea is a versatile crop (Boukar et al., 2019; Ehlers and Hall, 1997). Furthermore, some spreading (prostrate-growing) cowpea varieties are employed as cover crops to prevent soil erosion and reduce weed pressure (Wortman and Dawson, 2015).

Cowpea is an important legume forage species in crop rotation systems. Its deep root system improves soil structure and contributes to soil rest, making it particularly valuable in sustainable agricultural practices. Through its symbiotic *Rhizobium* bacteria, cowpea enriches the soil with nitrogen and facilitates the mobilization of phosphorus for subsequent crops, serving as an effective preceding crop (İdikut et al., 2015). Beyond its agronomic value, cowpea is widely used in animal feeding, with potential as green fodder, hay, silage, and pasture (Blade et al., 1997). Among summer annual legume forages, cowpea is particularly important for hay and silage production and is cultivated with varieties that have high leaf-to-stem ratios and abundant vegetative growth. In Türkiye, only one forage cowpea variety, "Ülkem," has been officially registered. Forage cowpea can be easily integrated into crop rotation systems as a main or secondary crop, providing flexibility for different production models. These characteristics make cowpea a multi-purpose crop, offering significant benefits both for soil health and as a feed resource (Özdemir, 1995). When cultivated for forage production, cowpea rapidly completes its vegetative growth and reaches the cutting stage within 70–90 days. Under suitable climatic and soil conditions, the plant can regrow after cutting, allowing multiple harvests (Gençkan, 1983; Ayan et al., 2012). This regenerative ability makes cowpea advantageous for sustainable forage production. Forage cowpea is also successfully used in intercropping systems with maize, sorghum, and other millet species. Such intercropping not only improves yield and quality but also mitigates the negative effects of pests and diseases while enhancing land-use efficiency. The resulting crop diversity positively affects silage quality. For instance, a study conducted under Samsun ecological conditions reported that mixed maize and cowpea cropping produced higher silage quality compared to monoculture systems (Sarıçiçek et al., 2002). Cowpea harvested for forage retains the ability to regrow after the first cut, and this second growth phase is commonly utilized as pasture. This dual use harvesting and grazing enables cowpea to be integrated into livestock systems, providing farmers with flexible production options (Figure 3).



Figure 3. Plant development and post-harvest regrowth in forage cowpea

3. Contribution of Forage Cowpea to Sustainable Agriculture and Food Supply Security

Cowpea is considered an important plant-based food source due to its high protein content in seeds. Fresh pods contain 2.0–4.3% protein, while fresh seeds contain 4.5–5.0% protein. The protein content of fully mature dry seeds varies between 20.42% and 36.40%, depending on the variety and environmental conditions (Şehirali, 1988). In addition to protein, cowpea seeds contain 50–67% carbohydrates, 1.3% fat, 3.9% cellulose, and 3.6% ash. Although the protein in cowpea seeds is limited in some amino acids, it has a superior amino acid profile compared to cereal seeds, particularly rich in lysine and tryptophan (Davis et al., 1991; Gençkan, 1983). However, compared with animal proteins, methionine and cystine levels are relatively low. Cowpea seeds are also rich in carotene and vitamin B1, making them a complementary source of protein and micronutrients for human nutrition. The crude protein content of dry seeds ranges from 23% to 31%, reflecting the high protein potential of the species (Gençkan, 1983). Cowpea is also nutritionally valuable as a forage crop. In animal feeding, cowpea is widely used as green forage, hay, silage (particularly mixed with sorghum or millet), and dry seeds. In monoculture systems, green and dry forage production is usually prioritized, whereas intercropping systems often focus on silage production. When dried, cowpea retains its structural integrity: stems are strong, reducing breakage, and leaves do not excessively crumble or fall off, minimizing physical losses in hay form. This property significantly

contributes to the preservation of forage quality. Incorporating cowpea into silage results in high-protein, high-quality silage. For example, studies have reported that crude protein, acid detergent fiber (ADF), and neutral detergent fiber (NDF) contents of pure maize silage were 7.65%, 25.56%, and 49.55%, respectively, while in maize–cowpea mixed silage, these values increased to 9.57%, 27.98%, and 54.22%, respectively (Alaca and Özaslan Parlak, 2017). These findings demonstrate cowpea's positive effect on silage quality.

Cowpea's green forage has a crude protein content ranging from 14% to 21%, while its seeds contain 18–26% protein (Adeyanju et al., 2007). The crude protein content of cowpea hay used for animal feeding has been reported between 17% and 27% in the literature. Additionally, ADF in cowpea hay ranges from 25% to 57%, while NDF varies between 25% and 60% (Başaran et al., 2011; Ayan et al., 2012; İdikut et al., 2015; Ayan et al., 2017; Omar and Ayan, 2018). Mineral contents of cowpea hay are also substantial, with potassium ranging from 1.3% to 1.65%, magnesium 0.46–0.51%, calcium 1.04–1.32%, and phosphorus 0.34–0.37% (Ayan et al., 2012). This chemical composition confirms that cowpea hay represents a high-quality feed source for livestock.

In addition to generating jobs and income for family farming, cowpea is considered a key crop in the context of global climate change and food security (Gomes et al., 2019). Cowpea is generally cultivated in rainfed areas rather than irrigated fields (Duke, 1981). It is more tolerant to water stress than soybean (McLeod, 1982).As soil salinity increases, cowpea water consumption decreases. Therefore, the evaporation-reducing effect of salinity should be taken into account in cowpea irrigation planning and scheduling. Excessive or limited water applications result in reductions in cowpea seed and pod yields. The yield response factor (Ky), derived from the relationships between relative evaporation and relative yield reduction, was determined to be 0.98 and 0.92 for pod and seed yields, respectively. It was concluded that cowpea is tolerant to water stress in terms of seed and pod yields (Düzdemir et al., 2009). Cowpea plants are sensitive to water deficit, and this abiotic stress can also cause flower abortion, pod failure, and grain filling reduction (Mwale et al., 2017). An extended period of water deficit at flowering stage reduces cowpea yield by approximately 63-98% (Ndiso et al., 2016).

Cowpea grows in a wide temperature range, between 18 and 37 °C, however, the optimum temperature point varies with the plant's phenological stage. Thus, temperatures outside the optimum point can impact seed germination to final production (Sehgal et al., 2018), with the reproductive phase being the most affected. Studies have shown that temperature above 35 °C, causes the abortive flowers, stimulates the senescence of the leaves, decreasing the photosynthetic capacity, affecting the productivity of cowpea pods and seeds, this temperature increase interferes with physiological and biochemical aspects of plants (Zandalinas et al., 2018).A study conducted with cowpeas found that high temperatures promoted more flower abscission and resulted in a decrease in yield in cowpea varieties. Researchers noted that photosynthesis, stomatal conductance, leaf transpiration, and enzymatic activity were significantly affected by high temperatures. The development of a heat-tolerant legume variety would be crucial for growing areas in warmer regions due to the high demand for these legumes for human consumption (Alves Barros et al., 2021).

4. Factors Limiting the Cultivation and Use of Forage Cowpea

Cowpea is a warm-season legume whose importance is increasing in the context of global climate change due to rising temperatures and declining water resources. Its high tolerance to heat and drought makes cowpea one of the most promising species under such conditions (Çulha and Bozoğlu, 2016). In terms of climatic requirements, cowpea is similar to maize, but it has a higher temperature requirement and greater resilience to drought (Şehirali, 1988). For seed production, cowpea can be cultivated in areas receiving approximately 400 mm of annual rainfall. However, for optimal growth as a forage crop, annual precipitation of 750–1100 mm is required. Increased rainfall may, however, lead to higher incidences of pests and diseases. Conversely, excessive drought negatively affects plant development, reducing both seed and forage yields, and can interfere with pollination and fertilization, limiting fruit and seed set. Cowpea is a short-day plant and exhibits moderate tolerance to shading, allowing successful cultivation in intercropping systems with tall crops such as maize and sorghum. However, it is highly sensitive to low temperatures and especially to late spring and early

autumn frosts. Its temperature requirement is higher than that of soybean, with minimum soil temperatures of 8–10 °C and air temperatures of 10–12 °C required for seed germination. Optimal growth occurs at temperatures between 20–35 °C (Coetzee, 1995).

Regarding soil requirements, forage cowpea is not highly selective and can grow in a wide range of soils from sandy to heavy clay. It prefers slightly acidic to slightly alkaline soils but is sensitive to salinity and waterlogging. While nutrient-rich soils favor vegetative growth for forage production, slightly lower-fertility soils are suitable for seed production. The cultivation of cowpea for dry seed production has increased in recent years in Türkiye; however, the total cultivated area remains limited. In 2022, cowpea was planted on 1,150 ha, yielding 1,161 tons with an average yield of 101 kg da^{-1} (TUIK, 2022). Forage cowpea cultivation in Türkiye is currently minimal, despite its potential to be integrated into the national agricultural system as both a main and secondary crop. In a study conducted under the ecological conditions of Samsun province, two harvests of forage cowpea were obtained as a second crop following wheat, producing a total of 500–800 kg da^{-1} of dry forage (Omar and Ayan, 2018). Planting dates vary according to ecological conditions: as a main crop, sowing occurs in April–May, while as a second crop, sowing can take place from late June to early July, depending on the harvest date of the preceding crop.

Since cowpea is not native to Anatolia, pre-sowing inoculation of seeds with *Rhizobium japonicum* bacteria is essential to ensure effective symbiotic nitrogen fixation (Geçit, 1995). The most suitable sowing method for forage cowpea is row planting using a precision seeder. The row spacing varies depending on the production objective. For forage production, row spacing is generally 20–50 cm, whereas for seed production it ranges between 50–70 cm. Specifically, for forage-oriented sowing, a row spacing of 30–50 cm with 10–15 cm plant-to-plant distance within the row is recommended (Ayan et al., 2017; Omar and Ayan, 2018). Depending on ecological conditions, row spacing for seed-type cowpea cultivation may vary between 30–100 cm. According to plant morphology, 30–40 cm spacing is recommended for erect types, while 50–65 cm spacing is suggested for semi-erect types (Özturan and Gülümser, 2004; Sert, 2011).

In forage cowpea cultivation, it is generally recommended to apply 2.5–3 kg da^{-1} of nitrogen (N) at sowing. However, in soils with poor fertility, this rate may be increased to 4–5 kg da^{-1}. Additionally, depending on the soil's nutrient status, phosphorus (P_2O_5) at 5–6 kg da^{-1} and potassium (K_2O) at 4–5 kg da^{-1} should be applied. In cases of deficiency, other macro- and micronutrients should also be supplemented (Singh et al., 2008).

Being a summer crop, adequate irrigation during critical growth stages is important to achieve high yield and quality. Drought (water stress) during the growing season adversely affects both seed and forage yield (Patel and Hall, 1990). Irrigation is particularly crucial during the seedling stage, prior to pollination and fertilization, and during seed filling. Light irrigation may be applied after sowing if dry conditions hinder germination. Depending on soil and climatic conditions, 2–6 irrigation events may be necessary throughout the growing period. Irrigation can be performed via furrow, sprinkler, or drip systems (Açıkgöz, 2021; Figure 4). High temperatures during pollination and fertilization can negatively affect pod set (Hall, 2004).

Forage cowpea can be cultivated in mixtures with crops such as maize, sorghum, Sudan grass (*Sorghum sudanense*), and sunflower (*Helianthus annuus*) to produce high-quality roughage. Products obtained from mixed cropping are generally harvested and utilized as silage (Sarıçiçek et al., 2002; Boz, 2006; Gülümser et al., 2021; Çıkış Kanca and Acar, 2021). In this method, the crops can be sown in the same row, in adjacent rows, or in strips across the field (Figure 5) (Dhonde et al., 2016).



Figure 4. Irrigation methods used in cowpea



Figure 5. Mixed planting examples in fodder cowpea

For forage cowpea, the optimal harvest time for green forage production occurs between the stage when the lower pods have formed and begun to fill and the full flowering stage (Van Rij, 1999; Cameron, 2003). Harvesting at the stage when the lower pods start filling ensures the production of high-quality green forage. At this stage, green forage yields of

1500–2000 kg per decare can be obtained (Gençkan, 1983). The dry matter yield of forage cowpea varies depending on ecological conditions and cultivation methods. For instance, yields have been reported as 300–500 kg da^{-1} in Africa (Cook et al., 2005), 278–767 kg da^{-1} in Ethiopia (Etana et al., 2013), 458–639 kg da^{-1} in Hatay, Türkiye (Atış, 2000), 600–800 kg da^{-1} in Samsun (Ayan et al., 2012), 587–948 kg da^{-1} in Amasya-Suluova (Ayan et al., 2017), and 672.5 kg da^{-1} in Çanakkale (Alaca and Özaslan Parlak, 2017). In mixed cropping systems, the yield potential of forage cowpea is further enhanced. In maize–cowpea mixtures, dry matter yields have been reported as 1000–1100 kg da^{-1} (Eskandari and Ghanbari, 2009), 1885 kg da^{-1} (Mut et al., 2017), and 1786–2713 kg da^{-1} (Çıkış Kanca and Acar, 2021). In mixtures with sorghum, yields ranged from 969–980 kg da^{-1} (Ahmad et al., 2007), while mixtures with sunflower produced 1458 kg da^{-1} (Boz, 2006).

Grain yield of forage cowpea also varies widely depending on environmental conditions and genotypes. Reported grain yields for forage cowpea range from 53 to 226 kg da^{-1} (Başaran et al., 2011; Polat, 2017). Under the ecological conditions of Samsun, some genotypes cultivated as a second crop produced grain yields ranging from 76.6 to 218.0 kg da^{-1} (Omar and Ayan, 2018). For cowpea grown specifically for dry grain production, yields have been reported between 100 and 273 kg da^{-1} (Gençkan, 1983; Özturan and Gülümser, 2004; Öztürk, 2010).

5. Conclusion and Recommendations

Cowpea has significant potential to play a strategic role in addressing the complex global challenges of hunger, malnutrition, environmental sustainability, climate change, and rising food prices in the coming decades. Cowpea is a highly versatile plant that, in addition to its role in agricultural production, can be utilized in various industrial fields such as perfumery and cosmetics, paper and furniture manufacturing, the pharmaceutical and healthcare sector, the dye industry, and ornamental plant production. Cowpea seeds are rich in proteins, vitamins, minerals, carbohydrates, and micronutrients, making them highly valuable for human nutrition. Cowpea fodder also plays an important role as animal feed. Haulms constitute nutritious feed for animals, most especially for ruminants. Another notable characteristic of cowpea is its ability to fix atmospheric nitrogen through

symbiosis with bacteria residing in its root nodules, thereby contributing to the sustainability of agricultural systems. Some factors including biotic and abiotic factors are limiting the production of this important crop. Water stress negatively affects both seed and forage yield. Irrigation is particularly important during the seedling stage, prior to pollination and fertilization, and during the seed-filling period. Cowpea is also susceptible to certain diseases and pests. Aphids and seed beetles (*Bruchus spp*.) are among its major pests, and fumigation should be carried out after seed harvest to prevent Bruchus development. Additionally, root rot, rust, and viral diseases caused by various microorganisms can also damage cowpea, with their impact varying depending on climatic conditions. In our country, research on forage cowpea is rather limited. Breeding programs should be continued by utilizing genetic resources, and varieties adapted to different agricultural regions should be developed. At present, there is only one registered forage cowpea variety in Türkiye, named "Ülkem." Forage cowpea can be cultivated both as a main crop and as a second crop within crop rotation systems.

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Chapter 4

FABA (BROAD) BEAN (*Vicia faba* L.)

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DOI: https://dx.doi.org/10.5281/zenodo.17453283

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1. General Characteristics of Faba Bean

One of the most important features of legumes is that they provide a high-quality source of protein at an affordable cost and improve soil fertility. The faba bean (*Vicia faba* L.) (Figure 1), found in the subfamily Papilionoideae of the legume family and best representing these qualities, raises the question of whether it is a neglected crop in our country. Considering data from publications (Kansu, 1936) during the early years of the Republic, when the population was around 17 million, the answer is definitely yes. According to the thesis presented and accepted as the doctoral work of Sedat Kansu, Assistant of the Ankara Higher Agriculture Institute, Agricultural Chemistry Institute, it was reported that in 1933, a total of 63 539 hectares were cultivated across 44 different cities, with a production value of 62 980 tons (Kansu, 1936). Since that day, it has been one of the plants with a continuous decrease in cultivation areas. Whereas, according to many researchers, faba beans are one of the best-performing crops under a global warming and climate change scenario because of their unique ability to excel under almost all types of climatic conditions, coupled with their wide adaptability to a range of soil environments (Sing et al. 2013a).

1.1. History, origin, and description

Legumes are a group of plants considered nature's insurance, helping to ensure food security by protecting human health, reducing climate change, and increasing biodiversity (Ambika et al., 2022). Legumes include approximately 765 genera and 19 500 annual and perennial species. The family is divided into 6 subfamilies, with the Papilionoideae subfamily including faba beans, encompassing 503 genera and 14 000 species (Zhao et al., 2021). Legumes evolved from a common ancestor about 60 million years ago (Young et al., 2011). They represent a plant family with a wide distribution worldwide, holding significant ecological and economic importance.



Figure 1. Faba bean in the Field

Faba beans, one of the species that best represent the legume family due to their soil-improving and medicinal uses, belong to the subfamily Papilionoideae. Faba beans are a diploid cool-season legume plant that is cross-pollinated at a rate of 5% to 79%.

Many foreign sources report that the origin of faba beans can be traced back to the Eastern Mediterranean and Western Asia regions. Muratova (1931) ve Maxted (1995) güneydoğu Avrupa ve güneybatı Asya'nın Vicia cinsinin köken merkezi olduğunu bildirmiştir. Zohary and Hopf (2000) state that archaeological evidence indicates that faba beans were cultivated primarily in Mesopotamia, Egypt, and the Levant (an area that can be defined as encompassing Lebanon, Palestine, and Israel) since 6000 BC. According to Ladizinsky (1975) and Hajjar and Hodgkin (2007), the origin is Central Asia. According to Link et al. (2008), faba beans are not among the plants cultivated very early on. Their transition to cultivation likely occurred during the Late Neolithic period. They noted that the centre of origin is the Middle East, specifically Iraq and Iran, and that secondary centres later developed in Afghanistan and Ethiopia. Large-seeded types are from a more recent period, likely developed only 1000-1200 years ago in Eastern Iraq, from where they spread to Asia, through North Africa to Europe, and ultimately to America.

According to Duc et al. (2010), the origin of faba beans is the Near East.From this centre, four routes of spread have been identified: (1) to Europe, (2) along the North African coast to Spain, (3) along the Nile to Ethiopia, and (4) from Mesopotamia to India (Cubero, 1973 and 1974). Afghanistan and Ethiopia have been expressed as secondary centres of diversity (Fouad et al., 2013).

According to Duc et al. (2010), the origin of faba beans is the Near East. From this centre, four distinct routes spread to (1) Europe, (2) along the North African coast to Spain, (3) along the Nile to Ethiopia, and (4) from Mesopotamia to India (Cubero, 1973). Afghanistan and Ethiopia have been cited as secondary centres of diversity (Fouad et al., 2013).

Zohary et al. (2013) report that this plant's wild ancestor, which originates in south-western Asia, including the Mediterranean and Turkiye, has not yet been found. They state that its domestication dates back to around 10 000 years ago, with examples of legumes found in early Neolithic settlements in Jordan, Syria, and Israel.

According to Akçin (1988), who wrote one of the first textbooks on edible legumes in our country, the cultivation of this plant was known in the Stone Age. It is mentioned that it was grown in China around 2822 BC, and faba bean seeds have been found in Egyptian tombs, consumed by priests and pharaohs and used solely in funerary rituals. Perhaps the historical information has led to the name "Jewish faba bean" being used for this plant in some areas of our country. The same source also notes that in Macedonia, besides being a food source, it was mixed into the soil as fertilizer, used in funeral meals during the Roman period, considered among the offerings to the gods, and referenced in proverbs and personal names (e.g., Fabius, Fabiola, Fabien, etc.). Additionally, seeds have been found in Pompeii ruins and Troy excavations. According to various sources, Akçin (1988) suggests that the origin of the lupin could be the southern Caspian Sea, Iran, or Abyssinia.

Şehirali (1988), who is the first person to researched on bean in our that reported that the origin of the faba bean extends from the Atlantic Ocean in the west to the Himalayas in the east, with large-seeded varieties found in Syria, Palestine, Morocco, Tunisia, Algeria, Greece, and Turkiye, while smaller-seeded varieties are located further east. According to Sepetoğlu (2002), summarising from various sources, it is suggested that the faba bean may have originated in West Asia or Central Asia. Archaeological

findings indicate that in the Egyptian civilisation around 3000 BC, this food was consumed more than meat by all segments of society, and that the Pharaohs particularly enjoyed consuming the faba bean.

The famous botanist Davis (1969) mentions that within the Vicia genus, including faba beans, 59 species and 2 doubtful species are found in Turkiye. It has been reported that they are cultivated in fallow areas in Turkiye, with sightings in Istanbul, Bilecik, and İçel. Davis states that the Turkish name is "bakla" and that large-scale cultivation occurs, with major, equina, and minor varieties according to Zhukovsk (1933). Despite such a diverse range of species within the Vicia genus, existing publications refer to areas in addition to the ones mentioned above, such as our neighbouring islands of Rhodes and Crete, and Greece, but generally neglect Anatolia. We believe that Turkiye's exclusion from the regions where faba beans have originated in the Eastern Mediterranean geography may be attributed to the lack of sufficient publications and research on this matter. Indeed, according to the famous traveller Evliya Çelebi, born in 1611, faba beans (*Vicia faba* L.) are generally distributed in the Northern Hemisphere and are among the crops grown in Turkiye. In volumes 1 and 2, Evliya Çelebi discusses faba beans found in Istanbul, Edirne, Baghdad, Damascus, Iraq, and Thessaloniki and used for nutritional purposes. (Seçmen et al., 2000).

Information regarding the wild progenitor, the region from which *Vicia faba* originated, and its subsequent domestication stage is limited and is an ongoing debate (Karkanis et al., 2018). The precise origin and wild ancestor of the faba bean are still uncertain. Several wild species, such as *Vicia narbonensis, Vicia johannis* and *Vicia galilaea* that are closely related to the cultivated faba bean have a chromosome count of 2n = 14. In contrast, the cultivated faba bean has a chromosome count of 2n = 12 (Singh et al., 2013b). Interspecific crosses of *V. faba* with other Vicia species have not been successful (Maalouf et al., 2018).

The existing crop gene pool of V. faba exhibits significant genetic variations. Over 38 000 collections of faba bean genetic resources are preserved worldwide in multiple gene banks, including the International Centre for Agricultural Research in Dry Areas (ICARDA) (Karkanis et al., 2018). Based on seed size, the faba beans can be grouped into three classes, viz., (a) faba bean small-seeded forms in south-western Asia, (b) large-seeded

forms in the west, and (c) the third group, medium-seeded type. Medium-seeded type is an ancient type, found in large areas and can be traced back to Neolithic times (Maalouf et al., 2018). Muratova (1931) called these groups based on seed size as subspecies of *Vicia faba*, viz., minor (small seed), major (large seed) and equine (medium seed). However, these sub-groups were cross-compatible; hence, they were considered one species but different botanical groups by Cubero (1973).

1.2. Botanic description of faba bean

The chromosome number of cultivated faba bean is 2n=12 (Singh et al., 2013). Hybridization studies have not been successful between *Vicia faba* and Vicia narbonensis, Vicia johannis, and Vicia galilaea (which have 2n=14) (Maalouf et al., 2018). The existing faba bean gene pool shows significant genetic variation. Worldwide, more than 38 000 faba bean genetic resources are preserved in various gene banks, including the International Centre for Agricultural Research in the Dry Areas (ICARDA) (Karkanis et al., 2018). According to seed size, there are three groups: (a) small-seeded forms in southwest Asia, (b) large-seeded forms in the west, and (c) a third group consisting of medium-seeded types. The medium-seeded type is an ancient type found across wide areas and is traceable back to the Neolithic era (Maalouf et al., 2018). Cubero (1973) has reported four botanical groups according to the seed shape of the faba bean: major, minor, equina, and paucijuga (Table 1).

Table 1. Seed and Pod Characteristics of the Four Botanical Groups of *V. faba*

Botanical Group	Seed Weight (SW) and Shape	Pod Characteristics
Major	SWa≥100 mg Very plate	Small to large (from 2 to 10 seeds)
Equina	50<SW<100 mg Plate	Medium size, 3–5 seeds Plate
Minor	30<SW<50 mg Cylindrical to rounded form	Small with 3–4 seeds, cylindrical form
Paucijuga	20<SW<30 mg Rounded to elliptical form	Very small, dehiscent or nondehiscent types

Vicia faba is an annual plant. It bears a strong, hollow, tetragonal erect stem, with zero or up to five (or even more) basal branches arising from the

basal leaf axis. There are only ineffective rudiments of tendrils at the leaf tip. The branching is at soil level (Figure 2).



Figure 2. General appearance of broad bean

During germination in faba beans (Figure 3), the emerging seed root forms the plant's primary root throughout its lifespan (Link et a. 2008). Although the primary root is not very strong, it can penetrate to a depth of 100-110 cm in sandy soils and up to 170 cm deep (Gülümser et al, 2013). As expected for a leguminous species, the roots bear the typical nodules formed by *Rhizobium leguminosarum.*

In the ecological conditions of Samsun, it has been determined that the number of branches in faba beans varies between 2.92 and 5.19, according to different genotypes and applications (Bozoğlu 1989, Pekşen and Gülümser 2007, Bezmen 2019).



Figure 3. Young seedling and nodules on the root of the faba bean

According to Toker (2004), the degree of inheritance of the number of branches is 63%, indicating that this trait is a medium to high heritable character. Hughes et al. (2020) stated that the number of branches is a quantitative trait influenced by multiple genes and shaped by environmental interaction. A two-year study under Samsun conditions investigated the effect of apical and lateral branch removal on yield. The study found that all characteristics of plants left with a single branch decreased compared to the control and plants with two branches (Topal and Bozoğlu 2016). Faba bean is the legume with the best-developed stem among the cultivated edible legumes. The plants can grow to 20-140 cm, depending on the variety and ecology. As the number of nodes that produce the first flowers increases, the height of the plant also increases. The stem is generally short in small-seeded varieties, while in large-seeded varieties, it is longer.

The first juvenile leaves bear two leaflets. After four or more nodes, the maximum number of leaflets (typically six) is reached (Figure 4). The first, lowermost inflorescence is located in the axis of a leaf with at least four leaflets, inserted on the stem as low as at the fourth node or several nodes later (Link et al., 2008).



Figure 4. Leaves in parts of the plant

Faba beans bloom early in spring because the overall temperature is low. They may produce numerous flowers depending on weather conditions, but most will fall off. Bozoğlu (2005) reported in a study conducted over two years in Samsun conditions on a total of 12 faba bean genotypes, three of which were local, that the total number of flowers produced by the plants varied between 9 and 279, depending on the climate and genotype. However, it was found that a large portion of the flowers that bloomed were shed, and the pod formation rate ranged between 10.2% and 27.1%. It was determined that significant positive relations were found between seed yield and branch number, total flower number, plant height, pod number per plant, total flower number per plant, node number of last-set flowers, node number of last-set pods (Bozoğlu, 2005, Pekşen, 2006). Two to more than eight flowers per inflorescence occur.. Brown, violet, red, and further grades of flower colours exist. White flowers are a pleiotropic effect of an allele for zero tannin in the seed testa, accompanied by greyish testa colour instead of buff testa and by absence of the wild-type stipule spot. (Link et al., 2008). The time required for all flowers on a plant to open is generally 14-20 days (Figure 5). Approximately 10-35% of the open flowers in a pod will set pods. Depending on climatic changes during the flowering period, the pod set rate has ranged from 9.08% to 31.48%. Low night temperatures cause pod drop. 5-79% of pods may be cross-pollinated (Gülümser et al., 2013).



Figure 5. Flowers of faba bean

In faba bean, pods are either upright or hanging on a cluster of stalks arising from the leaf axils. The number of pods per plant varies between 1 and 9 (Figure 6). The pods have round stems and are 8-12 cm long (Gülümser et al., 2013). In germplasm used for human consumption, very few, huge pods per plant are often realised, with more than 20 cm pod length, more than six (Link et al. 2008). Genotypes with knotted pods are more suitable for fresh consumption. The skin colour is green and shades of green. Young pods are filled with white parenchyma. Each fruit contains between 2 and 8 seeds.



Figure 6. Fresh pods of faba bean

The seed coat accounts for 11-15% of the weight of the seed. The outer surface of the coat is smooth. The hilum is about 1 cm long and black, or occasionally greyish. The seed shape is round in small grains and flat-rectangular in large grains. The shell of newly harvested seeds is mostly pinkish yellow, light brown, light green, grey, white and cream colored (Figure 7). As the seeds age, the shell colour changes to dark brown and black.



Figure 7. Dry seed of faba bean

1.3. Ecological requirements of faba bean

Faba bean is considered a highly resilient crop in extreme weather and changing climatic conditions due to its distinct ability to thrive in many climatic conditions and its vast resilience to variable soil regimes (Singh et al., 2013a).

Faba bean is a plant with a wide range of adaptation, from the equator to regions close to the polar circle and from sea level to high altitudes. The most important limiting factors in cultivation systems are high temperatures, arid conditions, extremely acidic, and saline soils (Spetoğlu, 2002). Faba bean is a crop with a faba adaptation range, from the equator to regions near the Arctic Circle and from sea level to high altitudes. The main limiting factors in its cultivation systems are high temperatures, arid conditions, extremely acidic, and saline soils (Spetoğlu, 2002). During vegetation, faba bean does not require high temperatures and prefers rainy, humid, maritime climates. The minimum germination temperature is 1-2°C, and the optimum is 20-25°C. Vernalisation may be facultative for plants that require only a short vernalisation period, such as winter faba bean (Link et al., 2010). These plants can flower with or without vernalisation. By contrast, some plants will not flower without vernalisation (obligate vernalisation requirement). Link et al. (2010) found the effective vernalisation temperature for the winter faba bean to be 4°C.

According to Patrick and Stoddard (2010), the optimal temperature range for the flowering of faba bean is between 22 and 23°C. The delay of faba bean flowering can be attributed to sub-optimal temperatures and photoperiods during the initial stages of plant growth. The impact of high temperatures exceeding 32ºC on the faba bean crop is significant, resulting in reduced seed germination, a rise in abnormal seedling occurrence, early flowering, degeneration of nodules that affect nitrogen fixation efficiency, and a decrease in plant biomass (Maalouf et al., 2021).

In Türkiye, faba bean is generally cultivated as a winter crop in coastal regions and an early spring crop in inland areas, making it a cool-season legume. During its initial growth stages, it can tolerate temperatures as low as -4°C; the total temperature requirement during the growing period is around 1600°C, and optimal yields are achieved between 18-27°C. The net photosynthetic assimilation rate of three Mediterranean faba bean genotypes was considerably reduced when the leaf temperature exceeded 32°C (Avola et al., 2008). The reproductive phase of faba bean plants is particularly vulnerable to the negative effects of heat stress (Bishop et al., 2016).

During its growth period, a rainfall requirement of 600-1000 mm is necessary (Şehirali, 1988). It has been reported that winter varieties can withstand temperatures down to -12°C without snow cover and down to -20°C with snow cover (Lawes et al., 1983). Seasonal temperature changes alter the timing and duration of the onset of flowering. Faba bean requires adequate and regular water throughout its period of growth, especially since water stress during the flowering phase leads to flower drop (Sepetoğlu, 2002). In areas such as the Black Sea coastal regions, where spring is rainy and annual precipitation ranges from 650 to 1000 mm, it can be cultivated without irrigation. Among grain legumes, it is the least tolerant to drought. In arid regions, it responds well to irrigation. Water management is another key challenge in faba bean cultivation. Faba beans are sensitive to waterlogging and drought and are best grown in well-drained soils with even moisture (Shahani et al., 2025). Faba bean can be cultivated in a wide range of soil types. It prefers well-drained soils and a soil pH close to neutral, as with all legumes. The optimal pH values are reported as 6.9–7.3 for winter faba bean and 6.5–7 for spring faba bean (Sepetoğlu, 2002). Tekalign et al., (2016) reported that the optimal pH is 6.5-7.5 for successfully cultivating faba bean.

In regions with high precipitation, acidic soils tend to form, necessitating liming when the soil pH drops below 6. Although faba beans can grow in sandy loam soils, they require more frequent irrigation. Faba beans have shallow roots, making them vulnerable to drought stress in rapidly drying soils. However, these plants can tolerate brief periods of waterlogging due to their shallow root system (Tekalign et al., 2016).

Studies conducted over many years in Samsun have shown that faba bean is highly suited to the region's ecology, achieves high yields with winter sowing, has strong nitrogen fixation ability and soil-improving effects, and produces L-DOPA (Topal ve Bozoğlu, 2016; Karayel at al., 2016; Topal et al., 2020; Bozoğlu and Bezmen, 2021; Oğuz and Bozoğlu, 2023).

1.4. Names of faba bean

Faba bean is a winter season annual pulse crop (Bilalis et al., 2003) commonly known by different names: faba bean, bell bean, faba bean, field bean, and horse bean (Singh et al., 2010). The word 'Bakla' originates from Arabic, meaning "herb, greenery." It was adopted as "bakla" by the Ottomans. This term was borrowed from the Arabic, Aramaic/Syriac word baḳilā, which has the same meaning (Anonymous 2025a). In Turkish records, the names ak bakla-akbakla-ağ bakla, kara bakla (in Black Sea Region), pakla, eşek baklası, eşek fasulyesi, and bakla are used (Karacaoğlan, 2021, Oğuz, 2023). According to Soydan and Battal (2019), faba bean is one of the most referenced plant names in neighbouring countries' languages after barley and corn.

Globally, inspired by English, it is commonly called faba bean, broad bean, or horse bean. In English, it is known as faba bean or fava bean; in Italian, fava; in Greek, kaukia; in Spanish, haba; in French, fève; in German, Ackerbohne or Saubohne; in Arabic, fool; in Russian, fava or bob; and Chinese, Cándòu.

2. Cultivation Purposes and Nutritional Value of Faba Bean

Turkiye, surrounded on three sides by seas and in the subtropical climate zone, is especially suitable for faba bean cultivation in its coastal regions. However, despite a slight increase in cultivated areas since the Republic's early years, there has been a 94% decrease in cultivation areas and

an 87% decrease in production compared to 1961 (Figure 8). In Turkiye, the largest cultivation areas are found in the Aegean, Marmara, and Mediterranean agricultural regions, with Muğla, Çanakkale, Balıkesir, İzmir, Bursa, Istanbul, İçel, Kütahya, Zonguldak, Sinop, and Kastamonu being the leading provinces. Additionally, approximately 16 hectares of faba beans are cultivated in Samsun.

The changes in global faba bean cultivation area and production over the years are shown in Figure 2. Compared to the 1960s, there has been a 48% decrease in total cultivated area worldwide, while the United Kingdom and Australia are among the few countries that have steadily increased their planting areas. In 1961, the total cultivated area of the world was 5.4 million hectares, which decreased to 4.8 million hectares by 2023; however, production increased by 25% (Anonymous, 2025a) (Figure 8). The faba bean is cultivated in 66 countries worldwide and ranks sixth among legume crops. The leading producers are Australia, China, Ethiopia, France, and the United Kingdom (Kumar and Naushin, 2025).

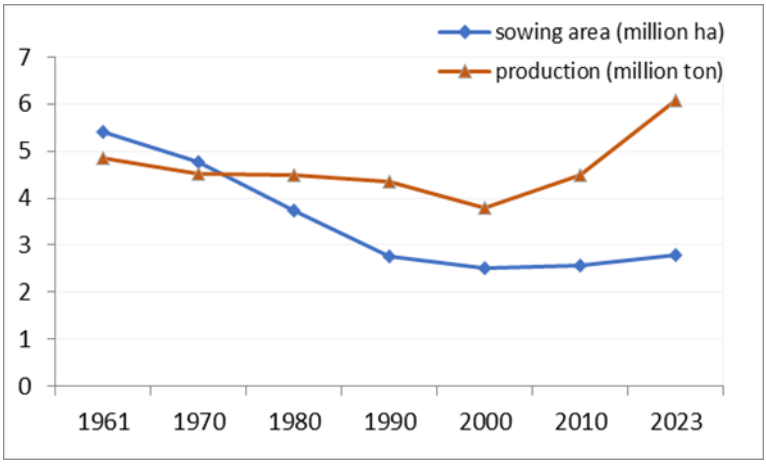
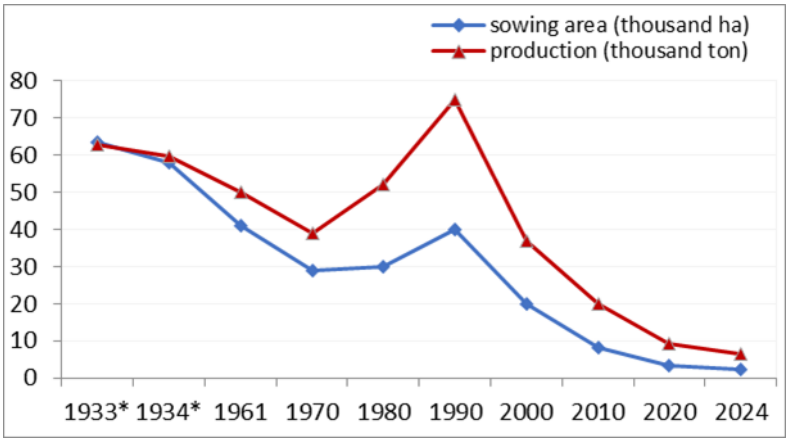


Figure 8. Changes in global faba bean cultivation and production over the years. (Anonymous, 2025a.)

When examining the average dry seed yield per decare for faba bean, the global faba bean yield value is determined to be 2183 kg/ha, while in our country, this value is 2609 kg/ha. According to these data, our country's average dry seed yield per decare is 19.52% higher than the world average.



Figures 9. Changes over the years in faba bean cultivation and production in Turkiye (Anonymous, 2025b, * Kansu (1936))

The faba bean is fundamentally valued in two aspects:

1. As food for humans and animals
2. As a soil improvement crop

The faba bean is used as food for humans and animal fodder due to its high nutritional quality. In human nutrition, it can be consumed as green pods, green seeds, canned beans, or dried beans. In our country, consumption mostly occurs as fresh pods, while the dried seeds are used in dishes or to prepare a meze called "fava."

Especially in the Central Black Sea region, "bakla sarma" is one of our most famous traditional foods made on festive occasions with ground dried faba beans wrapped in grape leaves instead of minced meat.

There are also rare recipes using the fresh leaflets as salad. Recently, various plant sprouts have become popular for healthy diets. Faba bean sprouts are noteworthy for their diverse polyphenols and high L-DOPA content. In Japan, it has been reported that faba bean sprouts grown hydroponically contain higher levels of L-DOPA compared to commercially available sprouts of white radish, red cabbage, and broccoli, and that L-DOPA is the major contributor to their antioxidant activity (Okumura et al., 2016).

Faba bean (*Vicia faba* L.) has considerable L-DOPA (3,4-dihydroxy-L-phenylalanine) content, ranging from 0.5% to 2%, making it the second-richest known plant source after Mucuna pruriens. L-DOPA, a non-

proteinogenic amino acid not naturally synthesised in humans, is pivotal in treating Parkinson's disease. Faba bean (*Vicia faba* L.) stands out for its considerable L-DOPA (3,4-dihydroxy-L-phenylalanine) content, ranging from 0.5% to 2%, making it the second-richest known plant source after Mucuna pruriens. L-DOPA, a non-proteinogenic amino acid not naturally synthesised in humans, is pivotal in treating Parkinson's disease. Topal and Bozoğlu (2016) determined that in different genotypes grown under varying cultivation conditions, L-DOPA content per dry weight ranged from 7.64–34.94 mg per kg in the leaf, 10.95–117.39 mg in the flower, and 1.52–79.90 mg in the fruit, with the flower having a higher content than the edible fruit. It was also found that when faba bean flowers are brewed with only boiling water, without any extraction process used as flower tea L-DOPA is transferred to the tea water (6.69–9.23 g/L), indicating potential for medicinal use of faba bean flower tea (Bozoğlu and Bezmen, 2021). Topal et al., (2020) reported that in *Vicia faba* L. flowers grown in greenhouse conditions and in the pollen and honey produced by bees feeding on these flowers, the L-DOPA content was 4.23% in the flowers, 0.98% in the pollen, and 0.076% in the honey. Based on this, studies have been recommended for the medicinal use of faba bean flowers and bee products. It has been reported that fresh fruit pods, due to their high polyphenol and L-DOPA (L-3.4-Dihydroxy phenylalanine) content, are not just waste but have functional food potential (Renna et al., 2020).

In recent years, faba beans have been utilised as a functional ingredient in various food products. Their use is especially notable in the following product groups: Due to problems in animal production and consumption in recent years, there has been an increasing demand in the global plant-based protein market. In this context, legumes are a group of plants whose potential for use as functional food in various fields is being researched, and faba beans are the subject of various studies for these purposes. Protein isolates derived from faba beans are being tested as functional ingredients with antioxidant activity and high fat-holding capacity, for inclusion in bread and other bakery products, yoghurt and tofu-like products, and fruit juices (Kumar and Naushin, 2025).

Faba bean flour has a nutty flavour and is a good protein and dietary fibre source. It is also gluten-free, making it a good option for people with gluten sensitivities or allergies (Kaya et al., 2018).

They can be cooked in various ways, including boiling, steaming, and baking. Faba beans can be used in soups, stews, salads, casseroles, side dishes, and desserts.

Inspired by one of Turkiye's traditional confections, candied chestnuts, developed a new functional food using dried fava beans to create a high-nutrient, low-cost treat suitable for those following a gluten-free diet. In this study, the preferred preparation method was soaking at 60°C for 2 hours, boiling for 5 minutes, and then microwaving at 160 watts for 4 minutes (Hecco, 2023).

The limited cultivation of soybeans, another high-protein crop in European countries, has increased the importance of faba beans in producing high-protein animal feed. Due to their abundant vegetative mass, faba beans are sometimes also used for silage.

In addition to being a valuable protein source for animal nutrition, legumes decompose more rapidly in the soil than cereals, and they contain high levels of nitrogen within the plant, producing substantial green matter, making them useful as green manure crops. After dry harvesting, the residual stalks and fruit pods can be used as fertilizer, fuel, or animal feed.

In the 1960s and 1970s, broad beans were added to cattle feed in rural Sinop. Dried broad beans were soaked in hot water, then spread out to dry. They were then ground in stone mills and mixed into barley and corn feed mixtures at a rate of one tin per sack (40-50 kg). Soaking the dried grains in hot water killed seed insects and reduced gas-producing effects.(Arslanoğlu, 2025).

Faba beans can fix nitrogen remarkably well under various environmental conditions through their symbiotic relationship with Rhizobium leguminosarum. This makes them an excellent rotation crop, significantly reducing the need for nitrogen fertilizers (Köpke and Nemecek, 2010). Faba beans can obtain up to 70–96% of their required nitrogen from the atmosphere (López-Bellido et al., 2006). Legume-based approaches, like the use of faba beans, increase soil fertility by improving soil organic carbon, humic composition, and the availability of nitrogen and phosphorus (Jensen et al., 2012).

Beyond their pharmacological significance, recent studies indicate that L-DOPA may exhibit allelopathic properties by inhibiting the growth of

weeds. Some research shows that L-DOPA can act as an effective herbicide and insecticide (Soares et al., 2014). In a study investigating L-DOPA's herbicidal effects for weed control in wheat and barley, it was found that concentrations of 1,500–3,000 mg/L did not affect wheat and barley growth but did show herbicidal effects on weeds (Topal and Kocaçalışkan, 2006).

According to Erk (1961), historical sources note that a paste made from faba bean flour, cumin, and olive oil was used in the treatment of horses, applied for ailments of the penis and testicles.

According to Kumar and Naushin (2025), as reported by Hulse (1994) In ancient times, faba beans were used for voting in countries like Greece and Rome, in which a "snowy bean" was utilised to give a 'yes' vote while a "dark bean" was used to cast a 'no' vote. Dropping beans on the earth's surface and deciphering a pattern in which they drop was a prevalent practice of divination (favomancy) for discovering what will happen in the future in Ubykh culture, and the name for "bean-thrower" has become a generic term for seers and soothsayers in general.

In some regions of Turkiye, faba bean divination is also practised. Faba bean divination is an ancient method of fortune-telling in which faba beans are cast and interpreted. The position and arrangement of each bean are believed to carry important messages about your life and clues about the future. Faba beans are commonly sown in Italy on the second day of November, also known as All Souls Day.

2.1. Nutritional content of faba bean

Faba bean is a crucial nutrient-rich legume, exceptionally high amounts of protein (high quantities of lysine and arginine), complex carbohydrates, dietary fiber, non-nutrient secondary metabolites, bioactive compounds (antioxidants, phenols, and γ-aminobutyric acid) and an excellent source of numerous micro as well as macronutrients, which include potassium (K), Calcium (Ca), Magnesium (Mg), Iron (Fe), and Zinc (Zn) (Dhull et al., 2021, Kumar and Naushin, 2025).

Especially in countries where animal proteins are expensive, legumes are significant, inexpensive, and easily accessible protein sources in human nutrition. Thanks to its high protein (15% - 28%) and carbohydrate (42% -

56%) content, as well as valuable vitamins (A, B, C, and K), faba bean is considered a valuable food source (Anonymous, 2024).

The protein in faba beans is of high quality and contains all nine essential amino acids. These amino acids are important for building muscle, maintaining healthy bones and skin, and producing hormones and enzymes (Turco et al., 2016).

Faba beans contain almost twice the protein content as that in cereal grains, with globulins (60%), albumins (20%), glutelins (15%), and prolamins (8%) (Dhull, 2021). Faba bean possesses high protein content from 20% to 41%; the wide variations are due to varietal differences and the source type, that is, flour, fraction, or isolate (Yang et al., 2018), as well as fertilization method, growth season, and planting site (Multari et al., 2015). In grain legumes, protein digestibility ranges from 67% to 97%, whereas in faba beans, this rate is between 50% and 60% due to trypsin inhibitors.

Numerous studies conducted under the ecological conditions of Samsun have shown that the crude protein content in dry seeds varies depending on the genotypes used, climate conditions, and cultivation techniques. In one study, four faba bean genotypes were sown eight times from November to first period of April. The protein content ranged from 24.61% to 28.19%, with sowing time having little effect, but statistically significant differences were observed among genotypes (Bozoğlu, 1989). Hacıseferogulları et al., (2003) reported that in faba beans, on a dry matter basis, the protein was 29.63%. In Samsun, the protein content in dry seeds of 15 different faba bean genotypes was determined to be between 20.00% and 25.65%, and in flowers between 17.26% and 20.03% (Bezmen, 2019). Compared to other beans such as lima, pinto, and red kidney beans, faba bean flour had the highest protein content at 29.76% (Gu et al., 2020).

Legumes are also rich in carbohydrates, making them notable for their satiating properties in human nutrition. When the starch content, one of the carbohydrate forms in dry seeds, was measured, it ranged from 31.12% to 38.97% depending on the genotype (Bezmen, 2019).

Prabhu and Rajeswari (2018) reported that the chemical composition of faba bean consists of 51–68% carbohydrates, 20–41% protein (with 79% globulin, 7% albumin, and 7% gluten), 2.3–3.91% fat, folic acid, niacin vitamins, and mineral elements (C, Ca, P, Mg, Na, S, Al, B, Ba, Co, Cr, Fe,

Ga, Mn, Pb, Sr, Zn). They also noted that faba bean contains small amounts of anti-nutritional substances such as vicine and convicine, and a high amount of polyphenols.

Faba beans are also an excellent source of vitamins and minerals. One cup of cooked faba beans contains significant amounts of iron, potassium, magnesium, phosphorus, and zinc. Faba beans are also a good source of B-group vitamins, including thiamin, riboflavin, niacin, vitamin B 6, and folate (Johnson et al., 2020a; Labba et al., (2021). Studies have shown that consuming faba beans can help reduce cholesterol levels, lower blood pressure, and reduce the risk of heart disease. Faba beans are also a good source of polyphenols, which are natural compounds with antioxidant and anti-inflammatory properties (Siah et al., 2012; Kwon et al., 2018; Johnson et al., 2020b).

In addition to its nutritional value, faba bean also contains anti-nutritional compounds (vicine, convicine, phytate, saponin, oligosaccharides, phenols, lectins, and trypsin inhibitors) (Labba et al., 2021). The two most important anti-nutritional glycosides are vicine and convicine, found in faba bean seeds, which have been responsible for acute hemolytic anaemia (the destruction of red blood cells), a condition known as favism. This disorder is particularly linked to the enzyme glucose 6-phosphate dehydrogenase (G6PD) deficiency. Individuals with G6PD deficiency are sensitive to oxidative stress and cannot regenerate depleted glutathione. Faba bean seeds contain beta-glycosidase activities that vary with developmental stages, highest in mature seeds and lowest in immature and aged seeds (Arese & De Flora, 1990). Appropriate preparation and processing methods, particularly traditional heating techniques such as steaming or grilling, have been repeatedly shown to denature proteins, reduce alkaloid content, and lessen the incidence of favism (Luzzatto and Arese, 2018).

3. Contribution of Faba Bean to Sustainable Agriculture and Food Supply Security

Global climate change, upheavals in the world economy, and wars mean that "food security and supply" will remain among the most strategic issues worldwide in the coming years.

With the rapidly growing world population, the pressure on agricultural food systems continues to increase. Changes in consumer behaviour, especially after the pandemic, climate change, and environmental sustainability, are among the many factors affecting food production systems. Around the world, intensive studies are being conducted on new food sources and production systems to protect the environment and promote healthy nutrition. The most remarkable developments occur in the rapidly expanding plant-based food sector (Anonymous, 2022). By 2054, the global protein demand is projected to double, reaching approximately 950 million tons. Legumes are among the first crops that come to mind regarding plant-based proteins. Bahl et al. (1993) report that, since the beginning of agriculture, four out of the eight founding crops have been legumes (*Lens culinaris L., Pisum sativum L., Cicer arietinum L., Vicia ervilia*). Today, 74% of plant-derived proteins are produced from pulses. Legumes enrich the soil and increase soil biodiversity and microbial activity, and some are tolerant to dry conditions, but they also serve as excellent rotation crops, making them environmentally friendly. Furthermore, their properties, such as texturising, gelatinization, emulsification, and water retention, can be used as functional foods in various applications.

Major pulse-producing countries are becoming centers for plant-based protein production and are attracting significant investment (Boğuşoğlu, 2022). The International Grains Council (IGC) reported that, over the past decade, global pulse trade has increased by one-third, influenced by population growth and dietary shifts toward plant-based nutrition. For the 2024/25 season, the IGC expects the production of dry peas, lentils, chickpeas, and faba beans to rise by 4% compared to last year, reaching 46.6 million tons. The expansion of global trade, increased awareness of health benefits, and the growing use of pulses in animal feed and processed food sectors continue to position legumes as key players in shaping resilient global food systems (Anonymous, 2025c).

Although many cultures do not traditionally use a lot of pulses in their cuisine, countries like Canada, Australia, and Russia have been increasing their cultivation and production areas for lentils, chickpeas, and peas; despite the war, Ukraine has boosted its pulse production, and India has implemented import restrictions. Considering these efforts to secure a place in the global

pulse market, our country should also recognize the importance of this trend. As Turkiye is the origin and gene center for many pulses that form a vital part of our culinary heritage, instead of shrinking the cultivation areas of these crops, we need to develop new product concepts to increase domestic consumption and establish strategies to create markets abroad.

4. Factors Limiting the Cultivation and Use of Faba Bean

The most significant factor limiting the use of faba beans as a food is the presence of antinutritional compounds in the dry seeds, such as phytates, vicine, convicine, saponins, lectins, oligosaccharides, condensed tannins, and trypsin and protease inhibitors. Vicine and convicine are the main antinutritional compounds found in faba beans, known to cause hemolytic anaemia (called favism) in people with glucose-6-phosphate dehydrogenase enzyme deficiency (Dhull et al. 2021). Symptoms of the disease include pallor, weakness, and kidney problems, and in some individuals, it can even be fatal. However, varieties with zero levels of these enzymes have been developed in different countries (Link et al., 2008).

The factors limiting the use and production of faba beans, which have reduced their cultivation areas in our country, also apply to other pulses. Consumption habits are generally changing; younger generations are moving away from these products and sometimes do not even recognise them. The acceleration of daily life and the increased consumption of convenience foods have caused people to shy away from foods with long cooking times. While chickpeas, lentils, and beans are widely cultivated in our country due to strong domestic demand, demand for other pulses, including faba beans, remains relatively low. I believe that consumers do not sufficiently understand the importance of faba beans as a food source, nor do farmers fully appreciate its soil-improving and agricultural benefits.

Although eating habits in Turkiye are changing worldwide, unfortunately, apart from being consumed in their raw form, chickpeas are not sufficiently evaluated as a functional food, except for unprocessed and as a snack. For faba beans, food diversity does not extend beyond being eaten as fresh vegetables or dry seeds. Yet, as mentioned above, legumes globally can serve as a source of functional foods in many different areas and can be transformed into high-value-added products.

Low product consumption should not be a reason to abandon its cultivation. Just as Canada has done with lentils and Australia with chickpeas, even if there is little domestic consumption, production should still be aimed at exporting to other countries. In this regard, faba bean is an important crop. There is potential to market it to many countries to our east, south, and west, such as Egypt, Iraq, Syria, Greece, and various other European nations, where faba bean consumption is high.

Faba bean is one of our products, and almost no export activity exists. The most significant limiting factor in the export of pulses is our inability to consistently produce products that meet the quality standards of importing countries each year. In Turkiye, pulse production is mainly dependent on climatic factors. One year may yield a good crop, but if a problem such as drought occurs the next year and we cannot produce goods that meet importers' demands, it becomes impossible to maintain a steady export flow.

Another limiting factor is that, although the Ministry of Agriculture offers different support programs for lentils, chickpeas, and beans, there is no such support for faba beans, which have a small cultivation area. As a result, farmers tend to prefer other crops for which they can receive support.

When the appropriate ecology is chosen, faba beans are not a crop with major limiting factors regarding adaptability and cultivation techniques. Due to its limited cultivation area, mechanisation has not been widely developed for it; however, it is not a crop that would pose significant challenges to mechanization

Faba bean is a legume with a high rate of cross-pollination depending on environmental conditions. Faba bean has been observed that the breeding work to develop the resistance in plants to biotic and abiotic stress is cumbersome due to the complex nature of the resistance mechanism (Sing et al. 2025). There is also a lack of sufficient agronomic and breeding research on faba beans in our country. There is a significant deficiency in terms of seed production. Since it is generally cultivated on very small area, farmers use their seeds, leading to yield variations between years. Currently, there are only three registered faba bean varieties in Turkiye intended for dry grain production

The lack of yield stability is highlighted among other countries' limiting factors for agriculture. Yield instability can be attributed to several factors

related to plant traits (e.g. phenology, morphophysiology) and biotic and abiotic stresses. Faba bean has a very poor flower pod ratio, with a maximum of 20% of flowers resulting in pods. Environmental stresses such as frost, heat and drought cause significant damage to flowers and young pods; therefore, matching the phenology of crops to the environment is important for avoiding or minimising detrimental effects of unfavourable environmental conditions (Alharbi and Adhikari, 2020)

Our country is not listed as a center of origin and diversity for faba bean in most foreign sources. However, Turkiye, rich in plant biodiversity, contains more than 59 species within the Vicia genus, including the faba bean. The richness of the Vicia genus suggests that faba bean could very well have originated in our lands. In fact, during surveys conducted from the westernmost to the easternmost parts of the Black Sea region, faba bean was found, even in small amounts, in nearly every household garden.

According to TUİK (2023) figures, annual per capita consumption of fresh faba beans is 0.4 kg, and production meets 102% of demand. There is no available consumption data for dried faba beans. This information indicates that faba beans have not been sufficiently studied. It is well known that, apart from chickpeas, lentils, and beans, there are few or no nationwide projects by the Ministry of Agriculture regarding other legumes. However, due to nitrogen fixation of faba bean capability, soil-improving properties, high adaptability, ability to be grown as a winter crop in mild regions without irrigation, and the option to harvest fresh pods in spring and incorporate the remaining biomass into the soil as green manure—thus leaving time for a main crop faba bean stands out as a significant plant species.

5. Conclusion and Recommendations

According to IPCC (2021) reports, Turkiye has been among the 10 countries with the highest urban population at risk of water scarcity since 1971. Indeed, compared to the year 2000, precipitation has decreased by 6.3%. As for agricultural land, there has been an 8% decrease in total agricultural areas and an 18% reduction in cultivated land compared to 1990.

Climate change impacts agricultural lands the most. The fundamental task ahead is to learn how to live and farm under changing climatic conditions, particularly emphasising the efficient use of water. To achieve

this, it is necessary to develop and utilize locally adapted materials that are soil- and environmentally-friendly and use water efficiently. In this way, agriculture can be elevated to the level of a national security policy.

Agriculture is one of the most crucial human activities and represents a defining turning point in human history. Its primary inputs are biodiversity, soil, water, air, and people. Every human activity affects these essential resources often negatively rather than positively. Yet, their protection and sustainability are vital for continuing human life. Unfortunately, as life accelerates, industrializes, and digitizes, people are becoming disconnected from rural areas, the land, and nature, preferring more artificial lifestyles. As a result, nutritional deficiencies and even diseases are becoming increasingly common. Due to their nutritional value, we must reconsider our dietary choices and make more room for pulses on our tables.

There is a global trend toward plant-based protein and healthier, more sustainable foods. Faba bean, with its high protein content, soil-improving properties, low carbon footprint, and efficient water use, is a crop that should remain integral to our agricultural systems.

Turkiye is a country with very diverse geographic and ecological conditions, making it possible to cultivate all types of grain legumes in its various regions. Moreover, these products hold an important place in our culinary culture. By leveraging our infrastructure in food technology to produce high-value-added goods and by developing products that meet domestic and international market demands, we should secure our place in the global plant-based protein market.

In conclusion, I hope we can again embrace the spirit and motivation of the early years of Turkiye Republic, when the population was 16 million and the literacy rate was around 20%, as reflected in the statistics collected province by province on pulses and the scientific efforts carried out. Let us reclaim our values and continue to advance in this direction.

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Chapter 5

FENUGREEK (*Trigonella foenum-graecum* L.)

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DOI: https://dx.doi.org/10.5281/zenodo.17453294

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1. General Characteristics of Fenugreek

Fenugreek (*Trigonella foenum-graecum* L.) is an autogamous, diploid, annual herbaceous crop belonging to the Fabaceae family (*Leguminosae*). Native to the Mediterranean Basin and Western Asia, its earliest cultivation is believed to have started in Ancient Egypt during the second millennium BCE. Prominent Greek physicians and philosophers, such as Theophrastus and Dioscorides, referred to the plant using names like "Buceras" (meaning "cow-horn") and "Aegoceras" (meaning "goat-horn"). In the Roman period, Pliny and Columella maintained these appellations, as well as the term "*foenum-graecum*," which translates to "Greek hay" (Gökçe and Efe, 2016; Baldemir and İlgün, 2015). Historically, fenugreek cultivation has extended from parts of Iran to northern India, and it remains significant in various regions of Asia, including China (Sun et al., 2020).

Several researchers have investigated the origin of fenugreek. Dangi et al. (2004) proposed that the center of origin of fenugreek is Turkey; Fuller and Stephens (2015) argued that it is native to India and North Africa; and Vavilov (1926) traced its origin to the Mediterranean region. The genus Trigonella is reported to comprise approximately 260 species worldwide (Petropoulos, 2002 a,b,c). In Turkey, 49 species and four subspecies are recognized, 18 of which are endemic (TÜBİVES, 2019), although Trigonella foenum-graecum is the most widely encountered species.

Fenugreek, with its wide distribution (Figure 1), is cultivated as a food, forage, green manure, and cover crop in countries such as India, Egypt, Morocco, Algeria, Turkey, Italy, Spain, the United States, Australia, France, Canada, and Greece; it is also widely grown for its medicinal, pharmaceutical, and nutraceutical properties (Acharya et al., 2008; Özdemir and Gürbüz, 1998). Fenugreek is an ancient crop with a natural distribution in Anatolia and the Mediterranean region. In Turkey, fenugreek is referred to by various vernacular names, including “çemen otu,” “boy otu,” “buyotu,” and “çaman otu.” In Arabic, it is known as *hulba*; in English, it is called *fenugreek*; in Hindi, it is referred to as *methi*; in Armenian, *shambala*; and in Ethiopia, *abis*. The Latin name of the genus, Trigonella, translates to “little triangle,” referencing the plant’s characteristic trifoliolate leaves (Baldemir and İlgün, 2015). Fenugreek is cultivated in several provinces in Türkiye, including Konya, Kayseri, Çankırı, Ankara, Gaziantep, Kahramanmaraş, Afyon, Urfa,

Hatay, and Tokat. Both the fresh and dried leaves, along with the seeds, are utilized as a spice (Zandi et al., 2015).

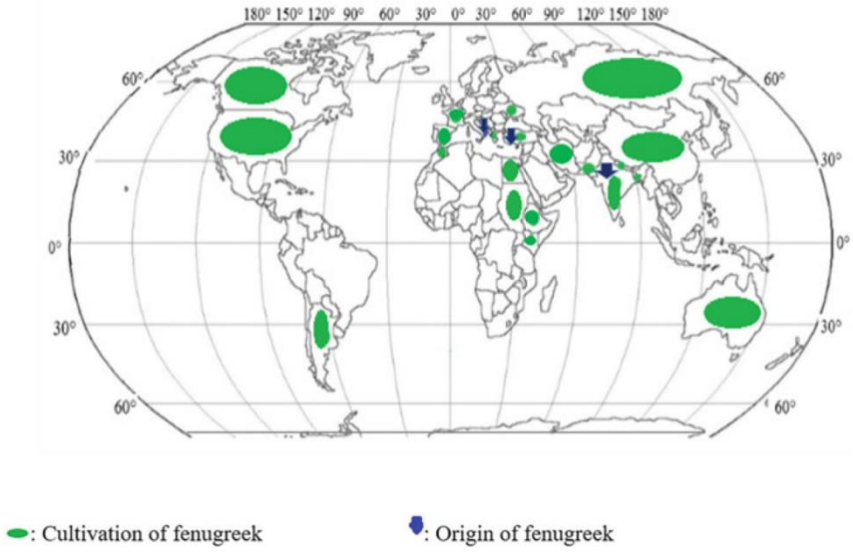


Figure 1. Origin and cultivation of fenugreek (Camlica and Yaldiz 2021)

Fenugreek (*Trigonella foenum-graecum* L.) is an annual herbaceous plant (Figure 2) that typically grows to a height of 30–60 cm and has a notable ability to branch extensively. The stems are hollow, rounded, and covered in fine hairs during the early stages of development, with colors ranging from green to pinkish-purple. Lateral (axillary) branches emerge from the leaf axils. The root system has a digitiform (finger-like) structure. While the seeds are the most recognized part of the plant, the entire plant, including leaves and stems, contains secondary metabolites (phytochemicals) such as alkaloids, saponins, tannins, and phenolic compounds (Visuvanathan et al., 2022; Aasim et al., 2018) . The leaves are dark green, with petioles that have a cartilaginous texture and are typically thickened at the end (Aasim et al., 2018). The foliage is trifoliolate, featuring obovate leaflets with serrated edges and a cuneate base. The stipules are prominent and lanceolate in shape (Petropoulos, 2003; Gökçe and Efe, 2016).



Figure 2. Leaf, flower and pods of fenugreek. a; leaf and flower, b; fenugreek pods.

Flowers may be white, yellow, purple, blue, or pink. They are borne singly in the leaf axils, with peduncles extending up to 15 cm. Each flower produces 2–8 pods. Pods are straight or slightly curved, pubescent, and measure approximately 10–18 cm in length and 3.5–5.5 mm in width. Initially reddish or greenish, they turn brown upon maturation. The pods contain hard seeds—rhombic, rectangular, or square in form—in shades of yellowish, greenish, reddish, golden, light brown, or dark brown (Petropoulos, 2003; Gökçe and Efe, 2016). On average, 10–20 seeds occur per pod. Chemically, the seeds comprise ~27% protein; 7–10% lipids (predominantly oleic and linoleic acids); essential vitamins such as A, B1, B2, and C; abundant dietary fiber; alkaloids; trigonelline; flavonoids; saponins (notably diosgenin); mucilage; and other nitrogenous compounds. This composition underpins both their nutritional and medicinal value (Özdemir and Gürbüz, 1998; Meghwal and Goswami, 2012; Akbay and Erol, 2021). Fenugreek seeds usually germinate within 5 to 10 days, and the first trifoliolate leaves emerge5 to 8 days after germination. Although growth is relatively rapid, the crop takes approximately 4 to 7 months to reach full maturity. Flowering typically occurs in mid-summer (June to August), with seeds maturing towards the end of summer (Hilles and Mahmood, 2021). The seeds can remain viable for

extended periods, allowing them to stay dormant until conditions become favorable for germination.

Fenugreek (*Trigonella foenum-graecum* L.) demonstrates significant adaptability to various environmental conditions. It is particularly well-suited for arid and semi-arid climates (Tewari et al., 2024). In temperate regions, fenugreek is typically sown in the autumn as a winter annual, whereas in cooler areas, it is planted in spring as a summer crop. This species exhibits high tolerance to drought and elevated temperatures, but it is moderately susceptible to frost. In terms of soil requirements, fenugreek is relatively undemanding, achieving optimal yields in light loam to sandy-loam, well-drained soils. It thrives in a pH range of slightly acidic (~6.0) to slightly alkaline (~8.0). As a legume, fenugreek enhances soil fertility through biological nitrogen fixation (Aasim et al., 2018; Venkata et al., 2017). Due to its ability to adapt to various climates, environments, and soil types, fenugreek can be reliably cultivated for sustainable production in drought-prone arid and semi-arid regions. However, increasing drought severity may still adversely affect yields, despite its notable tolerance to cold and water deficits (Beyzi et al., 2010).

2. Cultivation Purposes and Nutritional Value of Fenugreek

Fenugreek (*Trigonella foenum-graecum* L.) is a highly versatile legume widely cultivated for numerous applications, including food, cosmetics, pharmaceuticals, spices, animal feed, cover cropping, green manuring, and various industrial uses (Tewari et al., 2024). Overall, fenugreek is valued as a multipurpose species for its medicinal, nutritional, and culinary uses. Its rich profile of bioactive constituents makes it a popular candidate for research and applications aimed at improving health and well-being (Visuvanathan et al., 2022; Dhull et al., 2022).

Fenugreek extracts exhibit a broad spectrum of activities, most notably antitumor, antiviral, antimicrobial, anti-inflammatory, hypotensive, and antioxidant, and, together with their traditional uses and documented pharmacological actions, confer significant therapeutic and nutritive properties (Rahmani et al., 2018). Owing to its abundance of secondary metabolites (phytochemicals), including alkaloids, saponins, tannins, and phenolic compounds, fenugreek is utilized in various applications, including

as a spice, a medicinal herb, and in traditional medical systems (Aasim et al., 2018; Venkata et al., 2017).

These compounds form the basis of fenugreek's traditional applications, which include facilitating childbirth, promoting lactation as a galactagogue, and serving as a laxative (Visuvanathan et al., 2022). Recent studies have explored its antimicrobial, antioxidant, and antidiabetic properties, highlighting potential uses in managing conditions such as insulin resistance, obesity, and cancer (Aasim et al., 2018; Naika et al., 2022; Li et al., 2018). Furthermore, under specific experimental conditions, fenugreek has demonstrated the ability to stimulate mitochondrial function and improve insulin sensitivity, indicating possible advantages for metabolic health (Li et al., 2018). In addition to the seeds, the leaves are well-regarded for their therapeutic properties, which stem from their high content of bioactive secondary metabolites. These metabolites include alkaloids, saponins, flavonoids, and similar compounds, all of which contribute to their antidiabetic and cholesterol-lowering effects (Naika et al., 2022; Acharya et al., 2008). (Moreover, the seeds demonstrate antioxidant activity (Kaviarasan et al., 2004) and have been shown to help regulate plasma cholesterol levels (Madar and Shomer, 1990).

Fenugreek is widely recognized as a valuable medicinal plant with diverse applications. Its seeds are frequently used in traditional therapies for various health conditions around the world (Sun et al., 2020; Bahmani et al., 2015). In Ancient Rome, fenugreek was reportedly used to induce labor (Yoshikawa et al., 1997). In Traditional Chinese Medicine (TCM), it is utilized to dispel "cold" and relieve pain. In Europe, fenugreek has been applied to treat skin inflammations and transient loss of appetite (Yao et al., 2020). In TCM, both the seeds and flowers are used to manage hyperlipidemia, hypertension, and immune-related disorders (Luan et al., 2018). Additionally, the leaves of fenugreek were used to produce the sacred smoke of the Egyptian incense Kyphi for fumigation and in mummification rites (Rosengarten, 1969). As a key ingredient in Indian spice blends, fenugreek is often germinated to enhance its antioxidant activity and lower its glycemic index (Chaubey et al., 2018).

In the food industry, fenugreek seeds (Figure 3) are added to a variety of products, including bakery items, meats, alcoholic beverages, confections,

condiments, ice creams, syrups, sweet sauces, gelatins, puddings, chewing gums, and sweet creams. The phenolic constituents of fenugreek are valued for their contributions to flavor, aroma, and color, as well as their antimicrobial and antioxidant properties and their ability to inhibit specific enzymes (Häkkinen, 2000). It is also a principal component of the paste used to coat 'pastırma' (Turkish cured beef). Owing to its characteristically bitter–slightly sweet seeds, used whole or ground, fenugreek is widely employed to flavor numerous foods, including spice blends and teas (Madhava Naidu et al., 2011). Fenugreek further possesses notable nutritional value as a source of dietary fiber, protein, and essential vitamins such as A, B1, B2, and C (Tewari et al., 2024). It is utilized as a spice, herb, food additive, flavoring agent, and preservative. Both seeds and leaves are rich in phytochemicals, including alkaloids, carbohydrates, steroidal saponins, and amino acids, the combination of which underlies a broad range of reported bioactivities, such as antimicrobial, antioxidant, antidiabetic, antihyperlipidemic, and anticancer effects (Aasim et al., 2018; Acharya et al., 2008).

Fenugreek plays a significant role in food technology, primarily due to its high dietary fiber content and the presence of galactomannans, which provide emulsifying and stabilizing properties across a wide array of applications. The gum extracted from fenugreek seeds (Figure 3), derived from the endosperm, contains these galactomannan structures, with the seeds comprising approximately 20–28% gum (Jani et al., 2009; Sindhu et al., 2017). This substantial gum content positions fenugreek as a valuable functional additive in contemporary food processing (Dhull et al., 2022).

Stabilizers, commonly referred to as gums or hydrocolloids, are extensively utilized as gelling, thickening, stabilizing, and suspending agents (Jayakody et al., 2023). Their ability to enhance sensory attributes, extend shelf life, facilitate storage, streamline manufacturing processes, and help preserve both nutritional value and product quality makes them indispensable across numerous industries, particularly in the food sector (Altuğ, 2001). Given these qualities, gums represent a primary classification of food additives. The utilization of stabilizers as coating and film-forming materials within the food industry (Zhang et al., 2022) has further solidified their essential role (Glicksman, 1982). Remarkably, fenugreek seed gum surpasses tara gum, locust bean gum, and guar gum in galactose content, resulting in

significantly higher water solubility compared to these alternatives (Garti et al., 1997).



Figure 3. Fenugreek seed and gum, a: fenugreek seeds, b: fenugreek gum, c:powdered gum (Emerald Seed Products, 2023)

Fenugreek is a highly beneficial option for animal nutrition, thanks to its medicinal and nutritional properties. It has been indicated that it enhances the activity of antioxidant enzymes and lowers oxidative stress markers, which can contribute to improved overall health and potentially enhance livestock production systems (Bakhtiar et al., 2024). Nutritionally, fenugreek seeds are abundant in protein, carbohydrates, lipids, and essential amino acids, providing considerable energy for feed formulations (Bakhtiar et al., 2024). These attributes make fenugreek seeds a desirable feed additive, particularly for ruminants and poultry, as they promote growth performance and overall health (Aasim et al., 2018).

Fenugreek is a legume capable of producing substantial quantities of high-quality forage, and it shows promise as a natural additive to enhance ruminant production performance. It can be cultivated for hay or silage and contains growth-promoting compounds, such as diosgenin, that are uncommon in other forage legumes and are non-bloating (Ibidhi and Salem, 2022). Owing to its nutrient profile, which is comparable to alfalfa hay, fenugreek has been proposed as an alternative forage for ruminant diets and may stimulate appetite and increase feed intake (Akbay et al., 2020). In livestock, fenugreek herbage has been reported to support muscle development, contributing to higher carcass weights (Basu et al., 2016).

Despite these favorable attributes, relatively few studies have examined herbage yield and quality in this species (Bobos et al., 2022).

Cultivation of fenugreek also entails pest and disease management, which is critical for maintaining plant health and yield. When employed as a cover crop, its dense canopy and allelopathic effects can suppress weed growth. Moreover, fenugreek is relatively less affected by pests than many other crops; nevertheless, successful production requires targeted protection against specific pests and pathogens (Giannopolitis, 2002).

3. Contributions of Fenugreek to Sustainable Agriculture and Food Supply Security

The global population is projected to reach approximately 9–10 billion by the middle of this century. Food demand is expected to rise by about 50%, underscoring the critical need to increase agricultural production (Lee et al., 2023). However, expanding output from existing agricultural land presents major challenges due to climate change, soil degradation, biodiversity loss, rising carbon emissions, resource constraints, and broader sustainability concerns (Pandian et al., 2024). In agriculture, sustainability encompasses systems that produce high-quality food without damaging natural resources, disrupting the equilibrium of agro-ecosystems, or undermining their capacity to adapt to changing conditions.

Achieving a balance between the sustainability of large-scale food production and the preservation of climate-resilient agricultural ecosystems is crucial for ensuring food supply security. This balance requires not only an increase in production but also the mitigation of environmental risks and the maintenance of high quality standards for food products (Gomiero et al., 2011; Qi et al., 2018). Agricultural sustainability is inherently linked to climatic conditions and supports the continuity of production on both cultivated lands and rangelands/pastures, thereby contributing to the safeguarding of food security (Tubiello et al., 2007).

Fenugreek is among the oldest medicinal plants with a well-established medicinal and nutritional profile. Its seeds contain substantial amounts of dietary fiber, phospholipids, glycolipids, oleic acid, linolenic acid, choline, vitamins A, B1, B2, and C, nicotinic acid, niacin, and numerous other functional constituents. It performs well under a wide range of conditions;

shows moderate tolerance to drought and salinity; and can be profitably cultivated even on marginal lands. Owing to these attributes and its heavy-metal remediation potential, fenugreek can be integrated into diverse cropping systems. In addition to its medicinal applications and use as a thickening agent in foods due to its galactomannan content, it also serves as a valuable livestock feed supplement and as a green manure (Ahmad et al., 2015; McCormick et al., 2009).

Food supply security has gained significant global attention due to the challenges posed by a growing world population, diminishing arable land, climate change, and the urgent need for sustainable use of natural resources (FAO, 2008). The foundation of food supply security is heavily reliant on the sustainability of agricultural production, the cultivation of nutritionally rich alternative crops, and the incorporation of stress-tolerant plant species into farming practices (Godfray et al., 2010). In this regard, fenugreek (*Trigonella foenum-graecum* L.) stands out for its biological, ecological, and nutritional qualities, presenting a strategic opportunity to enhance food supply security.

As a member of the Fabaceae, fenugreek (*Trigonella foenum-graecum* L.) is capable of fixing atmospheric nitrogen. This trait facilitates the development of sustainable production systems by reducing reliance on synthetic fertilizers, enhancing soil fertility, and helping to suppress soilborne pathogens (Acharya et al., 2006). Fenugreek is therefore a valuable option for low-input, environmentally friendly production schemes, particularly on marginal lands. From a nutritional perspective, fenugreek contains high levels of protein (~23–25%), dietary fiber, iron, calcium, and an array of bioactive compounds (flavonoids, saponins, alkaloids) (Srinivasan, 2006). Both seeds and leaves are used as functional food ingredients in human diets and incorporated into livestock feed rations, thereby contributing to the food supply chain through both direct and indirect pathways.

Plant genetic resources possess significant potential to diversify crop gene pools, improve yield capacity, and provide resilience against biotic and abiotic stresses. With continued population growth, the conservation of plant genetic resources has become increasingly critical; ongoing demographic expansion, ecosystem alteration, and climate change further amplify their importance. The identification and conservation of plant genetic resources are among the most essential prerequisites for sustainability in agriculture. In

fenugreek germplasm, traits such as high seed and forage yield, together with resistance to biotic and abiotic stresses, have been documented (McCormick et al., 2009). Introgression of these attributes into cultivated fenugreek is anticipated to support sustainability and, consequently, strengthen food security.

Fenugreek exhibits notable ecological adaptability, marked by its resilience to drought, salinity, and nutrient-poor soils. These attributes position it as a promising alternative crop in response to the environmental challenges posed by climate change. Moreover, with its short growth cycle and versatile uses, fenugreek allows for flexible crop rotations, thereby supporting the continuous production of food. Due to its capacity for biological nitrogen fixation, rich nutritional profile, tolerance to environmental stresses, and adaptable production capabilities, fenugreek significantly contributes to food supply security. Expanding its application within sustainable farming systems, particularly in low-income regions and areas adversely affected by climate change, has the potential to enhance agricultural productivity. Consequently, the integration of fenugreek into agricultural systems should be viewed as a strategic measure to strengthen future food supply security.

4. Factors Limiting the Cultivation and Use of Fenugreek

Despite its agronomic benefits and nutritional value, the cultivation of fenugreek encounters various agronomic, environmental, and economic challenges. These limitations hinder its adoption in mainstream agricultural practices and prevent the full realization of its potential. The crop's responsiveness to management practices including soil preparation, timing of sowing and harvest, irrigation methods, as well as the dosage, application method, and timing of both micro and macro nutrient applications significantly influences seedling establishment, disease control, and the medicinal quality of the harvested product. Additionally, interactions between genotype and environment play a crucial role in determining seed quality (Akinrinde and Olanite, 2014).

Fenugreek seedlings exhibit a delicate morphology and are known to have a low tolerance for transplanting (Parwez et al., 2021). The challenges associated with fenugreek cultivation have been detailed by Edison (1995)

and Petropoulos (2002), highlighting issues such as deficiencies in breeding programs aimed at developing high-yield cultivars, limited genetic diversity, seed-related challenges that result in weak and inadequate germination, shortcomings in seed production systems, poor nutrient absorption in light and sandy soils, and an overall lack of high-quality cultivars.

A review of the literature indicates that the principal constraints to fenugreek cultivation can be summarized as follows:

Underutilization and insufficient cultivar development: Despite its high medicinal and nutritional value, fenugreek remains an underutilized crop. To realize its full potential as an edible and medicinal species, there is a need to develop new cultivars (Aasim et al., 2018).

Secondary Metabolites and Cultivation Focus: Many cultivation studies have prioritized the isolation of key secondary metabolites, such as diosgenin and trigonelline, rather than promoting fenugreek's use as an edible crop. This narrow emphasis constrains broader cultivation and limits its utilization as a food source (Aasim et al., 2018).

Ecophysiological Challenges: Although fenugreek is a resilient species capable of growing across diverse environments, ecological and physiological factors can influence both growth and secondary metabolite production. Addressing these constraints will require additional genetic and ecological research to optimize cultivation practices (Chaudhary et al., 2018).

Need for Breeding and Biotechnological Advances: To meet the rising demand for phytochemicals, new breeding programs and modern biotechnological tools are needed. Enhancing the genetic resources of fenugreek will facilitate trait improvement and lead to better cultivation outcomes (Aasim et al., 2018).

Nutraceutical and Nutritional Aspects: Fenugreek is abundant in active constituents, including saponins, flavonoids, and alkaloids, as well as essential nutrients. However, its potential in the functional food industry has not yet been fully realized. Thus, it is essential to connect traditional uses with contemporary scientific applications (Tewari et al., 2024).

Water availability is a critical environmental factor influencing fenugreek cultivation, as it is vital to all life processes and often a limiting factor in production. In semi-arid and arid regions, fenugreek is frequently impacted by drought due to insufficient, untimely, and erratic rainfall. Meena

et al. (2016) noted a genotypic variation in drought tolerance, highlighting that water deficiency can reduce the membrane stability index and yield while increasing malondialdehyde and L-proline levels. Additionally, Sexena (2019) suggested that water stress may enhance seed oil content. However, it is important to note that water stress during the vegetative stage, pod set, and seed filling can negatively affect yield, quality, and harvest index (Ahmed et al., 2018; Beyzi and Güneş, 2021).

Plants are subjected to a range of environmental stressors, including biotic agents such as pathogens and abiotic factors like freezing temperatures, radiation, salinity, flooding, drought, high heat, and heavy metals. Additionally, exposure to chemicals such as pesticides, herbicides, and insecticides serves as a significant source of stress. These factors can adversely affect plants at various developmental stages, ultimately leading to declines in both productivity and quality. In fenugreek, environmental stressors can impact morphological traits, yield characteristics, and the composition of secondary metabolites. Field experiments have demonstrated that several abiotic constraints, including water deficits or drought, extreme soil pH, salinity, and nutrient deficiencies, alter physiological and biochemical processes, thereby hindering plant growth. Furthermore, root-nodulating soil bacteria are also exposed to the same challenging environmental conditions as their legume hosts. Moreover, pesticides can induce oxidative stress and cytotoxic effects in fenugreek seedlings. This leads to a significant decrease in the mitotic index, the occurrence of chromosomal abnormalities in root meristematic cells, and reduced levels of key regulators of the cell cycle (Yaldız and Çamlıca, 2021).

In comparison to other legumes, fenugreek displays lower yields, production levels, and cultivated area. Therefore, it is essential to implement effective scientific strategies, encompassing both breeding programs and agronomic practices, to enhance the productivity of fenugreek cultivars. The adoption of diverse cropping systems can not only improve yield but also enrich phytochemical profiles, thereby benefiting both crop production and soil management (Çamlıca and Yaldız, 2021). To develop genotypes that are resilient to stress factors, it is important to advance both conventional breeding and biotechnological approaches; these techniques can enable growers to achieve higher-yielding cultivars even under challenging

environmental conditions. Additionally, there should be a focus on developing rhizobial strains that can tolerate abiotic and biotic stresses.

5. Conclusion and Recommendations

Fenugreek (*Trigonella foenum-graecum* L.) is notable for its high nutritional value, rich array of bioactive compounds, and versatile applications, making it strategically important for both the food and feed sectors. It offers promise as a sustainable agricultural crop due to its adaptability to arid and semi-arid climates, ability to fix atmospheric nitrogen (which enhances soil fertility), and short growth cycle. These characteristics position fenugreek as a valuable alternative crop that can strengthen food supply security. The seeds' substantial contents of protein, dietary fiber, vitamins, minerals, and functional compounds underpin documented antidiabetic, antioxidant, antihyperlipidemic, and anticancer activities in human nutrition, while their performance-enhancing effects in ruminant feeding further augment fenugreek's economic and functional value.

Nevertheless, several challenges impede the wider cultivation of fenugreek. These include low yields, limited advancements in cultivar development, sensitivity to climatic and environmental conditions, vulnerability to water scarcity, and exposure to various biotic and abiotic stressors. Moreover, the insufficient adoption of modern agronomic practices presents a significant barrier. Current research tends to concentrate on specific secondary metabolites, such as diosgenin, which restricts the broader development and utilization of fenugreek as both a food and forage crop.

5.1. Recommendations

- ✓ Breeding and Genetic Diversification: Combining conventional breeding with modern biotechnological approaches to develop high-yielding, high-quality, and environmentally stress-tolerant fenugreek cultivars.
- ✓ Improved Agronomic Practices: Optimizing sowing date, irrigation management, fertilization regimes, and harvest techniques to enhance yield and quality attributes.
- ✓ Expanded Use in Functional Food and Feed: Utilizing the rich nutritional and bioactive properties of fenugreek to explore and

develop functional foods, nutraceuticals, and livestock feed additives.

- ✓ Production in Arid and Marginal Areas: Promoting fenugreek cultivation in low-input systems on marginal lands, capitalizing on its nitrogen-fixing capacity and drought tolerance.
- ✓ Advances in Postharvest and Processing: Scaling up drying, storage, and processing technologies that preserve the nutritional value of both seed and herbage.
- ✓ Market Access and Producer Support: Improving producers' access to markets, lower production costs, and promote the development of value-added products.
- ✓ Enhanced Research and Extension: Supporting multidisciplinary research across diverse ecologies on adaptation, yield, quality, and end-use applications, coupled with effective extension services.
- ✓ By implementing these strategic measures, fenugreek can secure a broader role in agriculture as both an economically attractive and ecologically sound crop, thereby contributing meaningfully to sustainable agriculture and food supply security.

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Chapter 6

FODDER BEET (*Beta vulgaris var. crassa* Mansf.)

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DOI: https://dx.doi.org/10.5281/zenodo.17453394

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1. General Characteristics of Fodder Beet

1.1. Origin of fodder beet

Fodder beet (*Beta vulgaris var. crassa* Mansf.) is an important forage crop belonging to the family Chenopodiaceae, also known as goosefoot, saltbush, or spinach family (Ayaz, 2015). This family comprises 103 genera and approximately 1,400 species worldwide (Yıldırımlı, 2003). In Turkey, the family is represented by 33 genera and 120 taxa. Fodder beet is a biennial plant, completing its vegetative growth in the first year and its generative development in the second year. It includes both halophytic (salt-tolerant) and xerophytic (drought-tolerant) types.

The origin of fodder beet traces back to the Middle East, and it is known to have been used as cattle feed in Ancient Greece around 500 BC (Henry, 2010). It was recorded to have been cultivated as a root crop in Germany and Italy during the 16th century. Today, this plant is widely cultivated in the temperate climate zone up to 55° north latitude across the world (Anonymous, 2006). Beta vulgaris L. ssp. maritima is considered the ancestor of cultivated beet genotypes, including fodder beet, sugar beet, red beet, yellow beet, and chard (OECD, 2001; Al-Jbawi, 2012). This species is thought to have originated as a hybrid of red and white garden beets. Over time, the plant spread throughout Europe and, from the mid-1500s onward, was cultivated across the continent-primarily as animal feed but also consumed by humans during times of famine. According to Wrightson (1889), a writer on fallow and forage crops, by the late 1800s approximately 2.3 million acres in Great Britain were cultivated with turnips, rutabagas, and fodder beet. The crop was introduced to the United States around 1800 and is now widely cultivated in cool climates across North America and New Zealand, as well as in tropical regions at elevations above 600–1000 meters (Oyen, 2004). Fodder beet remained a significant forage crop in livestock production until the early 1900s due to its drought tolerance, long-term storability of roots, high sugar content, quality leafy forage, rich nutritional composition, and higher yield per unit area compared to other forage crops.

Throughout history, beet species have been utilized for both their leaves and roots. The earliest agricultural records indicate that species of Beta were used in Mesopotamia around 2000 BC (Zohary et al., 2012). However, the thickening of the root structure and classification based on different purposes

occurred in later periods. During the Roman Empire, Beta species began to be distinguished botanically. Within this historical evolution, fodder beet stands out for its rounded, tuberous, and radish-like root morphology (Ford-Lloyd et al., 2011).

1.2. Botanical characteristics

1.2.1. Root structure of fodder beet

In fodder beet, the development of the root is primarily influenced by the epicotyl (crown) and hypocotyl (neck) regions. Depending on the variety, these structures can constitute between 25% and 65% of the total root mass, while the actual taproot portion is less developed. The root can extend up to 1.5 to 2 meters deep into the soil. Morphological differences between fodder beet and sugar beet roots include characteristics such as shape, crown and neck morphology, root color, and soil penetration depth. The size of the above-ground root portions (crown and neck) and their penetration into the soil directly affect the drought tolerance of the variety and the dry matter content in the root. In general, the more developed the above-ground part of the root is, the greater the plant's water requirement, and the lower the dry matter content in the root.

Roots are classified by color into categories such as white, pink, raspberry shades, red, yellow, and orange. Furthermore, the roots of fodder beet and sugar beet differ anatomically. In fodder beet, the vascular and supporting tissues form concentric rings that are usually fewer in number (about 5–8), and large parenchyma cells with lower sugar content are found between these rings (UniversityAgro, 2025).

Dalke (1998) reported that fodder beet possesses the widest genetic diversity among the cultivated beet groups. This diversity primarily concerns the morphological traits of the roots and their agronomic potential, focusing on root shape, position in the soil, yield, and dry matter content. According to Dalke, there are significant differences among fodder beet varieties in terms of root yield, leaf yield, and dry matter content. A negative correlation has been identified between root yield and dry matter content among these parameters.



Figure 1. The tuber (root) of fodder beet (Anonymous, 2025a)

Moreover, similar to sugar beet, high-yielding monogerm hybrid varieties have been developed in fodder beet as well. In the development of these hybrids, sugar beet has been used as a genetic resource. Dalke highlighted that one of the main advantages of monogerm hybrids is the increased efficiency of selection, achieved by elevating dry matter content and narrowing the diversity of root types. He also noted that the dominant root form in these hybrids is conical.

Varieties

Fodder beet varieties are classified into several main groups based on root shape:

– Flat globe
– Bag-like (cylindrical)
– Globe
– Conical

Varieties with cylindrical or bag-shaped roots have a distinct neck region, with approximately 20–25% of the root growing below the soil surface. However, due to their weak root system development, these varieties tend to have high moisture requirements. Varieties with a long oval (conical) root form develop about 30–35% of the root below ground, facilitating easier harvesting. Root color is generally light yellow or orange, with internal tissues that may be white or yellowish. This group typically contains 12–15% dry matter and is frequently used in production, although it also requires relatively

high moisture levels. Conical-rooted varieties are mostly classified as semi-sugar types. About half of the root is located below the soil surface. These varieties allow for greater dry matter yield per unit area, with dry matter content generally ranging from 13% to 19%. Additionally, they are compatible with the agricultural mechanization systems used for sugar beet cultivation. Varieties with round root shapes develop most of their root mass above the soil surface. In this type, the dry matter content typically ranges between 15% and 17% (University Agro, 2025).

Unlike sugar beet, fodder beet develops the majority of its root body above the soil surface and contains lower levels of sugar in comparison. Sugar constitutes approximately 50–80% of its dry matter content (Ergün et al., 2011).

1.2.2. Leaf structure of fodder beet

The leaves of fodder beet are large, heart-shaped, and ovate in form, with well-developed petioles. Compared to sugar beet, the leaf surface is flatter and the leaf orientation is more upright. The number of leaves is approximately 20–30% lower than that of sugar beet. In seed-producing plants, seed shedding is significantly lower than in sugar beet. In the second year of growth, the leaves are smaller in size compared to those formed in the first year. The stem is grooved, robust, branched, and may grow vertically or slightly inclined, bearing a few leaves and reaching up to approximately 150 cm in height. The inflorescence is in the form of spiral spikes. The plant is cross-pollinated. The flowers are bisexual, five-parted, greenish in color, and may exhibit reddish or yellowish hues. In the spiral arrangement, 2 to 4 flowers can occur at each node. The fruit is a dry nutlet, which aggregates to form clustered fruit structures (glomerules) composed of 2 to 6 fruits. The weight of 1,000 glomerules ranges between approximately 20 and 30 grams. As in sugar beet, fodder beet also undergoes three main stages of growth and development during the first year (UniversityAgro, 2025).



Figure 2. The leaf of fodder beet (Anonymous, 2025b)

The vegetative part predominantly develops during the first year of growth. The dark green, heart-shaped leaves grow horizontally to capture as much light as possible. After the first year, if the root is not harvested and the plant is exposed to cold, a flowering stalk bearing bisexual flowers develops, reaching a height of 50–80 cm (Henry, 2010). The appropriate harvest time is indicated by the drying, curling, and downward drooping of the leaves. After harvesting, it is recommended to let the roots rest for a period before being fed to animals. Excessive consumption of fodder beet can lead to risks such as abortion in pregnant animals, digestive disorders, hypocalcemia (calcium deficiency), and even death. The leaves can also be used for silage production (Garipoğlu, 2013).

1.2.3. Stem and flowering of fodder beet

Fodder beet does not develop generative structures during its first year; it follows a biennial growth cycle. In the first year, vegetative organs (root and leaves) develop, while in the second year the plant enters the generative phase, initiating flowering and seed production. The flowering stem is erect and branched, with an average height ranging between 60 and 120 cm. The flowers are small and greenish in color, lacking both sepals and petals, and pollination occurs via wind.



Figure 3. The flower and fruit of fodder beet (Anonymous, 2025b)

1.2.4. Seed of fodder beet

Fodder beet seeds are small, hard-coated, and spherical in shape. Although they are resistant to drought and cold, they require a soil temperature between 10–25 °C for germination. Seed yield is lower compared to sugar beet, which is one of the limiting factors for its widespread agricultural adoption.



Figure 4. The seeds of fodder beet (Anonymous, 2025c)

1.3. Climatic and soil requirements of fodder beet

Germination of fodder beet seeds typically begins at ambient temperatures between 2 and 5 °C. Healthy seedling emergence occurs around 6–7 °C, while uniform and consistent seedling development is best achieved at optimal temperatures of approximately 12–15 °C. Although seedlings can tolerate frost down to –4 to –5 °C, some sources report short-term tolerance ranges between –1 to –3 °C or –2 to –4 °C. The leaves of mature plants can withstand short-term early morning frosts down to –6 °C; however, other studies suggest this threshold may be around –3 to –4 °C. Harvested roots that are left uncovered can suffer frost damage at –2 °C, negatively affecting storage quality. The optimum temperature range for leaf and root growth is between 15 and 20 °C. Growth ceases in autumn when the average daily temperature falls below 6 °C. The total accumulated active temperature required during the growing season ranges from 1500 to 2400 °C. Fodder beet is a moisture-demanding crop and thrives under warm and humid climatic

conditions. An annual precipitation of at least 400 mm is required. While it can tolerate short periods of drought, it performs best under moist conditions. As a long-day plant, fodder beet prefers environments with abundant sunlight.

Fodder beet requires high soil fertility for optimal yield and grows best in well-structured, permeable, and loose-textured soils that are rich in organic matter, particularly loamy and sandy-loam soils. Its growth is negatively affected in acidic, nutrient-poor, or waterlogged soils. The optimal soil pH should range between 6 and 7 (UniversityAgro, 2025).

1.4. Distribution and local names of fodder beet

Fodder beet has been referred to by various local names across different regions. These vernacular terms are closely linked to the plant's morphological characteristics, intended uses, and traditional knowledge. Each name provides ethnobotanical insights into how this crop is recognized and utilized within local communities. In Türkiye and surrounding regions, the following local names are used for fodder beet: "hayvan pancarı" and "yem pancarı"

Table 1. Local Names Used for Fodder Beet in Türkiye and Neighboring Regions

Region	**Local Name(s)**	**Description**
Eastern Black Sea	*Fodder beet* *Cracked beet*	Emphasizes its use in animal feeding.
Aegean and Mediterranean	*Fodder beet*	Highlights its application in livestock feeding.
Eastern Anatolia	*Roughage beet* *Goat beet*	Used due to its large and fibrous root structure.
Central Anatolia	*Fodder beet* *Village beet*	Forms obtained through village type selection.
Georgia	*Rapanakhi*	This is the name used for local beet varieties.

Table 2. Other Local Names for Fodder Beet in Europe and Worldwide

Country / Region	Local Name(s)	Description
Germany	*Runkelrübe*, *Futterrübe*	A large-rooted beet type used as animal feed.
France	*Betterave fourragère*	fodder beet
United Kingdom / USA	*Mangel-wurzel* Fodder beet	Refers to the variety cultivated since the 18th century.

2. Cultivation Purposes and Nutritional Value of Fodder Beet

2.1. Cultivation of fodder beet

The most suitable soil texture for fodder beet cultivation is light to medium; it does not perform well in soils that are excessively clayey, sandy, stony, or gravelly. The highest yields are obtained in regions with a long growing season (120–150 days) (Gülümser, 2024). The optimal sowing time for fodder beet is April–May in areas where sugar beet is cultivated, and September–November in temperate regions. The seeding rate is calculated as 1 kg per decare when using a seed drill and 2–3 kg per decare when sowing manually. Due to the very small size of fodder beet seeds, the recommended sowing depth is 2–3 cm. At planting, 5–10 kg of phosphorus per decare should be applied along with a total of 15–20 kg of nitrogen, half of which is given at sowing and the remainder following the first hoeing. Consecutive cultivation of fodder beet on the same field for two years is not recommended (Gülümser, 2024).

When the plants emerge and reach a height of 3–4 cm above the soil surface, the first hoeing and thinning operations are carried out. Fodder beet should be sown with row spacing of 40–45 cm and plant spacing within rows of 30–35 cm. Irrigation is essential in areas with insufficient rainfall. Especially in arid regions, the crop should be irrigated 4–5 times during the growing season. A large portion of the fodder beet tuber develops above the soil surface, making harvesting relatively easy. The harvest date varies depending on the region and sowing time. With proper care, yield can reach up to 10–15 tons per decare.

2.2. Usage areas of fodder beet

Compared to other forage crops, fodder beet produces a notably high yield per unit area (10–15 tons per decare), which also reduces the overall cost of production (Acar et al., 2020). Both the leaves and tubers of the plant are used in animal feeding (Sakr et al., 2014), and its ability to provide abundant and high-quality forage during periods when pastures and meadows dry out or become insufficient makes it particularly attractive (Erdoğdu et al., 2011). In Europe, soft-stemmed varieties of fodder beet are used directly for grazing. Ease of ensiling and high energy content, which contribute to increased milk and meat production, are among the most important advantages of this crop (Gülümser, 2024). The plant can also be utilized as silage, a practice common in countries with advanced livestock industries. Both the leaves and tubers of fodder beet are highly suitable for silage production; however, the tubers need to be chopped to a certain size for this purpose. The high dry matter yield and ease of storage further support its preference as silage (Güleş, 2009; Gülümser, 2024).

Fodder beet is a suitable feed for dairy cows and fattening cattle, with a recommended maximum daily allowance of 30 kg per animal (based on live weight). Excessive consumption may lead to a decrease in milk fat content and result in butter with a firm consistency. For fattening sheep, a daily allowance of 3–4 kg per head is advised, while other sheep should receive about half of this amount. However, since fodder beet is low in protein, minerals, and vitamins, rations should be supplemented with feeds such as legume hay, bran, and oilseed cakes (Garipoğlu, 2013). With its high yield and quality potential, fodder beet represents an important source of roughage.

2.3. Nutritional value of fodder beet

Fodder beet is a biennial crop cultivated for its high productivity and nutritional qualities. It serves as a valuable feed resource in animal nutrition (Enchev and Bozhanska, 2024). The palatable and easily digestible nature of both the aerial parts and roots makes fodder beet preferred by most livestock (Chatterjee and Das, 1989). Inclusion of fodder beet at certain proportions in the daily diet of dairy animals significantly improves milk quality. Compared to other forage crops, fodder beet yields a substantial amount of dry matter

under suitable growing conditions. Although it is relatively low in dry matter content, its high yield compensates for this deficiency.

The leaves are rich in calcium (Ca), magnesium (Mg), sodium (Na), potassium (K), chloride (Cl), iron (Fe), and manganese (Mn) (Akyıldız, 1983). The chemical composition of fodder beet varies depending on the cultivar and cultivation conditions (Magat and Goh, 1990). The roots contain up to 60% sugars (mainly sucrose), low crude protein content (approximately 10%), and about 12% neutral detergent fiber (Matthew et al., 2011). The aerial parts constitute roughly one-third of the total dry matter of the plant (Clark et al., 1987) and have a relatively high protein content ranging between 11.4% and 15.8% (Nadaf et al., 1998).

3. Contribution of Fodder Beet to Sustainable Agriculture and Food Supply Security

3.1. Importance in terms of natural resource conservation

Considering that feed expenses account for approximately 60–70% of total costs in livestock enterprises, roughage is one of the most critical inputs in animal feeding (Alçiçek et al., 2003). Beyond being abundant and affordable, roughage must also be of high quality and contribute to the sustainability of agricultural systems.

Fodder beet has been cultivated in Türkiye for many years as a forage crop, particularly in dairy farming (Gemalmaz & Bilal, 2016). It is a biennial or annual plant with thick roots and is a rich energy source due to its high sugar content, which also makes it highly palatable for livestock (Karadağ et al., 2014). Fodder beet is an important part of sustainable agricultural systems. It makes an indirect but powerful contribution to food security and supply, both environmentally and through its role in supporting the livestock sector.

Due to its high yield potential and energy value, fodder beet is a strategically important crop in crop rotation systems supporting livestock production. However, challenges such as pest and disease transmission and difficulties in weed management require careful planning. When included in crop rotation, fodder beet contributes to soil recovery and nutrient cycling (Acar et al., 2023). Its deep root system enhances soil structure, improves aeration, and helps prevent erosion. Moreover, the inclusion of fodder beet in

crop rotation provides advantages such as high dry matter yield, use as a winter crop, and overall soil improvement (Turan et al., 2015).

3.1.1. Soil fertility and erosion prevention

Fodder beet, through its deep root system, loosens the soil (Tuğrul et al., 2012), thereby enhancing the infiltration of water and air and contributing to improved soil enrichment. Post-harvest residues, including roots and leaves, are rich in organic matter, which supports microbial activity and enhances soil fertility. This effect is particularly significant in crop rotation systems (Wang et al., 2020).

Although fodder beet is not a perennial or cover crop, and thus its erosion control potential is relatively limited in comparison, it still provides indirect benefits in protecting soil health and reducing surface erosion. Compared to cover crops or perennial plants, although their erosion prevention effect is limited, they provide a protective effect against wind and water erosion by covering the soil surface.

Despite certain limitations in erosion control—such as its annual growth cycle, limited canopy coverage, and the need for deep tillage—fodder beet can still contribute to erosion reduction when appropriate agronomic practices are applied. Its broad leaves reduce surface runoff during rainfall by intercepting raindrops and slowing down water flow, which limits soil particle displacement. Additionally, as the roots develop, they improve soil aeration and structure, facilitating water infiltration and further reducing surface erosion. The residual organic matter in the soil enhances its quality by increasing both water retention capacity and structural resilience (Carter, 2002).

3.1.2. Conservation of water resources

Compared to another energy-rich forage crop such as maize, fodder beet contributes—albeit indirectly—to water conservation due to its ability to produce higher yields with less water (Mohamed et al., 2013). Research has demonstrated that fodder beet exhibits a high level of tolerance to both drought and salinity stress, along with efficient water use. It has been proven that animal beet provides 106% more forage yield than Alexandria clover (*Trifolium alexandrinum*) under stress conditions (Mohamed et al., 2013).

In addition, fodder beet requires significantly less chemical fertilizer compared to silage maize. This characteristic helps reduce the risk of water pollution, offers economic benefits, and supports the preservation of soil structure (Khogali et al., 2011; Abdel-Lattief et al., 2020). Owing to its adaptability to diverse climatic and soil conditions, fodder beet can also be cultivated on marginal lands with low productivity (Dirim et al., 2022). In this way, it contributes to the reclamation of abandoned or underutilized agricultural areas, enhancing the effective use of natural resources such as soil and water.

3.2. Significance in terms of food and feed security

3.2.1. Feed source for sustainable livestock production

Fodder beet is a highly efficient forage crop due to its high energy and low fiber content (Salama & Zeid, 2017). It serves as a valuable alternative feed source, particularly during periods when pastures are dry or insufficient, providing both high-quality fresh forage and root biomass. This productivity helps farmers bridge the forage gap during critical periods, thereby reducing dependence on external feed inputs (Parlak & Ekiz, 2008). Consequently, it contributes significantly to the sustainability of livestock production systems. Moreover, by offering an alternative to monoculture forage crops, fodder beet supports agricultural biodiversity, which is a key component of resilient and sustainable food systems (Ferris et al., 2003).

3.2.2. Reducing the carbon footprint

The local cultivation of fodder beet contributes to a reduction in carbon emissions by decreasing the need for long-distance transportation of feed, especially during periods of forage shortages. By partially closing the roughage gap with locally produced feed, the dependence on imported or transported feed resources is minimized. Additionally, thanks to its broad leaves and rapid growth capacity, fodder beet plays a role in atmospheric carbon sequestration by capturing carbon dioxide from the air. Local feed production also supports food availability, accessibility, and usability—key dimensions of food security—by enhancing resilience in supply chains.

Furthermore, fodder beet is a valuable crop for biogas production. Biogas is a renewable energy source that reduces reliance on fossil fuels and

contributes to environmental sustainability. The conversion of agricultural residues into energy through biogas systems enhances resource efficiency and supports climate-smart agricultural practices.

Thus, fodder beet is not only important for livestock production but also holds strategic value in the conservation of natural resources, sustainable agriculture, and renewable energy generation. Particularly within integrated farming systems, it serves as a component that helps maintain ecological balance while improving economic efficiency.

4. Factors Limiting the Cultivation and Use of Fodder Beet

Fodder beet is among the forage crops with a continuously declining cultivation area in our country. Production quantities over the past decade are shown in Figure 5. This section discusses the obstacles hindering the development of fodder beet cultivation.

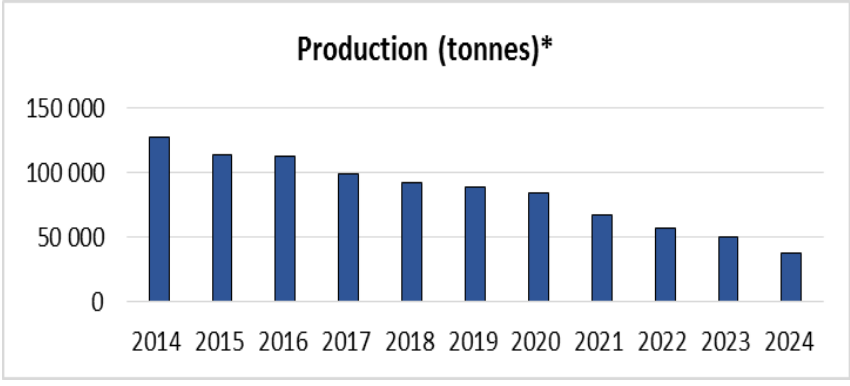


Figure 5. Fodder Beet Production Values in Turkey Over the Last Decade. *Prepared using data from the Turkish Statistical Institute (TÜİK, 2025).

4.1. Climate requirements of fodder beet

Fodder beet demonstrates optimal growth under moist and temperate climatic conditions (Gülümser, 2024). Low temperatures during the seedling stage reduce germination rates, while high temperatures adversely affect root development by impacting metabolic activities. Sensitivity to drought stress is also a significant limiting factor. Water stress inhibits root growth, decreases dry matter accumulation, and consequently reduces the feed value of the crop. Furthermore, sudden temperature fluctuations and extreme weather events

(such as frost) related to climate change can have destructive effects on the plant (Gülümser, 2024).

4.2. Soil requirements of fodder beet

Providing suitable soil conditions plays a decisive role in the yield of fodder beet cultivation. Clayey, sandy, stony, and gravelly soils limit root development. Soils with a pH value between 6.5 and 7.5, rich in organic matter, and well-drained are preferred (Kır, 2002). Fodder beet is also suitable for cultivation in saline soils (Rammah et al., 1984). It can be grown in all soil types where potatoes are cultivated (Gülümser, 2024). Soil compaction impedes both seed germination and proper root development, thereby reducing yield and quality (Aksakal, 2004). Additionally, since beet roots develop underground, stony and compacted soils cause roots to remain shallow, become misshapen, and increase the risk of mechanical damage.

4.3. Sowing and cultivation practices of fodder beet

Sowing depth and density directly affect the yield of fodder beet (Khogali et al., 2011). Excessive sowing density increases competition among plants, while sparse sowing leads to inefficient land use. Optimal sowing density and depth vary depending on regional climatic and soil conditions, and lack of this information often results in application errors at the producer level. Fodder beet should be sown with row spacing of 40–45 cm and intra-row spacing of 30–35 cm. Due to the very small size of fodder beet seeds, the sowing depth should be 2–3 cm (Kır, 2002; Gülümser, 2024).

4.4. Weed control of fodder beet

Weeds limit growth primarily by competing with young plants. Due to fodder beet's low competitive ability during the seedling stage, careful weed control is essential after sowing (Gülümser, 2024). However, the limited availability of recommended herbicides and the labor-intensive nature of mechanical hoeing present disadvantages for producers.

4.5. Lack of mechanization of fodder beet

Fodder beet production requires substantial labor input. Mechanization levels are particularly low in small-scale farms. Insufficient harvesting machinery prolongs harvest time and increases the risk of root damage.

4.6. Diseases and pests of fodder beet

Fodder beet is susceptible to various fungal and bacterial diseases, notably damping-off, tail rot, beet rust, and beet gall disease. The absence of resistant cultivars necessitates the use of agrochemicals, which increases production costs and contributes to environmental pollution. Pests such as aphids (*Myzus persicae*) and beet fly (*Pegomyia betae*) reduce photosynthetic capacity and slow plant development. Chemical control also entails risks of residue and high costs, exacerbating these problems.

4.7. Harvesting, storage, and transportation problems of fodder beet

Due to its high-water content (approximately 85–90%), fodder beet is prone to rapid deterioration after harvest. Prior to storage, tubers must be clean and intact. Improper storage conditions cause root rot, mold, and nutrient loss. Storage temperature should be maintained between 1–5 °C, and tubers must be kept away from light (Kır, 2002). Pile height during storage should not exceed 1.5 meters (Gülümser, 2024). Furthermore, the bulky and heavy nature of the crop results in high transportation costs.

4.8. Economic factors of fodder beet

Fodder beet production is costly in terms of seed, fertilizer, labor, and energy inputs. Since seed yield is lower compared to sugar beet, seed costs are higher. As fodder beet is typically consumed fresh, it is not suitable for long-distance marketing. Moreover, the absence of specialized processing industries restricts the product's utilization to local markets only.

4.9. Agricultural support policies and research gaps of fodder beet

Fodder beet receives limited support under forage crop programs in most countries. The scarcity of direct incentives for producers, coupled with insufficient investment in research and development, negatively affects its cultivation. Additionally, the lack of comprehensive breeding programs conducted by universities and research institutes has constrained the development of new varieties that are high-yielding, disease-resistant, and adaptable to diverse environmental conditions.

5. Conclusion and Recommendations

Despite its high nutritional value and potential as an alternative feed source, fodder beet remains underutilized due to environmental, technical, economic, and political constraints. To mitigate these limiting factors, the following strategic measures are recommended:

- Breeding programs should be supported to develop resistant, high-yielding varieties adaptable to changing climatic conditions.
- Efforts should be made to increase mechanization levels and enhance the efficiency of harvesting and transportation processes.
- Producer training programs must be implemented to standardize agricultural techniques. Additionally, field days, demonstrations, and technical brochures should be employed to disseminate best cultivation practices. Advisory services on fertilization, irrigation, and planting density should be provided to farmers.
- Development and wider adoption of storage and silage technologies are necessary, along with improvements in marketing opportunities.

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Chapter 7

GRASS PEA (*Lathyrus sativus* L.)

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DOI: https://dx.doi.org/10.5281/zenodo.17453416

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1. General Characteristics of Grass Pea

The *Lathyrus* is a large genus consists of 187 species or subspecies distributed in 15 sections in the tribe Vicieae of the Leguminosea (Fabaceae) family (Allkin et al., 1986). The number of annual or perennial species in the genus Lathyrus is 160 (Plitmann et al., 1995). The Mediterranean basin, Western Asia, North America and the warm regions of South America are shown as the areas where the genus Lathyrus shows richness in species and varieties (Jackson and Yunus, 1984). It is indigenous to the temperate zones with a breakdown of 78 species in Asia, 52 in Europe, 30 in North America, 24 each in tropical East Africa, and temperate South America (Asmussen and Liston 1998). In the flora of Türkiye, 58 species (67 taxa) of Lathyrus have been identified, 18 of which are endemic (Davis, 1970). With the latest records, the presence of Lathyrus in the Turkiye flora has reached 79 taxa, 26 of which are endemic (Yıldırım et al., 2023).

Only a few species of *Lathyrus* genus have an economical importance as food, feed and forage (VazPatto and Rubiales, 2014). *Lathyrus sativus* (grass pea), *L. cicera* (chickling vetch) and *L. ochrus* (Cyprus vetch) are the most important species of the *Lathyrus* genus in terms of agricultre (Jackson and Yunus, 1984). Grass pea is generally used in human nutrition while *L. cicera* and *L. ochrus* is for animal feeding as forage and grain feed. The most economically important and widely cultivated *Lathyrus* species is grass pea. Grass pea is an annual cool season legume grown for human food but also for animal feed and as forage.It is characterized by its tolerance to low temperatures, drought, moderate waterlogging and poor soil fertility, as well as its insect and disease resistance and high protein content (Jackson and Yunus 1984; Dixit et al., 2016; Solovyeva et al., 2020; Kumar et al., 2021).

Grass pea has a very long history of cultivation. Kislev (1989) suggests that grass pea has been used as food since the early Neolithic era and that its cultivation first began in the Balkans around 6000 BC. Lambein et al. (2019) state that grass pea seeds found in Balkan excavations date back to as early as 8000 BC. The earliest fossils of grass pea related human consumption date back to the Middle Pre-Pottery Neolithic (8200-7500 BCE) in the Euphrates valley (Ferrio et al., 2012), indicating that grass pea may be among the earliest crops to be domesticated by humans. These data also show that Türkiye,

along with Iraq, is an important center in terms of the origin of grass pea cultivation.



Figure 1. General view of grass pea at the stage of full flowering (a) and pod formation (b) stages.

Grass pea is short and bushy plant (Figure 1). It exhibits great morphological diversity in terms of vegetative characters. Floral characters are much less variable and show a distinct grouping in terms of flower colour (Jackson and Yunus 1984), seed and yield traits (Hanbury et al. 1999). Its characteristic flowers, which can be in various shades such as white, pink and blue (Figure 2). Pods can be rectangular, flat, about 2.5-4.5 cm long, 0.6-1.0 cm wide, slightly swollen and curved on the seeds (Figre 3). The 2-winged structure in the dorsal part is the characters of the pod. The pod has a short beak and contains 3-5 small seeds with 4-7 mm in diameter (Campbell 1997).

Seed coats are white or grey-brown colours (Figure 4). Cotyledons are yellow and yellow tones depending on the genotype



Figure 2. Flower colors seen in grass pea



Figure 3. General view of grass pea pods

Some researchers have divided grass pea samples into two groups, those from the Indian subcontinent and those from the Mediterranean region. There is a relationship between flower colour and seed colour; blue and pink flowers produce grey and brown seeds while white flowers have plain white seeds. Accordingly, Hanbury et al. (1999) reported that Mediterranean grass pea has higher yield potential than Indian grass pea, which has larger and whiter seeds and has been selected for human consumption. Similarly, Gonçalves et al (2024) investigated 182 accessions of grass pea collections, representative of the worldwide-cultivated diversity, and found that in agro-morphological terms, the South Asian and Sub-Saharan African accessions were quite different from the Mediterranean accessions. The Mediterranean and East European accessions were characterized by light coat colour and large seed size, while the Asian and Sub-Saharan African accessions were characterized by dark coat colour and small seed size.

Grass pea is predominantly a self-pollinated diploid (2n=14) plant. Insect-mediated cross-pollination occasionally occurs, up to 30% (Ben Brahim et al. 2001). Flower density, large and bright colour of petals and nectar production attracts bees (Figure 5) and influence the cross-pollination in Lathyrus species (Kiyoshi et al. 1985). When climatic conditions are suitable and pollinator activity is intense, the rate of cross-pollination can be much higher. For this reason, special attention should be paid to isolation in hybridization and breeding studies in peas against out-crossing that may occur from both culture and wild genotypes.



Figure 4. Different seed colors of grass pea



Figure 5. Polynators visiting the grass pea flowers

Grasspea grows in locations with annual precipitation from 300 to 1500 mm and is able to withstand temperature changes. Require cool and humid conditions for vegetative development, and respond better to warm and low rainfall conditions during flowering and fertilization (Atzler et al., 2015). It grow best in areas where average temperature is 10-25 C and annual rainfall is 400-650 mm (Girma and Korbu 2012). It can withstand heavy rains and prolonged drought in the early growth stage, and is tolerant to moderate alkalinity and salinity, but sensitive to acidity. Grass pea grows well in almost all types of loamy to clay loam soils, but its cultivation is common in heavy clay soils (Chen et al., 2010). It thrives in environments including at sea level up to 1200 m in India and 1700–2700 m in Ethiopia (Atzler et al., 2015; Butler et al., 2019).

As in most of the world, grass pea has the greatest economical importance and is widely cultivated in Türkiye. In the Central and Western Black Sea Region, grass pea was cultivated as a forage and pulse until the 1980s (Başaran et al., 2007). Today, grass pea is cultivated in Türkiye to meet household consumption mainly in the inner Aegean and southeastern regions (Başaran et al., 2019). Until about 50 years ago, L. hirsutus was cultivated as a forage plant (Tosun 1974) and L. odoratus as an ornamental plant (Davis, 1970) in Türkiye.

Grass pea has good tolerance to cold during germination and early development. Therefore, it can be planted in early spring. In Central Anatolian conditions, the vegetation period can be around 90-120 days in spring sowing. There may be a decrease in yield in late planting in spring. Grass pea responds well to rainfall during early seed filling, but heavy rainfall promotes vegetative development and prolongs flowering and seed maturation

processes, and also causes the plant to lodge. Excessive rainfall during this period can negatively affect seed quality and cause difficulties in harvesting. In places where the winters are not harsh, grass pea can be planted in the outumn. However, in the fall planting, spring rains promote vegetative development and may cause a more heterogeneous and long generative period, moreover, intensive vegetative development may decerease the seed yield. Therefore, it can be recommended that grass pea is to plant in coastal areas and rainy temperate regions after the winter. This reduces the risk of lodging and is more advantageous in terms of seed yield. As a result, in Türkiye's ecological conditions, it can be recommended to grow grass pea for forage in coastal and rainy regions and for seed in inland regions.

Grass pea known different local names in Türkiye; mürdümük (common uses), culban (in East and South Esat Anatolia), fasıl (in Inner Eagean) and feslek (in Middle Black Sea). These different local names support the finding that grass pea cultivation has a long history in Türkiye. Türkiye is located between the Balkans and the Euphrates Valley where the earliest examples of grass pea cultivation were found. Türkiye may have been influenced by both centers, so it is possible that grass pea genotypes grown in the country exhibit the characteristics of both regions. Morphological differences observed in pea plants grown in Türkiye confirm these findings. Basaran et al. (2013) determined white, pink and blue flower colors and cream and brown seed coat colors on fifty-one landraces collected from all over the Türkiye and based on this; they reported that Türkish grass pea landraces have both Mediterranean and Indian subcontinent group characteristics, but mostly Indian group origins.

2. Cultivation Purposes and Nutritional Value of Grass Pea

2.1. Cultivation purposes

Grass pea is grown worldwide as forage and seed for animal feeding, as green manure, and as pulse or vegetable for human consumption. In the past, grass pea was consumed in almost all continents, today it is an almost entirely forgotten plant in many countries or produced in very small quantities mainly as fodder. However, it is still grown on 1.5 million hectares globally, yielding 1.20 million tonnes, mostly in South Asia and Sub-Saharan Africa, with a decline in Mediterranean environments (Rubiales et al., 2020). Grass peas are

currently grown in many regions of southern, central, and eastern Europe, as well as in the Mediterranean Basin, Iraq, and Afghanistan (Bishoi and Khetarpaul, 2013). It is a valuable crop in Bangladesh, India, Pakistan, Nepal, and Ethiopia for human consumption (Campbell 1997) and commonly grown as a fodder crop in Australia, Europe and North America (Siddique et al., 1999). Its association with lathyrism is caused grass pea to have a negative reputation for human nutrition (Lambein et al., 2019).

Grass peas are still popular in several European countries (Spain, France, Portugal, Italy, and Poland), Africa (Ethiopia), and South Asia (India, Bangladesh, and Nepal) for various dishes, including cooking, boiling, roasting, making into drinks or sauces, and eating uncooked seeds(Lambein et al., 2019; Knez et al., 2024). Its consumption as food varies by country and region and includes special consumption types. Dry grains are generally used to make soup and to make bread by grinding them into wheat flour in certain proportions, while fresh leaves, unripe pods and grains are used as salad, vegetables and snacks (Kumar, 1997). In Ethiopia, the immature seeds of grass pea are used green (Eshet), mature seeds are boiled (nifro) or roasted (kollo), and also in the production of traditional sauces (shiro-wot and kik wot) and local beverages (areke) (Yegrem et al 2024).

2.2. Nutritional value

Grass pea is the cheapest source of protein for millions of people who do not have a balanced diet and do not have access to or prefer animal products. The protein concentration is 17.7-49.3%, which is higher than other legumes such as dry peas, broad beans or lupins (Pastor-Cavada et al., 2011; Rizvi et al., 2016), but lower than those of soybean (Ravindran and Blair 1992). It contains sufficient amounts of 17 amino acids, especially lysine, compared to other legumes or cereals (Yang and Zhang, 2005) but is limited by low levels of sulfur-containing amino acids (methionine and cysteine) and tryptophan. (Pastor-Cavada et al., 2011). With this amino acid spectrum, it is a complementary product to most cereals that are rich in sulfur-containing amino acids but poor in lysine.

Besides their rich protein content, grass pea seeds constitute a valuable source of energy components, dietary fiber and many mineral elements such as zinc, copper, sodium, magnesium and calcium (Pisulewska et al., 1997;

Kasprzak and Pzedzicki, 2008). Grass pea is a unique dietary source of the non-protein amino acid L-homoarginine (Rao et al., 1964), making it a functional food important in the treatment of problems such as cardiovascular diseases and tumors (Lambein, 2000; Llorent-Martínez et al., 2017). Homoarginine is catabolized into the vasodilator hormone nitric oxide which has benefits on cardiovascular health (Rao, 2011). In addition, grass pea seeds are a rich source of a number of proactive non-nutrient food components such as protease inhibitors, tannins and neurotoxins, especially β-ODAP, but this content may limit the consumption of seeds, especially in raw form (Grela et al., 2000).

Grass pea cultivation has a history of thousands of years in Türkiye. However today it is remained a underutilized crop and is grown as forage, feed and rarely as food to meet household consumption. It is consumed by humans in soup, pilaf, as a snack, and in mixtures with some other foods. Muğla is also a province where garass pea soup is widely consumed (Figre 6 a). *Lathyrus ochrus* are also consumed in Bodrum-Muğla. *L. oochrus* is known locally "Gambilya" and "Bodrum baklası" and, its seeds are used making fava, a traditional appetizer (Figure 6 b). It has been also reported that *L. clymenum* grown Datça- Muğla for human consumption (Başaran et al., 2019).

In Türkiye, over the last 50 years, grass pea cultivation has decreased significantly and been abandoned completely in many region, probably due to the spread of other alternatives such as vetch, lentils and chickpeas which can be grown in the same ecology and are more amenable to mechanization and are more economical (Başaran and Acar, 2013). According to the records of the Ministry of Agriculture, grass pea was grown for forage and feed purposes in 1540 hectares of land by 1045 farmers in 160 villages in Denizli, Nevşehir and Elazığ provinces in Türkiye in 2004 (Firincioglu et al., 2004). After the 2000s, within the scope of the state's forage crop support policies, the grasss pea cultivation area increased greatly and reached approximately 24,300 ha (1,270 ha for seed, 23,030 ha for feed) (TUIK, 2014), but it tended to decrease again in the following years. Grass peas still receive little attention in Türkiye and are cultivated using only landraces in eleven provinces across the country (Adıyaman, Burdur, Bursa, Çankırı, Denizli, Elazığ, Kütahya, Malatya, Nevşehir, Samsun, Uşak) (Başaran and Acar, 2013; Başaran et al., 2016). As

of 2024, there are a total of 7 registered grass pea varieties in Turkiye.However, there is no evidence regarding their trade and use in production.

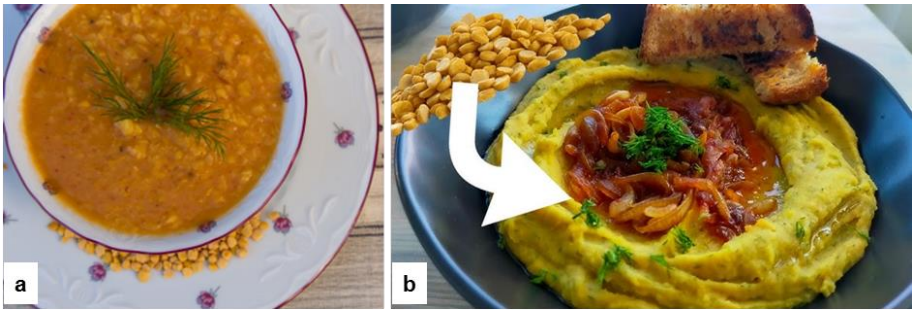


Figure 6. Traditonal grasss pea foods in Türkiye; (a) Grass pea soup, (b) Gambilian fava making from *L. ochrus* seeds.
a: https://www.kulturportali.gov.tr/arama/Mu%C4%9Fla+mutfa%C4%9F%C4%B1
b: https://www.youtube.com/watch?v=lZDBC3UwEOk

Grass pea can be grown for herbage in coastal areas, but seed production is more suitable in the arid inner regions of Türkiye. Since it is sensitive to cold, it can only be grown as a summer crop in inland areas. There are several crop rotations in which pea can be successfully applied. It can replace fallow, especially in arid regions where cereal-fallow cropping is the main pattern. In coastal regions with a temperate climate, it can be included in the rotation as a winter intercrop (Firincioglu et al., 2004). In Türkiye, grass pea and common vetch are largely similar in terms of growing conditions and ecological requirements and their uses as forage crops, that is, these two plants compete in terms of finding a place in the field and being preferred. Compared to common vetch, grasspea is more resistant to drought, requires less input, and has a higher grain yield and nutritional value, which are the reasons why it is preferred by farmers. Unlike many legumes, pod shattering, which is a major problem for seed harvest, is absent or at a very low levelproviding a great advantage in seed production (Başaran et al., 2011).

3. Contribution of Grasss Pea to Sustainable Agriculture and Food Supply Security

Many projections show that world food consumption will double by 2050 due to population growth, economic development and increased prosperity. However, climate change and associated environmental stresses are hampering agricultural productivity and food security (Gonçalves et al., 2022). In addition, the decline in natural resources, environmental pollution and the increase in production costs also pose significant threats to agricultural sustainability. This situation increases demand and interest in environmental-friendly agricultural practices and climate-resistant crops.

Grass pea is an environmentally successful and resilient legume with promising properties for food and nutrition security (Yegrem et al., 2024). Grass pea is a multi-purpose, hardy and climate-smart legume crop which has favorable characteristics, including very high nutritional value (Solovyeva et al., 2020), nitrogen fixation ability (Lambein et al., 2019), tolerance to temperature extremes (Dixit et al., 2016) and to moderate water logging (Solaiman et al., 2007), fertility in poor soil (Kumar et al., 2021). Grass pea is an excellent low-input and cost-effective crop that can be grown without irrigation or fertiliser, and is more resistant to insects than most other legumes (Campbell, 1997). Grass pea is able to thrive in agricultural conditions and marginal areas that are unsuitable for other common crops. Due to its wide adaptation to different soils and climates and with relatively low input requirements, it is considered a model crop for sustainable agriculture and serve as a valuable alternative crop for diversified cropping systems on marginal lands (Vaz Patto et al., 2006). When other crops fail due to adverse weather conditions or natural disasters and all other food sources are destroyed, it can become the sole source of food, especially for the poors, and can sometimes be a life-saving emergency food source for millions of people (Girma and Korbu, 2012; Yegrem et al., 2024). Therefore, it is viewed as an "insurance crop" (Mahapatra et al., 2020).

Grass pea is an annual cool-season legume that attracts attention all over the world with its high adaptability and tolerance to stress conditions, especially drought (White et al., 2002). It grows with as little as 250 mm of annual precipitation and it is typically the last surviving plant in drought times (Tekele-Haimanot et al., 1990; White et al., 2002) It is also resistance to many

diseases and pests compared to other legumes (Tiwari and Campbell 1996). Grass pea may be considered as the most important legume in agricultural systems in drylands (Calderón et al., 2012). It has higher water use efficiency compared to other legumes (Siddique et al., 2001) due to some morphological and physiological drought tolerance traits such as narrow leaves, winged-edged stem, deep and extensive root system (Lambein et al., 2019). These traits enable grass pea to extract significant amounts of water from various soils and tolerant to terminal drought. However, water scarcity, especially during the post-flowering period, can significantly reduce its growth and seed yield (Calderón et al., 2012; Kong et al., 2015).

It has remarkable yield stability compared to other legumes under mild and severe drought conditions (Silvestre et al., 2014). Seed yield in gras pea shows significant variation with the effects ecology and genotype. Looking at studies around the world; seed yields have been reported as 0.42 to 3.86 t ha^{-1} in Italy (Piergiovanni et al., 2011); 2.87 and 2.93 t ha^{-1} in Poland (Ksıężak and Bojarszczuk (2020), 1.32 to 1.80 t ha^{-1} in India (Campbell, 1997) and up to t ha^{-1} under very favorable conditions in Ethiopia. In trials conducted throughout Türkiye, grass pea seed yield was reported to be between 1.14-3.10 t ha^{-1} (Karadağ and Yavuz, 2010; Sayar and Han, 2015; Başaran et al., 2016; Tenikecier, 2020).

Grass pea is grown as roughage and is very nutritious for animals with the protein content of 17% (Rizvi e t al. 2016) and 22.30-25.78% (Özyazıcı and Açıkbaş, 2023). It is grown alone and in mixtures with small grain ceraeals for roughage. Dry matter yield was 4.40 t ha^{-1} in pure grass pea and it increased to 10.4 t ha^{-1} in "60% graas pea + 40% Wheat" intercropping (Atis and Acikalın, 2020). In Iranian conditions, the hay yield of grass pea was 9.76 and 4.71 kg ha^{-1} in autumn and spring plantings, respectively (Zahra et al., 2025). Grass pea is also suitable for silage making as alone or intercropped with cereals (Başaran et al., 2018; Azak and Gülümser, 2025; Sezer and Gülümser, 2025)

Grass pea offers an alternative to other protein-rich legumes such as peas and beans which need better growing conditions (Piwowarczyk et al., 2017). It is also capable of highly efficient nitrogen fixation with the annual rates of up to 124 kg/ha (Schulz et al., 1999). So it is an extremely effective product in increasing soil nitrogen, especially in dry conditions. Grass pea is

an excellent green manure, produce large amounts of biomass, and add significant amounts of nitrogen to the soil when ploughed into the soil (Jeromela et al., 2017). In this way, contributes to increasing the organic matter and nutrient content of the soil, improving crop productivity and reducing fertilization costs.

4. Factors Limiting the Cultivation and Use of Grass Pea

Althought grass pea environmentally successful and robust legumes with major traits of interest for food and nutritional security, its cultivation has not been videsperded wordwide.With the emphasis on adaptation to climate change and the increasing demand for plant-based protein diets, grass pea, an important legume plant, has begun to gain importance in recent years (Kumar et al., 2021). However, it is still an underutilized crop worldwide. Of course, there may be different reasons for this on a local basis, but the most important and globally valid reason is its B-ODAP content. Grass pea has a reputation for being toxic due to its β-ODAP content. Even its cultivation has been banned in some countries in the past due to its consumption being linked to neurolathyrism (Lambein and Kuo, 2009).

Lathyrism, a neurodegenerative disorder in humans and animals hypothesized to be caused by a neurotoxin, β-N-oxalyl-1-α,β diaminopropionic acid (β-ODAP) present in the plant. Lathyrism is an upper motor neuron disease, characterized by lower limb paralysis after consumption large quantities of seeds for several months (Barceloux, 2009). β-ODAP is found in all parts of the plant and its amount changes depending on the growing stage. It is found mainly in seedlings and seeds, and less in other tissues. Accordingly; β-ODAP is found in high amounts in the seedling period, its rate in the vegetative parts decreases with growth and disappears at harvest maturity. It decreases in the pod with maturation, and in the seed, it is at high levels in all seed-filling stages (Zhao et al., 1999; Çopur Doğrusöz et al. 2022). β-ODAP content in the seed can vary from 0.2 mg to 24 mg g^{-1} (Kumar et al., 2011) with the strong effect of genotype x environment interaction (Fikre et al., 2011). For safe consumption, daily β-ODAP intake can be as high as 2 g when consumed with antioxidant-rich foods or cereals (Lambein et al., 2019). In the same varieties, β-ODAP levels have been reported to increase or double depending on the stress conditions. Drought

conditions, excessive iron or cadmium presence, and zinc deficiency can promote β-ODAP synthesis (Liu et al., 2017). Therefore, it may be possible to reduce the β-ODAP content by selecting appropriate soil conditions and effective fertilization.

Grass pea is a valuable alternative crop for diversifing cropping systems (Vaz Patto et al., 2006), sustainable agriculture and development especially in areas with difficult growing conditions and adverse climate. However the presence of β-ODAP has resulted in its failure to achieve the status of a major crop globally (Vaz Patto et al., 2006). Therefore there is a strong need to breed safe grass pea varieties with low β-ODAP contents and high seed yield. The amount of β-ODAP varies in gras pea varieties and has been reduced to less than 0.1% with hybridization (Barone & Tulumello, 2020; Quintieri et al., 2023). The target of breeding zero β-ODAP contents is tedious and has not been achieved yet (Kumar et al., 2011).

The presence of β-ODAP has led to a decrease in interest in the plant and a lack of breeding efforts. Therefore, sufficient genetic improvement has not been achieved in grass pea, and productive and high-quality varieties have not been developed (Knez et al., 2024). However, the negative perception about grass pea has largely faded in recent years and the plant has been widely accepted as a health food (Kumar et al., 2021). In parallel with these developments, agronomic improvements and technological supports in cultivation can help unlock the potential of grass pea as a valuable crop for food security and sustainable agriculture (Solovieva et al., 2025). In this context, the development of varieties with low β-ODAP content is vital to both realize the true potential of peas and ensure their continued role in providing food and nutritional security to many low-income communities (Rizvi et al., 2016). In addition to developing toxin-free or low-toxin varieties, food processing techniques are also effective in reducing toxicity.Long-term and excessive consumption of grass pea, especially the green parts and unripe seeds as raw should be avoided (Yegrem et al., 2024). Cooking and heat treatments can significantly reduce β-ODAP content. Barpete et al. (2021) reported that β-ODAP decreased by 70%, 30% and 14% after boiling, microwave cooking and autoclaving processes, respectively. Cooking and heat treatments can significantly reduce β-ODAP content. Barpete et al. (2021) reported that β-ODAP decreased by 70%, 30% and 14% after boiling,

microwave cooking and autoclaving, respectively. The same authors determined that these processes also increased the protein content by 4.99%, 3.50% and 2.49%, respectively.

There is no case of lathyrism in scientific records in Türkiye. Moreover, there is no negative experience or opinion regarding grass pea consumption in the Turkish society. One reason for this can be that this crop is not used intensively in Türkiye. Another reason may be the low β-ODAP content in Türkiye origin grass pea genotypes. In fact, previous studies have shown that the majority of grass pea genotypes cultivated in Türkiye have low β-ODAP content that below the recomended limit (0.22%) for safe consumption (Başaran et al., 2011; Başaran et al., 2013; Onar et al., 2014; Yıldırım et al., 2023). Aletor et al. (1994) examined the β-ODAP content of genotypes worldwide and found the lowest values (0.02-0.07%) in those originating from Türkiye, Cyprus and Syria.

5. Conclusion and Recommendations

In recent decades, global warming and the increase in climatic anomalies have increased interest in underutilized crops that are tolerant to drought and other environmental stressors.

Grass pea is one of the underutilized crops and can be an important complement to sustainable food and feed production. This annual legume stands out with its three main characteristics: its productivity, drought resistance and high adaptability, including to marginal soils. However, the world is not taking full advantage of the agricultural potential of this plant. The most important reason for this is that the plant is associated with a motor nervous system disease called Lathyrism, which is seen in humans and animals. Lathyrism is caused by β-ODAP, a non-protein amino acid, and occurs especially with the intense and long-term consumption of grass pea seeds. While developing varieties with low B-ODAP content is an important and permanent solution, avoiding intensive consumption and consuming it together with different foods is also extremely effective to avoid toxic effects. Apart from this, appropriate fertilizer and stress-reducing practices will also be beneficial in grass pea cultivation.

In Türkiye, no negative situation has been reported in human or animals related to grass pea. In fact, when the agricultural production pattern, rich

food sources and nutritional habits in Turkiye are taken into consideration, this is quite understandable. There is no information in Turkiye about the intense consumption of the grass pea in the past or a situation that may require this. Also Turkiye origin gras peas are genarally low B-ODAP compared to world accessions. It means that there is no serious obstacle for the widespread of the grass pea in Türkiye. So, with effective broadcasting services, a serious improvment can be achieved.

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Chapter 8

JERUSALEM ARTICHOKE (*Helianthus tuberosus* L.) (TOPINAMBUR)

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DOI: https://dx.doi.org/10.5281/zenodo.17453494

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1. General Characteristics of Jerusalem Artichoke

Taxonomy

Kingdom: Plantae
Subkingdom: Tracheobionta
Super-division: Spermatophyta
Division: Magnoliophyta
Class: Magnoliopsida
Subclass: Asteridae
Order: Asterales
Family: Asteraceae (Compositeae)
Genus: *Helianthus* L.
Species: *Helianthus tuberosus*L. (Kays and Nottingham, 2008)

Jerusalem artichoke (*Helianthus tuberosus* L.) is a North American native. Grown as an annual, it is a perennial of the *Asteraceae* (Compositae) family. The tubers are harvested in the early winter when the tops die off. There are numerous cultivars, and the location of production determines which cultivar is chosen. The Jerusalem artichoke is a plant with deep roots. It also features a fringe at the bottom right and strong side roots. Most of the roots are dispersed between 60 and 80 cm, though some can reach a depth of 2 meters. Near the soil's surface is where the great majority of the roots are located. Its average stem length is 200 cm, with a range of 150 to 300 cm (Anonymous, 2011a). Early types have shorter stems. The essence's interior is covered in stalks. The beginner's stem is green, and the neck is hairy. At later times, the color of the plants changes to green-gray or green-brown. The average neck diameter is 3 cm, with a range of 2 to 5 cm. These nodes may give rise to leaves, and the nests of these leaves may give rise to branches. The plant grows and produces more than its branching rate when it is kept and nourished properly. The number of branches increases with sparse planting. At the end of each branch, there is a flower. Plants have oval (egg-shaped) leaves at the lower parts and heart-shaped leaves at the upper parts. Its petiole is long. The leaves are hairy and have toothed edges. It is green or light green in colour. Jerusalem artichoke blossoms are formed on a plate, with a fleshy lower part of the disc structure. There are sterile yellow leaves on this disc and on the edges of the large flowers. They are in two rows around the disc. There are real seeds that find fertile flowers in the middle part of the disc. The

number of seeds is about 50-150. The seeds may be formed with their pollination. Insects, especially bees, are the most effective pollinators of this plant. Jerusalem artichoke may be a self-pollinating and cross-pollinating plant. The tubers of Jerusalem artichokes grow in the soil similarly to potatoes. Tuber diameters range from 1 to 9 cm, which is a highly variable range. Small tubers weigh two to three grams, while large tubers weigh in the range of 200 to 300 grams (Figure 1). They weigh between 60 and 80 grams on average. They have radically different shapes. Tubers may take on asymmetrical shapes. The colors of bark include rose, yellow, light brown, red, and white. Features are determined by the color of the tuber, and the shape of the bark is thin (İlisulu, 1986; Er, 1984; Özünlü, 2002; Acar et al., 2011).

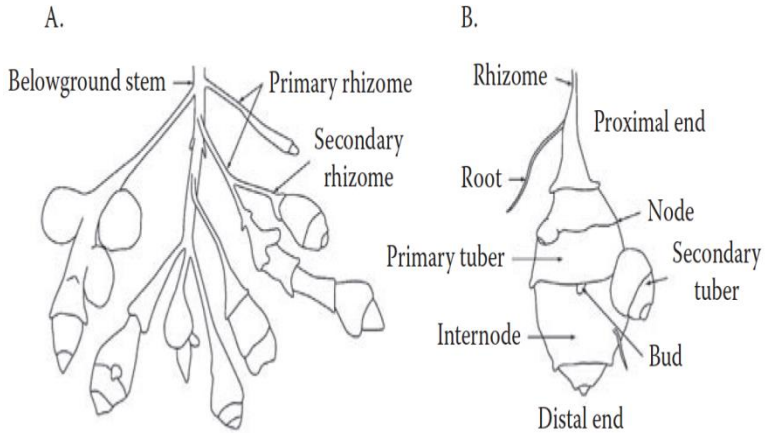


Figure 1. (A) General morphology of the belowground stem, rhizomes, and tubers of a small Jerusalem artichoke plant. (B) External morphology ofa tuber (Kays and Nottingham, 2008).

Table 1. Characteristics of three topinambur varieties (Bassam, 2010)

Characteristic	'Bianka'	'Waldspindel'	'Medius'
Growth height	Low	very high	very high
Ripeness	very early	Middle	late
Tuber size	very large	Large	Middle
Dry matter (%)	19.27	26.59	24.33
Fructose (%)	10.67	17.90	16.24
Total sugar (%)	13.7 I	20.80	19.50
Tuber yield (t/ha)	49.67	61.42	62.33
Dry matter (t/ha)	9.57	16.33	15.16

2. Cultivation Purposes and Nutritional Value of Jerusalem Artichoke

Jerusalem artichoke has been used for the purpose of human and animal nutrition, as well as raw material for industry or energy production. Jerusalem artichoke tubers were consumed by the people directly in fresh ways, and it was also evaluated at many places like potato tubers. In particular, the information regarding diabetes care is good (Duke, 1983; İlisulu, 1986). According to Gençkan (1983) and İlisulu (1986), Jerusalem artichokes are good for livestock in three ways: the tops (as green forage and hay and especially for making silage), the tubers alone (either directly or as an additive), and the tubers and tops together. Making silage from Jerusalem artichoke leaves and stalks is the best way to assess them (Table 3). Bingol et al. (2010) investigated the benefits of fermentation and organic matter digestibility as alternative feed sources. They found that adding 5% molasses to silage forage combined with silos of Jerusalem artichokes increased the yields. Jerusalem artichoke can be used for silage alone or used in conjunction with plants such as silage corn, sorghum, etc. Jerusalem artichoke is given to most dairy cows, fattening cattle, and horses. However, it is also used for feeding sheep and rabbits (Morrison, 1948; Bulgurlu and Kilic, 1977). It has many branches with a receptacle formed at the end of each branch in agricultural areas, especially important for beekeeping in terms of late summer blossoming. It has yellow flowers, which are produced as ornamental plants because of their beautiful appearance in some places, too. By-product

of hand pulp obtained after using in industry is a valuable animal feed. 2 tons of pulp were obtained from 10 tons of tubers with 7-9% moisture. Its pulp is particularly rich in carbohydrates and protein (Table 1). Tubers contain carbohydrates (75-80%) in the form of inulin rather than starch, and inulin can be converted to fructose. Fructose is used in the food industry. Moreover, alcohol was produced from the Jerusalem artichoke. Instead, both tubers and tops of Jerusalem artichoke are used to obtain biofuel. Usages of Jerusalem artichoke are growing, and the organic wastes of the plant are also evaluated as fertilizer (Langer and Hill, 1982; İlisulu, 1986; Özünlü, 2002).

Table 2. Plant productivity and energy content

Crop	Yield (kg-ha)	Calories	
		(kcal-kg^{1})	(kcal)
Jerusalem artichoke	17.843	760[d]	1.356
Sweetpotato	13.493	1.000	1.349
Potato	16.448	710	1.168
Cassava	10.763	990	1.066

(Adapted from Kays and Nottingham, 2008)

2.1. For Human Nutrition:

The fresh tubers of Jerusalem artichokes can be consumed freshly right away. The fresh tubers have an appetite-boosting effect when eaten with other foods after being chopped or grated. Fresh tubers made into salads and pickles are tasty. Tubers are regarded as potatoes in many places. Meat can be used as an ingredient in other foods or in a variety of hot dishes. Hospitals and nursing homes have a high demand for Jerusalem artichoke tubers because they are used to making diet food. Tubers that contain "inulin" are used in medicine and are particularly beneficial in diabetic diets. As can be observed, Jerusalem artichokes have nutritional qualities; they are especially high in starch (Table 2, 3), and diabetics should take note of inulin and insulin. Fresh leaves are also eaten as a vegetable, particularly those of certain types. Although there is some oil in the seed, it is currently not economically viable to extract it(İlisulu,1986; Er,1984; Özünlü,2002; Baldini et al.,2004; Duke,1983).

Table 3. Jerusalem artichoke Usage Areas

Agricultural	Tubers and plants	Starch
1. It gives many benefits as an anchor plant. 2. There are many benefits to turning planting. 3. It gives more dry matter per unit area compared to many other plants. 4. However, more starch is achieved per unit area. 5. It gives an advantage inthe struggle with wild plants, diseases, and insects.	1. It can be used for human and animal food. 2. Starch in obtaining raw material in industry. 3. Plant residues are used in animal nutrition utilized in pulp. 4. Factory waste is used instead of fertilizer. 5. Leaves, flowers, and stalks can be used. 6. Seeds are utilized.	1. Glue production. 2. Alcohol production. 3. Dextrin production. 4. Glucose production. 5. Cosmetic Powder. 6. Baby food. 7. Weaving. 8. Some other usage.

(İlisulu, 1986)

2.2. Industrial usage

Jerusalem artichoke tubers contain starch. In addition to being a raw material for the starch industry, starch is consumed in the food industry. Instead of starch, Jerusalem artichokes are good for a lot of different kinds. Among these are the following: the production of alcohol, glue, and adhesive materials used in the yarn and textile manufacturing process to strengthen the material as a hardener and to provide resistance. Sugars such as laevulose and dextrose are produced when starches hydrolyze, and sugar syrup is produced when dextrose is converted. This leads to the use of a range of sugars and sugary pastries (İlisulu,1986; Er,1984; Galindo and Guiraud, 1997).

2.3. As for energy-fuel plant

The stalks are being used as fuel for small towns, villages, and producer farms. Stoves can be used as firing materials, and shelters and bread ovens are useful for heating. The Jerusalem artichoke's stem and tubers are both utilized

as bioenergy sources (İlisulu, 1986; Galindo and Guiraud, 1997; Cheng et al., 2009; Curt et al., 2006). Bianka, Waldspindel, and Medius Jerusalem artichoke varieties yield approximately 3969.85 L/ha, 7447.67 L/ha, and 7086.33 L/ha of ethanol, respectively (Bassam, 2010).

Table 4: Impact of different treated water on the plant parameters measured under advanced and biological treatments

Parameters (%)	Advanced	Biology
Fresh stem weight ratio	37.59	29.07
Fresh leaf weight ratio	42.84	46.45
Fresh root weight ratio	19.57	24.47
Fresh tops ratio	80.43	75.54
Dry plant weight ratio	34.37	38.05
Dry stem weight ratio	34.43	29.05
Dry leaf weight ratio	42.83	44.88
Dry root weight ratio	22.74	26.06
Dry tops ratio	77.26	73.94

(Adapted from Acar ve Dursun, 2010)

The water used to irrigate Jerusalem artichokes comes from the advanced and biological treatment of wastewater from the Beyteks textile factory (Figure 2). *Helianthus tuberosus* L. may be used as human food, animal feed, bioenergy, and as a source of used and wide adaptation capability will be irritated textile wastewater (biological and advanced treatment outcomes, table 4), and the plant yield and the land and the accumulation of irrigation (Acar ve Dursun, 2010).



Figure 2. A view from the study area (Acar ve Dursun, 2010 Org)

2.4. Usage as fodder crop

There are three ways that Jerusalem artichokes can be used in animal husbandry.

1. The stem is used in more than way,
2. Only use of tubers,
3. Both the stems and tubers are used.

Jerusalem artichoke is given to mostly dairy cows, beef cattle, horses, etc. But it can also be used to feed rabbits and sheep. After the stem's loss of viability is eliminated, animal feeding tubes are exploited if the tubes are used. The best ingredients for silage are thought to be the leaves and stems of Jerusalem artichokes. Thick harvesting of plants before flowering is particularly common; this produces good green fodder that can be made into silage or hay (Table 5). Animals may be fed tubers directly as raw feed or in silage. The young calves (4-6 months) are developing well on about 3 kg of silo feed. Horses should receive 10–15 kg of it along with dry grass. Additionally, it is administered in accordance with the guidelines for ruminants (Gençkan, 1983; Bingöl et al., 2010; Duke 1983; Kılıç 1986; Ergül 1988; Akyıldız 1983; Anonymous 2011). In addition, the Jerusalem artichoke's aboveground portion yields a high biomass production and is packed with beneficial nutrients and bioactive compounds. The Jerusalem artichoke's shoot biomass is perfect for making silage because it contains fructo-oligosaccharides, which act as a substrate for lactic acid bacteria during the ensiling process. When the Jerusalem artichoke is ensiled alongside other plants, this might be a benefit. Jerusalem artichokes are higher in difficult-to-degrade substances (ADF, CF, and ADL, table 5) and lower in readily degradable substances (starch, crude proteins, and lipids) than maize (Kintl et al., 2022). Although Jerusalem artichokes' aboveground portions are not eaten by humans, their tops and tubers can be used as fresh animal feed or in feed and silage recipes. Since the tops of the forage crop are regenerated annually from tubers left in the ground, it can be grown as permanent planting. When it comes to animal feed, the leaves are a good source of protein because they are especially high in the amino acids methionine and lysine. Since leaf protein levels decrease as the growing season ends, delaying harvesting may result in lower crude protein levels that are suitable for fodder. In general, when rapid tuber development began, nutrient levels in vegetative structures decreased.

Phosphorus supplementation is advised when feeding Jerusalem artichokes alone, but when combined with grass, they offer ruminants a sufficient level of nutrition. Early in the season, tuber yields are scarce. before flowering, which is the best time of year for top harvesting. To allow tubers to begin filling out, it is advised to harvest later in the season, when there is some foliage loss, if tops and tubers are to be combined in animal feed. Following flowering, the forage's protein content decreases while its lignin content rises. As a substitute forage crop, Jerusalem artichoke tops show promise in cool, humid regions of Northern Europe. In these regions, Jerusalem artichokes with tubers are superior to annual crops, whose establishment may be impacted annually by unfavorable spring weather.

However, in Northern European conditions, successful perennial cultivation requires fertilizer applications. Only the tops of Jerusalem artichokes have attracted attention recently as forage. The production of tops for forage takes advantage of the crop's potential as a perennial, with tubers left in the ground to regenerate the crop, in contrast to most of the food and nonfood applications, which involve cultivation as an annual. In terms of feeding value, Jerusalem artichoke green fodder can be added to ruminant rations, particularly during the summer (Osman 2003). On average, animals that are fed Jerusalem artichoke feed from a very young age are three times healthier than those that are not and do not require antibiotics. In addition to improving the milk's fat and protein content, Jerusalem artichokes boost milk yield by 20–25 percent. On the other hand, it is important to remember the standard safety measures for switching animals to new feed when feeding them Jerusalem artichokes. e. Add a small amount of Jerusalem artichokes to the feeding ration at first, then gradually increase the dosage. Cattle should consume up to 25–45 kg of Jerusalem artichoke silage per day, sheep and goats up to 3–5 kg, horses up to 8 kg, and rabbits up to 0–25 kg. Both large businesses and individual subsidiary farms should use Jerusalem green mass to produce affordable, high-quality feeds. Jerusalem green mass had a dry matter content of 28–29 percent, while tubers had a dry matter content of 23-24 percent. It is evident from the chemical composition that the green mass was primarily composed of sugars and cellulose (Manokhina et al., 2022). As a substitute feed ingredient, Jerusalem artichokes have the same nutrient content and forage yield as premium forage. Animals can be fed Jerusalem

artichoke green mass as silage if needed (Acar, 2023), but it is best to feed them as green forage. The effect on tuber yield was examined after the aerial parts of Jerusalem artichokes were harvested for silage at three distinct developmental stages (a: August 18 (before flowering), b: September 21 (beginning of flowering), and c: October 20 (full flowering)). The control and first-time treatments produced the largest tuber yields (Acar et al., 2011).

Table 5. Comparison of DM, CP, NDF, ADF, and ADL contents in Jerusalem artichoke silages and several main fodder silages (% DM)

Silage	DM	CP	NDF	ADF	ADL
Jerusalem artichoke	30.6	5.1	33.2	27.8	8.1
Yellow maize, normal	33.6	9.3	43.8	21.1	2.3
Barley	35.5	12.0	56.3	34.5	5.6
Ryegrass (annual, vegetative stage)	29.7	16.1	57.8	34.9	4.5

(Adapted from Kintl et al., 2022)

Table 6. Different nutrient yields of Jerusalem artichoke silage and original green mass, kg/da

	Control*		Group I*		Group II*	
	Silage	Original	Silage	Original	Silage	Original
KM	454.8±53.9	535.2±25.9	297.3±61.7	337.0±64.2	694.9±100.5	768.1±80.4
HP	42.80±4.27	56.05±5.09	29.00±6.25	36.31±6.25	69.36±9.16	82.13±9.42

(Adapted from Karslı and Bingöl, 2009)
(*); Plant Density: 70x50 cm (Control), 30x50 cm (Group I), 50x50 cm (Group II)

Pulp from Jerusalem artichokes that have undergone industrial evaluation is useful for animal feed. From 10,000 kg of tubers, 2000 kg of pulp with 7-9 percent moisture was produced. Pulp is particularly high in protein and low in nitrogen extract. Pulp from Jerusalem artichokes is good for the diets of sheep, cattle, horses, rabbits, and poultry. Jerusalem artichokes can be grown in the same spot for many years without needing to be planted to produce food (İlisulu, 1986; Er, 1984).

2.5. Other uses area

It is also used as a shelter because some people use it as insulation for buildings. Following the application of burning ash to the field, it serves as a source of potassium fertilizer. However, it is preferable to use a machine to break up the soil and bury it as organic fertilizer. The Jerusalem artichoke plant has several branches. Every branch has a receptacle. The yellow flowers in this container make a lovely display. Its ability to persist and form multiple containers to store the flowering period over several months makes it a good ornamental plant. It is easy to care for as a flowering plant, resistant to cold and disease, and can be grown in the same spot for many years. Breeding is done with seeds. Seeds don't offer any significant advantages (İlisulu, 1986; Er, 1984; Acar and Dursun, 2011). Jerusalem artichokes should be grown with adequate rainfall or good irrigation; however, depending on their adaptability and salt-affected areas, some locations may need irrigation with saline water or wastewater. Wastewater with accumulated heavy metal residues can grow if it is used to produce bioenergy. It is crucial for the sectors that contribute to the economy because of these factors (Acar and Dursun, 2011; Parameswaran, 1999; Zhao et al., 2008).

Table 7. Nutritional value in dry matter of Jerusalem artichoke tubers (%)

Dry Matter	Crude Protein	Crude Oil	Crude Cellulose	Carbohydrate	Ash	Starch
23	2.0	0.2	1.1	17	1.1	15

(Er,1984)

Table 3. Thefeedvalue ofthe greenpart of Jerusalem artichoke (%)

Harvesting Times	Dry Matter	Crude Protein	Crude Oil	Crude Cellulose	N' Free Main Mat.	Crude ash	Starch Value
Young	17.5	1.9	0.3	5.5	8.1	1.7	7.6
Autumn	30.0	3.0	1.0	6.5	15.5	4.0	11.8

(Akyıldız, 1983)



Figure 3. Different vegetative parts of the Jerusalem artichoke (Acar et al., 2011, Org)

3. Contribution of Jerusalem Artichoke to Sustainable Agriculture and Food Supply Security

Production is being increased due to the following factors: low-quality wastewater or wastewater that can be used with less chance of growing Jerusalem artichokes; the global situation; the ease of production; the advantages of ecological adaptation, yield potential, and the ease of production. Furthermore, gradually, the value of plants will become clearer due to the growing human population, the consumption of the Jerusalem artichoke variety, and the industry of raw materials and energy plants. The benefits and drawbacks of irrigating Jerusalem artichokes, which are used as animal and human feed, with wastewater using biofuels, will help to reduce any remaining hazards.

4. Factors limiting the cultivation and use of the Jerusalem Artichoke

It is best to establish a permanent location when selecting a spot to plant Jerusalem artichokes. These plants are extremely resilient and can be challenging to eradicate once they are established. Artichokes require very little soil preparation and are highly tolerant of harsh soil conditions. They thrive when grown in a mulch made of straw or rotted hay. They effectively compete with weeds once they begin to grow. The soil needs to be properly prepared. It must be devoid of grass and perennial weeds. Compost or manure

additions increase crop growth and soil fertility. Fertility from a typical vegetable garden is sufficient. propagation by tubers; any tiny fragments that remain in the soil after harvest are likely to sprout, causing plants to grow as weeds where they are not needed, because they can be difficult to remove. Spring is the ideal time of year to plant. Cutting the tuber into two or three sections, each with a developing bud "eye," is how it is done. The tubers are then covered with soil down to a depth of 10 cm. Full sun, well-mulched, and arranged in rows with 70 cm apart and 25 cm apart between plants (Anonymous, 2011a). To prevent the tops of Jerusalem artichokes from growing at the expense of the roots, they require a healthy supply of potassium, which can be provided by ash. High nitrogen fertilizers should be avoided. Choose tubers with a diameter of 25 to 35 mm. With two eyes or buds, larger tubers should be divided into pieces of comparable size. An excessive number of buds produces plants with multiple stems and a lot of tiny, challenging-to-prepare tubers. It is best to cultivate tubers in the middle of winter, about 100 mm below the soil, with 450 mm between plants. They can create a practical summer windbreak once they reach a height of two meters or more. Cut off the flower buds because flowering has an impact on tuber size and quality. Although the tubers are typically consumed in the winter, they are ready for use for approximately a month after the flower budforms. If the tubers are stored well in sand, they will keep cool. Applying compost at a rate of up to 50 m^3/ha during the rotation or before planting may be advantageous for crops cultivated on sandy soils. This will help the soil retain moisture, add nutrients, and supply organic matter. Before planting, nutrient analyses of the soil and irrigation water are advised, and one to two analyses of the youngest mature leaves should be performed after planting.

For best results, four to five irrigations might be required. Jerusalem artichokes can withstand dry spells, but regular irrigation yields the best tuber production. To improve weed control when the plants are young, cultivate in between rows. Before the plants reach a height of one meter, weeding should be done. The tubers are now starting to form around the plant's base and shouldn't be disturbed. Most weeds are shaded out by artichoke plants from this stage until they reach maturity. The incredibly hardy Jerusalem artichoke plants fiercely rival weeds. It is advised to cultivate in the early season to minimize emerging weeds. In soil, overwinter tubes thrive. Volunteer

Jerusalem artichokes may therefore pose a significant weed threat to the subsequent crop. Herbicides can be used to eradicate weeds for growth and development to control Jerusalem artichokes in later crops, before other crops.

Table 9. Recommended fertilizer levels for topinambur

Fertilizer	Amount (kg/ha)
Nitrogen (N)	40-80
Potassium (K_2O)	240-300
Phosphorus (P_2O_5)	90-140
Magnesium (MgO)	60-90

(Adapted from Bassam, 2010)



Figure 4. Planting density demonstration (Acar ve ark., 2011Org)

With a few exceptions, harvesting tuber crops is comparable to harvesting potatoes. In contrast to the robust artichoke stems, which continue to grow, the weak potato vine typically senesces before harvest. As they are being harvested, tops, roots, and tubers can be sorted, or they can be dried and then sorted. Artichoke tubers cannot be stored at low humidity levels for extended periods of time because they will wilt and soften considerably more quickly than potato tubers.

5. Conclusion and Recommendations

The plant known as Jerusalem artichokes serves a completely different purpose. It grows easily. These factors necessitate the widespread cultivation of Jerusalem artichokes. The appropriate industry should be consulted to determine areas of use. The world situation and growth potential in the expanding marginal areas, the benefits of ecological adaptation, yield potential, ease of production, and low-quality wastewater or wastewater that can be used with less chance of growing Jerusalem artichokes are the reasons for increasing production. Furthermore, the consumption of the Jerusalem artichoke variety, the industry with raw materials and energy plants, due to the growing human population, suggests that the value of a plant should be better understood over time.

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Chapter 9

LINSEED (*Linum usitatissimum* L.)

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DOI: https://dx.doi.org/10.5281/zenodo.17453704

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1. General Characteristics of Linseed

The Linum genus belongs to the Linaceae family which comprises nine genera and approximately 150 species (Hektor, 1936). Among these *Linum usitatissimum L.* is the only species of significant economic importance, and all cultivated forms fall within species (Kurt, 1996). Although the precise wild ancestor of cultivated linseed remains unknown, the considerable variation observed among its varieties suggests a complex domestication history. It has been hypothesized that the domesticated form may have originated from natural inbreeding of *Linum strictum* in Northern Europe or *Linum perenne* in the Middle East (Richharia, 1962). A study to determine the genetic relationships among four groups encompassing oil and fiber type, winter hardiness, and dehiscent capsule behavior revealed that the evolutionary process among each group occurred at different times and in different ways, independently of each other. The oil-type forms were domesticated earlier stage, non-dehiscent capsule types evolved prior to winter-hardy types, and the genetic basis of winter hardiness was found be more complex than that of capsule dehiscence (Fu, 2024).

Many researchers have reported that linseed has a multicenter center of origin and is generally concentrated in two broad geographic regions (Kurt, 1996). According to this view, the gene center of oil-type linseed forms is considered to be Southwest Asia (India, Afghanistan, and Turkestan), while the gene center of fiber-type linseed forms is the Mediterranean region. However, it has also been reported that some fiber-type linseed forms originated in the Baltic region of Northern Europe, and that these forms later evolved into shorter, more branched, abundantly seeded forms with high oil content in their seeds (Vavilov, 1951). Furthermore, based on the wide variation in linseed species, it has been suggested that linseed's center of origin was likely India, from where it spread to both northern and southern regions, but this view has not been generally accepted (Gill, 1987).

Based on archaeological records, the discovery of *Linum angustifolium* seeds dating back to 8000 BC in Sweden suggests that linseed cultivation dates back to the 8th century BC (Matheson, 1976; Turner, 1987). It has also been reported that linseed was cultivated in Egypt and the Middle East in ancient times, and that linseed oil was used in mummy

production during these periods (Durrant, 1979). Recent archaeological excavations have revealed that linseed was cultivated for various purposes much earlier than currently known. For example, remnants of rope made from wild linseed were found in a cave called Dzudzuana in Georgia during the Upper Paleolithic Age, dating back approximately 30,000 years. It has been reported that linseed samples dated 11,200–10,500 years ago were found at Tell Abu Hureyra in northern Syria, and archaeological finds in southwestern Germany reveal the existence of larger linseed seeds in the early stages of the Late Neolithic period (4000–2500 BC) (Fu, 2024). In 2013, archaeological excavations at Çatalhöyük in Turkey revealed that fabric fragments found in a tomb dating back 9,000 years were woven from the linseed plant (Anon, 2024). These findings suggest that linseed cultivation began much earlier than previously known in Mesopotamia, the intersection of Türkiye, Syria, Iraq, and Iran.

The linseed plant is known locally by different names in different regions of Türkiye. The most commonly used names are keten, ketir, zeyrek, zegerek, zeyerek, bezir, kırbaş seeds, and siyelek (Kurt, 1996; Tozlu and Kılıç, 2011). Linseed is mentioned as *flachs* in Germany, *len* in Russia, *lin* in France, *san* in İndia, *alkitaan* in arabia, *linari* in Grece, *yàmá* in China. The linseed generally appears in two distinct morphological forms. The tall, highly branched forms with long fibers are cultivated for fiber production, while short, partially low-branching forms are used for oil production.

The linseed plant has a taproot system extending to depths of 30-90 cm. The stem is slender and cylindrical, reaching a height of approximately 30-120 cm. The plant is taller, especially in fiber-type linseed varieties. The stem is lined with alternate, lanceolate leaves with pointed tips. The leaf surface is generally hairless. The flower consists of five sepals, five petals, five stamens, and one pistil. The sepals are green, while the petals are blue, purple, and white. In some linseed varieties, the petals are yellow and red (Figure 1).



Figure 1. Flax plant; a) Pre-flowering period, b) Flowering period, c) Mature period, and d) Seeds

Although linseed is self-pollinating, cross-pollination can occur at a rate of 3-5%, depending on insect populations and environmental conditions (Kurt, 2023). The linseed fruit is a capsule consisting of five carpels, each containing two chambers. Initially green, the capsules mature into balls ranging in color from golden to brown. The seed is approximately 4-6 mm long, yellow or brown, and has a shiny surface. The weight of 1000 seeds in cultivated linseed varies between 5-13 grams, depending on the linseed variety, growing conditions, and seed moisture content. The weight of 1000 seeds generally ranges from 7.5-9.0 grams for yellow-seeded varieties and 8.0-10.0 grams for brown-seeded varieties (Figure 1).

A mature linseed plant contains approximately 25% seed, 75% stem, and leaves (Lay and Dybing, 1989). Fiber accounts for 20% of the stem. The oil content in seeds varies between 35% and 45%. The seed also contains 35% husk, 28% to 30% protein, and 6% minerals and ash (Carter, 1993). The edible quality of vegetable oils varies depending on their fatty acid composition and iodine value, which are controlled by multiple allelic genes (Culbertson, 1954).

Linseed is well adapted to temperate climates and can germinate at minimum temperatures, of 4-5°C with optimal growth occuring at 20-22°C (Kurt and Bozkurt, 2006). Seedlings can temporarily tolerate temperatures as low as –3°C. Linseed thrives in full sunlight and grows best at temperatures between 15 and 25°C. However, high temperatures above 30°C during flowering can cause significant damage, making the crop sensitive to both extreme heat and drought. Therefore, linseed is among the plants susceptible to extreme drought and high temperatures. Additionally, excessive humidity increases susceptibility to fungal diseases, particularly powdery mildew.

Linseed can be grown without difficulty in deep-profile, well-drained, light, permeable, sandy-loam soils with a pH ranging from 6.0 to 7.5, with low climate and soil requirements. Acidic and heavily loamy soils are undesirable because they limit linseed growth and development and increase disease risk. The vegetative period for linseed varies between 90-120 days for summer plantings and 180-210 days for winter owing, depending on the growing season.

It is known that linseed cultivation area worldwide was quite limited until the early 19th century. After World War II, linseed production increased, albeit irregularly, overall (Turner, 1987). After 1975, European countries provided significant agricultural support to farmers to expand the cultivation of oilseed crops, including linseed, to meet vegetable oil demand. This support increased farmers' interest in linseed, and linseed cultivation area and production gradually increased until recent years.

An evaluation of the global linseed cultivation area, production volume, and yield data from 2015 to 2023 reveals that global linseed cultivation area has increased, with the exception of 2016 and 2017, while production volume has fluctuated, and yield has generally decreased. Specifically, considering 2022, there has been a 151.81% increase in cultivation area and a 126.29% increase in production volume. However, the positive increases in cultivation area and production volume have not been reflected in yield to the same extent (Table 1).

Table 1. Data on World Linseed Sowing Area, Production and Yield between 2015 and 2023*

Years	Sowing Area		Production Quantity		Yield	
	1000 hectares	Change Rate (%)	1000 Ton	Change Rate (%)	Kg da^{-1}	Change Rate (%)
2015	2987.213	100.00	3149717.39	100.00	1054.40	100.00
2016	2766.763	92.62	2912571.41	92.47	1052.70	99.84
2017	2923.538	97.87	2875299.62	91.29	983.50	93.28
2018	3151.386	105.50	3009258.50	95.54	954.90	90.56
2019	3209.567	107.44	3066741.27	97.37	955.50	90.62
2020	3528.306	118.11	3380822.81	107.34	958.20	90.88
2021	4090.740	136.94	3299999.96	104.77	806.70	76.51
2022	4534.773	151.81	3977902.88	126.29	877.20	83.19
2023	3089.169	103.41	2604121.08	82.68	843.00	79.95

*Anon, 2023.

When the distribution of global flax cultivation area and production by continent is evaluated, the European continent ranks first, providing 46.22% of the flax cultivation area and 49.17% of the flax production. In terms of yield, the Americas rank first, with 1033.10 kg ha^{-1} (Anon, 2023) (Table 2).

The Russian Federation ranks first with 41.76% of cultivation area and 42.24% of flaxseed production.Kazakhstan follows with 23.5% of sowing area and 13.89% of seed production. France ranks first in terms of yield, with 1,921.6 kg ha^{-1}. Turkey, with 24 hectares of cultivation area and 32,000 tons of production, holds a negligible share of cultivation and production among other countries (Anon, 2023)(Table 3).

Table 2. Data on World Linseed Planting and Production by Continent and Country*

Continents	Sowing Area		Production Quantity		Yield (kg ha^{-1})
	Hectare	(%)	Ton	(%)	
Europe	1427676	46.22	1280483.73	49.17	896.90
Asia	1222399	39.57	836052.33	32.11	683.90
America	339739	11.0	384952.33	14.78	1133.10
Africa	90636	2.93	93339.95	3.58	1029.80
Others	8719	0.28	9293.01	0.36	
World	3089169	100.00	2604121.08	100.00	843

*Anon, 2023.

Table 3. Data on leading countries in linseed production and their shares in production*

Country Name	Sowing Area		Production (2023)		Yield (kg ha^{-1})
	Hectare	Share (%)	Ton	Share (%)	
Russia	1290000	41.76	1100000	42.24	852.7
Kazakhstan	726097	23.50	361697	13.89	498.1
Canada	238500	7.72	272736	10.47	1143.5
China	200000	6.47	260000	9.98	1300
India	238731	7.73	166753	6.40	698.5
Ethiopia	82000	2.65	81000	3.11	987.8
USA	64750	2.10	75210	2.89	1161.5
Ukraine	47500	1.54	53910	2.07	1134.9
France	26900	0.87	51690	1.98	1921.6
England	20682	0.67	36194	1.39	1750
Türkiye	**24**	**0.00**	**32**	**0.0**	**1333.3**
Others	153985	4.99	144947	5.57	
World Total	**3089169**	100.00	**2604121**	100.00	

*Anon, 2023.

Turkey is a country with limited linen production capacity. Therefore, Turkey imports significant amounts of linen and linen products each year. Turkey imported approximately 4.3 billion TL worth of linen and linen products in 2024. Of these imports, linseed accounted for 51.3 million TL, linen yarn 1.45 billion TL, and linen textile yarn 2.3 billion TL (Table 4).

Table 4. Turkey's import items and values of linen and its derivatives (TL)*

Linen Import Items	**Value (TL)**
Linseed	51.397.834
Linseed tow and waste	301.098
Linseed oil and its fractions; raw	479.120
Linseed oil and its fractions; other	3.385.027
Linseed yarn	1.448.931.475
Linseed fabric - linen => 85% by weight	2.340.446.666
Linseed fabric - linen < 85% by weight	525.698.592
Total	**4.370.640.029**

*Anon, 2024a

2. Cultivation Purposes and Nutritional Value of Linseed

Due to its durability, breathability, and natural structure, linen derived from the Linum plant has been widely utilized across various sectors throughout history. In the textile industry, linen fibers are employed in the production of garments such as underwear, shirts, trousers, and jackets; home textiles such as tablecloths, curtains, bed sheets, pillowcases, comforters, and towels; and accessories such as bags, hats, and shoes. In the home and interior design sector, it is used in furniture upholstery such as chairs and sofas; and decorative items such as baskets, wall hangings, and painting surfaces. Drom an industrial perspective, linen serves as a lightweight and durable material in the automotive, aerospace, and construction industries, particularly in the production of composite materials. It is also employed in the development of eco-friendly sound and thermal insulation materials, as well as in the manufacture of high-quality, durable paper. In arts and traditional crafts, linen fibers are favored for the production of natural yarns, ship ropes, sails, tent cloth, sacks, and various handicrafts. Moreover, its durability makes it a preferred material for high-quality canvas used in painting (Carter, 1993). (1993; Delorit et al., 1984; Kurt, 1996; Sanahi, 2023).

Traditional linseed oil was not generally used as a cooking oil due to its rapid oxidation and rancidity over time. However, freshly extracted linseed oil is also known to be used in Third World countries as a salad supplement, frying oil, or similar purposes. Linseed oil has been widely used in the production of natural cosmetics such as soaps and creams, and in the paint industry. It has also been used to polish wooden products, particularly the coats of racehorses.

In recent years, linseed varieties with low linolenic acid levels have been bred in Canada using chemical mutagens (Green, 1986). These varieties have been marketed under the trade name Linola (Askew, 1991). Linseed oil, which contains low linolenic acid, is used not only for cooking but also as a frying oil because it oxidizes more slowly. While linseed varieties with these characteristics have not yet been established in production in Turkey, breeding efforts for this purpose are ongoing.

Flaxseed oil is very low in saturated fatty acids such as palmitic acid (%6) and stearic acid ((%5). However, it is high in omega-3 fatty acids,

particularly unsaturated fatty acids such as alpha-linolenic acid (ALA). In fact, the oleic acid content is 20%, linoleic acid content is 15%, and linolenic acid content is 50% (Table 5).

Table 5. Data on the fatty acid composition of linseed oil (*)

Name of Fatty Acid	%	Carbon Number	Symbol
Palmitic	6	16	16:0
Stearic	5	18	18:0
Oleic	20	18	18:1 (n, 9)
Linoleic	15	18	18: 2) (n, 6, 9)
Linolenic	50	18	18:3 (n, 3,6,9)

(*) Röbbelen et al., 1989.

Linseed oil has been reported to exhibit various health benefits including cholesterol reduction, protection aganist breast and colon cancer, and prevention of allergic reactions (Ingerberg and Johnston, 1990). It is also recognized as an effective supplement for weight management, owing to its capacity to support the excretory system and induce a prolonged sense of satiety. Furthermore, by affecting the hormonal system and increasing egg count and quality in women, it has been used in traditional medicine since the time of the Egyptians in the treatment of infertility. Recent studies have also reported that it plays a role in reducing infertility in men by increasing sperm motility (Yuan et al., 2023).

Among the essential minerals contained in linseed oil, potassium, in particular, regulates blood flow in the body (Young and McCabe, 1995). Furthermore, the pulp remaining after linseed oil extraction contains 25-30% protein, 3.5-7.0% fat (depending on the extraction method used), and 5-6% ash (Carter, 1993; Turner, 1987). Linseed meal is rich in protein and fiber but low in lysine (Langer and Hill, 1981). Thanks to its high mineral and nutrient content, linseed meal and bran are considered highly suitable as supplemental feed for livestock, particularly for sheep, cattle, and horses, contributing to balanced nutrition and improved health. In the food industry, linseed flour, when blended with wheat flour at a ratio of 6–8%, enhances the nutritional quality of baked products and imparts a nutty flavor. It is also incorporated as a functional additive in a variety of processed foods, including ready-to-eat breakfast cereals (e.g., corn flakes), biscuits, crackers,

cakes, and soups. Beyond its oil and meal products, linseed straw also hold economic value. Straw contains 12-18% hemicellulose and 2-3% lignin. Making it a viable, alternative raw material for paper pulp production (Marshall, 1990). Additionally, linseed straw is used for energy generation, particularly as a biomass source for heating.

3. The Contribution of Linseed to Sustainable Agriculture and Food Supply Security

Today, fundamental problems such as a rapidly increasing global population, climate change, natural resource depletion, and food waste pose serious threats to agricultural production systems. These developments make future food security even more uncertain and have led to the principle of sustainability becoming a priority in agricultural production (Yuan et al., 2024). One of the greatest challenges for the agricultural sector is to feed a growing population with sufficient and healthy food while adopting production techniques that reduce environmental impacts. In this context, managing the resources used in agriculture in a more efficient and environmentally friendly manner is of great importance. Plants that require low inputs, have minimal environmental impact, and can grow even in marginal soil conditions are among the indispensable elements of sustainable production systems (Von Cossel et al., 2019).

Sustainable agriculture is a production model that aims to prevent environmental degradation, preserve biodiversity, and use natural resources efficiently, while also considering the needs of future generations (Çakmakçı et al., 2023). Food security, on the other hand, is a multidimensional concept that encompasses not only sufficient production but also the continuity, accessibility, and nutritional value of this production (El Bilali et al., 2019). In this context, agricultural crops with high potential for the protection and development of natural resources hold a strategic place in sustainable agricultural policies.

Linseed reduces environmental pressure with its low input requirements for water, fertilizer, and pesticides; it also supports soil fertility with its taproot system and suitability for crop rotation (Biradar et al., 2016) Therefore, linseed cultivation directly contributes to sustainability goals such as preserving soil health, using water resources more efficiently, and

supporting agricultural biodiversity (Cui et al., 2022). Furthermore, linseed plays an important role in the context of food supply security. Linseed stands out as a highly nutritious resource with its rich content of omega-3 fatty acids, dietary fiber, and plant protein. It is considered an alternative and functional food source, especially in regions experiencing malnutrition problems (Goyal et al., 2014). Furthermore, the versatile uses of linseed enable it to participate in a wide value chain, from agricultural production to the food processing industry, in human nutrition, animal feed, and industrial products (Shahada et al., 2024). In these respects, linseed is a strategic plant that can contribute to both the building block of sustainable agricultural systems and the strengthening of food supply security.

Linseed's multifaceted role in sustainable production systems is significant not only globally but also locally. Historically cultivated in Turkey, particularly in the Black Sea and Eastern Anatolia regions, for fiber and oil production, linseed is currently receiving renewed interest due to increased environmental awareness and demand for functional foods. Projects conducted by the General Directorate of Agricultural Research and Policies and various universities demonstrate that significant steps have been taken to protect linseed's local genetic resources and re-evaluate its potential for low-input production. This demonstrates that linseed is a strategic crop not only globally but also in Türkiye, particularly for sustainable agriculture and food security policies.

3.1. Contribution of the linseed to sustainable agriculture

Sustainable agriculture encompasses practices that safeguard ecosystem health, protect natural resources, and maintain long-term productivity. With its agricultural and environmental advantages, the linseed plant offers versatile contributions to the goals of sustainable agriculture (Table 6).

Table 6. Properties of Linseed and Areas It Contributes to Sustainability

Features	Contribution Area
Low water and fertilizer requirements	Protection of water and soil resources
Deep root system	Prevention of soil erosion and soil health
Low pesticide use	Reduction of chemical pollution
Suitable for crop rotation	Agricultural biodiversity and reduction of disease pressure
Drought and cold tolerance	Adaptation and adaptability to climate change
Multi-purpose use	Waste-free production and economic sustainability

3.1.1. Low input requirements and reducing environmental limitations

Linseed is particularly notable for its low water and fertilizer requirements. Its ability to be grown even in arid and semiarid climates contributes to the sustainable use of water resources (Hussain et al., 2019). The limited use of chemical fertilizers and pesticides reduces the risk of soil chemical degradation and helps prevent nitrogen and phosphorus pollution in water resources (He et al., 2024). In a combination of organic and inorganic fertilizers, using linseed meal instead of 50% of chemical fertilizer increased yield by 16.5% and water use efficiency by 13.8% (Li et al., 2023), demonstrating the importance of linseed in supporting both production efficiency and environmental sustainability. Therefore, linseed not only reduces production costs but also provides an environmentally friendly alternative plant that can be used to replace plants highly affected by environmental factors.

3.1.2. Maintaining soil health and preventing erosion

Linseed's taproot system contributes to improving soil structure and increases organic matter accumulation. This plays an effective role in preventing soil erosion while also increasing the soil's water-holding capacity (Kurishbayev et al., 2020). Linseed is also known for its disease-suppressing effect in soil, which helps establish a microbial balance. Therefore, it contributes to maintaining soil biological fertility in the long

term. Its ability to thrive in neutral or slightly alkaline soils demonstrates its adaptability to a range of soil types (Hall et al., 2006; Heller et al., 2015).

Linseed demonstrates phytoextraction potential for heavy metals such as Cd, Pb, and AsWhen used in combination with chelating agents, its capacity to absorb metals and accumulate biomass increases significantly (Saleem et al., 2020). This phytoextraction capability not only aids in the remediation of contaminated soils but also supports environmental sustainability. By contributing to the rehabilitation of degraded areas, linseed plays a strategic role in expanding sustainable production zones and enhancing long-term food security.

3.1.3. Supporting agricultural biodiversity

Monoculture practices in agricultural systems increase ecological risks and threaten biodiversity. The ability of linseed to be grown in different regions and easily integrated into rotation systems increases diversity in production systems and contributes to the preservation of natural balance. Reintegrating linseed cultivation into agroecosystems, away from monocrop-based systems like wheat and barley, promotes soil health and agricultural biodiversity. Based on this understanding, significant work has been conducted in Poland to integrate linseed into modern agriculture and the agroecosystem, considering its significant potential for strengthening low-input agricultural systems, revitalizing local economies, and preventing biodiversity loss (Kiryluk and Kostecka, 2020).

The support the linseed plant provides to bees and other pollinator insects during flowering is also a significant contribution to ecosystem services. In recent years, as sustainability and biodiversity conservation have been prioritized in agricultural production, supporting pollinator insect populations has become a key area of focus. The alternative approach to agriculture with pollinators aims to increase pollinator density and diversity in agricultural ecosystems by planting pollinator-friendly, marketable plants around fields (Sentil et al., 2022). In these practices, planting local, marketable plants such as linseed, coriander, and arugula around linseed fields not only increases productivity by increasing pollination but also contributes to maintaining the ecological balance of agroecosystems.

3.1.4. Role in rotation systems

Rotation systems in crop production are one of the fundamental tools for maintaining soil health, increasing water use efficiency, and sustainably improving productivity. Plants like linseed, which are drought tolerant and have a short growing season, offer significant strategic advantages in rotation systems. Considering that growing linseed in rotation with different crops has positive effects on both soil moisture management and yield, linseed is considered a cornerstone of sustainable production patterns. Indeed, it has been determined that growing linseed in rotation with crops such as wheat and potato in different rotation systems increases soil water storage capacity, improves water use efficiency, and increases grain yield (Cui et al., 2022). In particular, in a potato-wheat-linseed rotation system, despite increasing soil moisture by 17%, water use efficiency was found to decrease significantly in continuous linseed cultivation.

The fact that the highest yield and water use efficiency do not always occur in the same rotation system demonstrates the need to consider both productivity and resource utilization in rotation planning. These findings demonstrate that the inclusion of linseed in rotation systems is strategically important not only for crop diversity but also for sustainable water management and yield growth. Furthermore, it has been determined that using linseed in a four-year rotation system significantly increases soil bacterial diversity and improves the density of beneficial microbial groups compared to continuous linseed cultivation (Gou et al., 2024). This suggests that linseed offers a significant advantage in maintaining soil health, microbial balance, and maintaining ecosystem services.

The integration of linseed into the rotation system has a valuable place in sustainable agricultural practices, not only in terms of macro agricultural indicators such as yield and water use, but also in terms of enriching the soil biological structure and supporting its functionality.

3.2. Contribution of linseed to food supply security

Food supply security is a multidimensional concept that is not limited to access to sufficient food but also includes the sustainable production, nutritional quality, and continuous availability of food. Therefore, food security has four fundamental dimensions: access, quantity, quality, and stability. Linseed has a multi-purpose use as both a vegetable oil and protein source. Therefore, linseed is a strategic crop that can contribute to all four dimensions of global food supply security. Its tolerance to climate change, its ability to grow under diverse agro ecological conditions, and its high nutritional content make linseed a prominent feature within sustainable food systems. Therefore, linseed has the potential to play a significant role in meeting increasing food demand and health-focused consumer trends.

3.2.1. High nutritional value and functional properties

Linseed is a plant source of high nutritional value, containing 30–45% oil, omega-3 fatty acids, especially high levels of alpha-linolenic acid (ALA), 20–25% protein, and rich dietary fiber (28–30%) (Goyal et al., 2022). Its richness in polyphenols called lignans places linseed in the functional food category and provides various protective health benefits (Kajla et al., 2015).

Linseed lowers cholesterol, improves insulin sensitivity, supports gut health, and plays a protective role against cardiovascular disease, type 2 diabetes, and some types of cancer through anti-inflammatory effects (Bhatty, 1995; Cardoso Carraro et al., 2012). These properties make linseed a strategic crop for nutritional security, especially in regions where protein and essential fatty acid deficiencies are common.

Linseed is a cost-effective plant in terms of production and processing. Therefore, linseed seed is used in the food industry to produce a variety of products, including flour, oil, seeds, capsules, and extracts. It is used as a nutritious and functional ingredient in school nutrition programs, social assistance programs, and rural development projects. Thus, linseed stands out as a versatile product that not only augments the food supply but also contributes positively to public health.

3.2.2. Versatile uses and the zero waste chain

Linseed has historically stood out for its versatile use as a source of fiber, oil, and food. Today, the effective utilization of all components of linseed in sustainable agriculture and industrial practices serves as a significant example of zero-waste production processes. Linseed seeds can be consumed directly or processed into oil, flour, pulp, and capsules. Its pulp is used as a high-protein animal feed. Its stems are used as a durable fiber source in textiles, composite materials, and biomaterials production (Kozlowski and Mackiewicz-Talarczyk, 2012; Berezovsky et al., 2020). This holistic use of linseed, with its zero-waste structure, both increases its economic added value and supports environmental sustainability.

3.2.3. Climate-resilient agricultural production and food chain stability

Global climate change poses serious threats to the sustainability of agricultural production and the continuity of the food supply. Therefore, the development and adaptation of climate-resilient agricultural practices is critical for food chain stability. The increase in environmental stress factors related to climate change in plant production has increased the importance of tolerant species and varieties (Wheeler and von Braun 2013). Linseed is a plant that stands out for its high tolerance to drought, salinity, and heat stresses. Indeed, linseed has been found to minimize yield loss by developing adaptive physiological and molecular mechanisms under stress conditions (Stavropoulos et al., 2023). These characteristics increase linseed's productivity even under challenging climatic conditions, ensuring continuity in agricultural production and thus contributing positively to the stability of local and regional food chains, thus supporting the protection of food supply security.

Linseed's stress tolerance increases production potential, particularly in arid and semiarid regions where water scarcity and soil salinity are common, and its integration into sustainable agricultural practices allows for the reduction of environmental risks (Pan et al., 2020). Therefore, developing and disseminating linseed varieties that adapt to climate change can strengthen the resilience of production systems and contribute to preventing fluctuations in the food supply chain.

4. Factors Limiting the Cultivation and Use of Linseed

Despite its versatile cultivation and use, linseed has unfortunately not received the attention it deserves in global agriculture. While this ancient plant has the potential to support rural producers, it has been neglected due to its weak competitiveness with other crops and unfavorable pricing policies. While the global average linseed yield increase was 209.9% from 1961 to 2023, this increase was only 369.1% for rapeseed oilseeds, 190.0% for sunflowers, and 240.2% for soybeans (Table 7).

Table 7. Changes in yield values of linseed and some other oilseed crops in the world between 1961 and 2023*

Year	Linseed Yield (kg/ha)	Rapeseed Yield (kg/ha)	Sunflower Yield (kg/ha)	Soybean Yield (kg/ha)
1961	401.6	572.8	1022.5	1128.7
1975	437.6	886.7	1067.9	1657.4
2000	770.1	1527.7	1254.8	2170.8
2010	890.4	1864.6	1363.3	2577.2
2023	843	2114.4	1942.8	2711.2

*Anon, 2025.

Although linseed yields have more than doubled worldwide since 1961, linseed's competitiveness remains low due to the comparable or even greater increases in other crops. Therefore, without positive discrimination and government support for linseed, its competitiveness with other crops is very low. Consequently, many producers worldwide have abandoned linseed production and shifted to higher-yielding crops. Meanwhile, the price of linseed in international markets is tied to the price of soybean seed. Both soybean and linseed oil are heavily used in industry (Turner, 1987).

The linseed plant has a taproot and utilizes water and nutrients found in a wide layer of soil. This gives the plant an advantage in water and nutrient-limited conditions. Its lance-shaped and small leaves provide a partial drought tolerance advantage. Indeed, winter plantings generally do

not require irrigation. However, summer plantings in arid regions require irrigation during the seedling stage and from the beginning of flowering until seed formation.

Most of the oil in linseed is accumulated within the first two weeks after flowering. High temperatures and drought cause premature senescence, limiting the time for oil synthesis (Turner, 1987). Therefore, growing without irrigation, especially in summer plantings in arid regions, leads to reduced yields. However, excessive moisture or overwatering is undesirable, as this can lead to the spread of many diseases, especially mold (Casa et al., 1999).

Although linen fiber is stronger than cotton, rayon, and wool (Gadalla and Öztekin, 2020), it is less flexible than fibers like cotton and silk. Cotton fiber accounts for 94% of the world's natural fibers. However, cotton is a warm-climate plant and can only be grown as a summer crop and cannot be grown in all climates. Linen, on the other hand, can be grown as a summer or winter crop in many regions where cotton is not grown. Therefore, linen is an extremely important source of plant fiber for the fiber industry.

Linseed is a versatile plant, utilized for both the fibers in its stems and its seeds. However, the high fiber content in its stems also makes mechanized harvesting difficult. The stems can become entangled in the combine harvester, making it difficult to operate. Furthermore, relative humidity and temperature are also important factors in mechanized harvesting for seed. During mechanized harvesting, temperatures above 37°C and low humidity pose a risk of static electricity causing the seeds to stick to each other and to the machine. To prevent static electricity, harvesting should be done at low temperatures and high relative humidity. Similarly, mechanized processes used to extract plant fibers cause the fibers to break down to only a few centimeters long (Yılmaz and Uzun, 2019). Therefore, today, linseed fiber production is still largely carried out through traditional methods, relying on labor-intensive methods such as composting in moisture or composting in water. The quality of the resulting fiber varies depending on the composting method used. Excessive moisture causes increased microbial colonization in the stems.

Linseed oil, due to its rich omega-3 fatty acid content, is a plant-based source of omega-3. Alpha-linolenic acid (ALA), the primary omega-3 fatty

acid in linseed seed, is an important source for humans and animals. The omega-3 fatty acid content of linseeds varies from 2% (low) to 60% (high). While linseed varieties with low ALA content can be used as cooking oil (Al-Madhagy et al. 2023), linseed varieties with high ALA content are more commonly consumed as linseed, used in the preparation of dietary foods, or used industrially to produce linseed oil.

The high ALA content causes the oil to quickly deteriorate and turn rancid upon contact with oxygen, limiting the use of linseed as a cooking oil. Furthermore, unground linseeds and cold-pressed linseed oil contain antinutrients such as cyanide glycosides (250–550 mg/100 g), which can have adverse health effects (Singh et al. 2011). Therefore, the recommended daily intake of linseed is approximately 10 grams. Consuming this amount of linseed results in a daily intake of approximately 5–10 mg of hydrogen cyanide. This dose is considerably lower than the daily toxic dose of 50–60 mg (Kaur et al. 2018). Indeed, there are no reports in the literature to date of cyanide poisoning following linseed consumption. Heat treatment is generally used as an effective method for removing cyanogenic glycosides. Therefore, for safe consumption, it is recommended to heat-treat linseeds (minimum 35°C) and then grind them into flour. However, because the polyunsaturated fatty acids (ALA) contained in the oil in the seed oxidize shortly after grinding, care should be taken to use freshly ground linseeds and to store them under appropriate conditions. Furthermore, the remaining linseed meal after the oil is removed contains 2.3–3.3% palmitic acid, so careful consumption of the meal is essential for nutrient absorption (Kaur et al. 2018).

Linseed oil, like rapeseed and sunflower oil, is produced in oil mills. However, there are no dedicated linseed-specific factories for extracting the oil found in linseed. This presents an obstacle to the efficient production of linseed oil and also presents a significant challenge for oil linseed cultivation.

Linseed has a long growing season. This limits the ability to grow a second crop in winter plantings, and the short growing season limits its use as a second crop in summer plantings. However, harvesting in summer linseed can occur from August to October, depending on the climatic conditions of the region where it is grown. Therefore, following the summer

linseed harvest, grain or rapeseed can be planted in winter. However, in areas where alternaria is prevalent, rotation of linseed with rapeseed is not recommended. Furthermore, because linseed does not enrich the soil with nitrogen like legumes, it does not leave a nitrogen-rich soil for the following crop. Therefore, this factor must be taken into account when meeting the nutrient needs of the crop planted after linseed.

Weed control is also important in areas where linseed is cultivated. Linseed has a poor weed control ability. Especially during spring planting, weeds can rapidly develop, overrunning the land and negatively impacting linseed growth. Furthermore, as the linseed plant approaches maturity, it sheds its leaves, creating an environment for weeds developing below to develop rapidly. Therefore, effective weed control is crucial in areas where linseed is cultivated. Dense plantings increase weed competitiveness, but this results in a thin stem, reducing the plant's tolerance to lodging under adverse conditions. Although more tolerant to lodging than cereals, lodging before flowering and capsule formation is a serious problem for linseed. Lodging, particularly observed early in the season with excess nitrogen and excessive seed set, is partially eliminated when the plant's stem dries.

Another problem that needs to be addressed in linseed cultivation is yield loss, which occurs when capsules crack open and seeds are shed. In some linseed varieties, the capsules partially or completely crack, and the seeds partially or completely fall out. However, because the capsules do not crack in all registered cultivars, there is no seed loss. Therefore, if linseed is to be cultivated, seeds from registered linseed varieties should be preferred for planting.

5. Conclusion and Recommendations

Meeting the evolving demands of a growing world population is putting increased pressure on agricultural resources and contributing to the steady decline of arable land. Given this constraint, enhancing productivity per unit area has become essential. However various challenges impede achievement of this goal. Linseed, with its versatile characteristics and wide range of uses, stands out as a promising crop capable of addressing these challenges.Although linseed has been cultivated for various purposes since ancient times, it has not yet achieved its secular place within the agricultural

system, both globally and in Türkiye. Therefore, it is impossible to predict the future of linseed today. Fundamental problems such as the varying processing processes used for fiber and oil production, limited access to appropriate harvesting and processing technologies, low producer awareness, and inadequate marketing chains hinder the development of linseed cultivation. Furthermore, low price competition against crops grown for different purposes in the same agricultural area and instability in seed yields limit farmers' interest in flaxseed cultivation.

It is possible to take advantage of the potential advantages of linseed cultivation by developing and implementing holistic approaches and strategies that overcome technical and economic barriers. Furthermore, to achieve the targeted yield and quality in linseed production, linseed varieties with good adaptation to growing regions, high yield potential, and having quality criteria in line with the demands of consumer groups, particularly those with low linolenic acid and high edible oil quality, must be developed and integrated into production. Thus, the widespread use of linseed in the future, expansion of production areas, and improvement of its adaptability to climatic conditions through breeding efforts will contribute significantly to both agricultural sustainability and global food security.

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Chapter 10

LUPINS (*Lupinus* sp.)

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DOI: https://dx.doi.org/10.5281/zenodo.17454121

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1. General Characteristics of the Lupins

The genus *Lupinus* (commonly known as lupin), belonging to the *Fabaceae* (legume) family, comprises approximately 300 species, including annuals, perennials, and shrubs. These species, which exhibit rich diversity and adaptability to a wide range of climatic conditions, are classified into two main groups based on their origin: "Old World" species (native to the Mediterranean region, North Africa, and East Africa) and "New World" species (Figure 1). Of these, approximately 12 species are native to the Old World, while the vast majority originate from the New World. Annual lupin species are generally considered to have originated in the Mediterranean region, whereas perennial species are believed to have originated in Central America and Brazil (Williams, 1984).

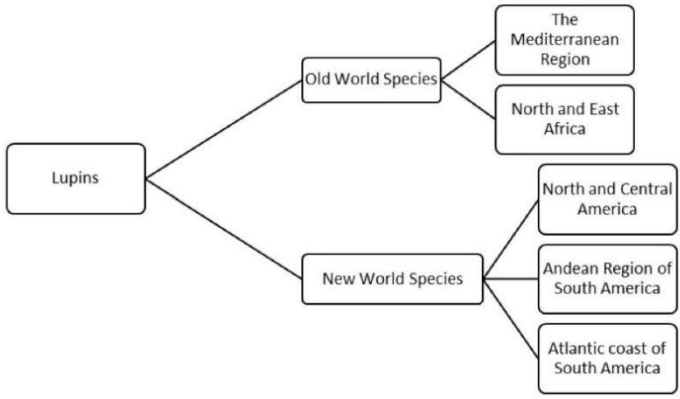


Figure 1. Origin and distribution of the lupine (Wolko et al., 2010).

Lupin cultivation has a history dating back over 4,000 years (Kurlovich, 2002). White lupin (*Lupinus albus*) was first domesticated around 2000 BCE in Ancient Greece and Egypt. During this period, the seeds were soaked and used both as food for humans and as animal feed; the plant was also utilized for cosmetic and medicinal purposes. The use of white lupin as green manure began around 800–1000 BCE in Ancient Rome, and this use later spread to other Mediterranean countries. In the America, pearl lupin (*Lupinus mutabilis*), which grows in the Andes Mountains, was domesticated around 600–700 BCE. Yellow lupin (*L. luteus*) and narrow-leaf lupin (*L. angustifolius*) were initially cultivated in

Mediterranean countries for green manure production, and later in Germany for similar purposes. By the 16th century, lupin cultivation for soil improvement had begun in the Baltic countries (Hondelmann, 1984). In the early 19th century, *Lupinus angustifolius* was used in France as animal feed, in Germany as green manure, and in England both as animal feed and as a green manure crop for improving sandy soils (Hondelmann, 1984). The first low-alkaloid (sweet) forms of lupin species were developed between 1927 and 1930 in Germany, and between 1929 and 1932 in Russia. In subsequent years, breeding efforts aimed at domesticating new lupin species continued in countries such as Australia, Russia, Finland, and others (Australian Government, 2013).

Lupins generally thrive in well-drained, slightly acidic to neutral soils. The sensitivity of species to soil pH, waterlogging, and soil fertility varies. For instance, *Lupinus angustifolius* adapts well to acidic sandy soils with low fertility and exhibits tolerance to temporary waterlogging. In contrast, *Lupinus albus* prefers fertile soils with a high pH and is sensitive to waterlogging (Brand et al., 2002). Lupins are generally cold-tolerant. The minimum temperature required for seed germination is relatively low, approximately 2 to 3°C (Kurlovich and Heinanen, 2002). Moreover, they can withstand low temperatures ranging from -6 to -9°C (Barbacki, 1960). When soil temperature exceeds 20°C, germination and emergence of *L. angustifolius* decrease, and at 30°C, germination and emergence are nearly absent. Reproductive tissues are particularly sensitive to high temperatures (Dracup et al., 1993). Under water stress conditions, the plant rapidly transitions from the vegetative to the generative phase. The flowering and seed-setting periods are shortened. The plant sheds its leaves and increases stem dry matter. Nevertheless, total seed yield is maintained (Rodrigues et al., 1995). The lupin plant does not tolerate high salinity conditions. Although differences exist among species, lupins are generally moderately sensitive to salinity (Dracup et al., 1998).

Lupin is a group of plants that has been cultivated for many years across various geographical regions worldwide and used for diverse purposes. This extensive usage and historical background have led to the plant being known by different local names in various countries and regions. Globally, especially in areas where Old World and New World

lupin species are widespread, the names given to lupin plants vary considerably. In English-speaking countries, the plant is called "lupin" or "lupine," while in German-speaking countries it is known as "Lupine," in French as "lupin," and in Spanish as "altramuz." In Italy, it is referred to as "lupino," in Portugal as "tremoço," in Poland as “łubin,” in Russia as “люпин (lyupin),” and in Arab countries as "termes." In South America, particularly in the Andes region, the species *Lupinus mutabilis* is commonly cultivated and called “Tarwi” or “Chocho” by the local people. In Turkey, lupin is generally known as "acı bakla." Additionally, depending on regional variations, it is also referred to by several local names such as delice bakla, gâvur baklası, koyun baklası, kurt baklası, yaban baklası, Yahudi baklası, and termiye (Lim, 2012).

Although there are many species of lupin, the ones commonly cultivated are annual species. Annual plants possess a strong taproot system, with the main root reaching depths of 1 to 2 meters. Root morphology can reflect differences in the adaptation of lupin species to various soil types. Cultivated genotypes of *Lupinus angustifolius*, which adapt well to deep sandy soils, have plants with a dominant taproot and numerous primary lateral roots but relatively few secondary or tertiary lateral roots (Clements et al., 1993). The surface of their upright stems can be hairy, waxy, or glabrous at varying densities (Petrova, 2002). The leaves on the stem are arranged alternately along the petioles (Figure 2).

The leaves of lupin species are composed of a varying number of leaflets that converge at a single point, depending on the species. The leaflets are oval in shape and their surfaces are generally hairy (Petrova, 2002). The inflorescence is typically racemose or a compound raceme. The flowers exhibit the characteristic morphology of legumes, consisting of five sepals, five petals, one female organ, and ten fused male organs. The ovary usually contains two or more ovules. The fruits are flattened, either straight or curved pods. The fruit coat is hard and can be cream, brown, or black in color. Seeds differ among species in terms of size, shape, and color. The seed surface is generally smooth (Kurlovich and Stankevich, 2002) (Figure 3).



Figure 2. Root and Stem System of Lupin (Anonymous 2025a, b)



Figure 3. Leaves, Flowers, Pods, and Seeds of Lupin (Anonymous, 2025c, d)

2. Cultivation Purposes and Nutritional Value ofLupins

Due to its high nutritional value, lupin is used in both human and animal nutrition. Additionally, thanks to its soil-enriching properties, it is also utilized as a green manure crop.

Lupin seeds are emerging as an alternative to dry beans and soybeans due to their nutritional value and food processing characteristics. Food products derived from lupin are commercially produced in Europe, North America, and Australia (Petterson, 1998). White lupin seeds are widely consumed as snacks in Southern Europe (Lim, 2012). They are considered a rich source of protein with a significant amount of lysine and are used in confectionery, snacks, and bakery products. Additionally, they serve as an alternative ingredient to meat, egg protein, and sausages. Lupin is also utilized in fermented foods produced through the action of bacteria and fungi (Guillamón et al., 2010; Prusinski, 2017). White lupin seeds have a high nutrient content, containing on average 32.2% protein, 16.2% fiber, 5.95% fat, and 5.82% sugar. Analysis of the seed oil's fatty acid profile reveals that 13.5% are saturated fatty acids, 55.4% monounsaturated fatty acids, and 31.1% polyunsaturated fatty acids. Approximately 71% of the total sugar content in the seed is sucrose. Bitter lupin seeds are also a notable source of vitamins, containing 3.9 mg/kg thiamine, 2.3 mg/kg riboflavin, and 39 mg/kg niacin. Based on these data, bitter lupin is regarded as a highly nutritious, potential food ingredient (Erbaş et al., 2005). In traditional medicine, lupin has been used for treating various ailments. It is applied against intestinal parasites by mixing the flour with honey or vinegar. It is also used in the form of infusions or poultices for boils and skin diseases (Lim, 2012). In Ethiopia, lupin seeds are roasted and used in the preparation of alcoholic beverages and other food products (Tizazu and Emire, 2010; Zelalem and Chandravanshi, 2014).

A large proportion of lupin produced worldwide is used as animal feed. Ruminants constitute the largest consumer group, followed by pigs and poultry (Australian Government, 2013). Lupin is often preferred as an alternative to soybean meal in animal feeds due to its high protein content. Its low starch content and high levels of fermentable carbohydrates make it a suitable and preferred feed source for ruminants. Sweet lupin species are widely used in dairy farming in Australia, Europe, and Japan. In Australia, the

most common use of lupin is as whole grain feed for sheep to supplement low-quality roughage (Lawrance, 2007).

Lupinus angustifolius seeds are a particularly high-quality protein source for monogastric animals, containing approximately 29% crude protein and exhibiting 80% in vitro organic matter digestibility (IVOMD) (Riga et al., 2021). The crude protein content of the dry forage is 23%, with an acid detergent fiber (ADF) content of 37.5% and an IVOMD value of 69%, making it a valuable feed resource in ruminant nutrition (Riga et al., 2021). In different locations in Mexico, *Lupinus angustifolius* green forage yield ranged from 15.7 to 24.7 t/ha, and dry forage yield varied between 2.2 and 4.2 t/ha. Nutritional composition showed crude protein levels ranging from 14.9% to 22.6%, ADF from 29.1% to 48.8%, and neutral detergent fiber (NDF) from 41.9% to 64.8%. Macro- and microelement contents included potassium (K) at 1.6–1.9%, calcium (Ca) at 1.1–1.4%, magnesium (Mg) at 0.15–0.23%, manganese (Mn) at 4.6–5.9 mg/kg, iron (Fe) at 6.8–7.9 mg/kg, and zinc (Zn) at 3.2–4.3 mg/kg. These data indicate that *L. angustifolius* possesses significant potential as a forage crop in terms of both yield and nutritional value (Natera et al., 2017). The nutritional quality of white lupin silage varies depending on harvest time and silage additives. Plants harvested at an early stage contain higher crude protein (18–22%) and lower ADF (25–30%). Appropriate additives improve fermentation and enhance the feed value of silage (Falińgowska et al., 2014).

Lupin contributes nitrogen to the soil in a plant-available form by fixing atmospheric nitrogen through symbiotic *Rhizobium* bacteria residing in its root nodules. Due to this characteristic, lupin has long been used as green manure on low-fertility soils and is incorporated into crop rotation systems alongside various crops. Especially in rotations with cereals, lupin provides agronomic benefits such as increased organic nitrogen content in the soil, weed control, and reduced disease incidence in cereal crops (Harries and Peek, 2008). In green manure studies conducted with lupin varieties, total nitrogen (N) accumulation ranged from 195.6 to 221.2 kg ha^{-1}. The proportion of nitrogen obtained through atmospheric nitrogen (N_2) fixation varied between 72% and 93%. The amount of nitrogen fixed in the aboveground biomass ranged from 106 to 185 kg ha^{-1}. Considering aboveground biomass production, total nitrogen accumulation, and N_2 fixation capacity, lupin

species are regarded as having significant potential for use as green manure (Natera et al., 2023). Thanks to these features, lupin stands out as a valuable plant-based protein source in human nutrition and as a high-quality feed alternative in animal husbandry. Additionally, by improving soil fertility, lupin contributes significantly to sustainable agricultural systems.

3. Contribution of Lupins to Sustainable Agriculture and Food Supply Security

Sustainable agriculture aims to ensure food accessibility for all while preserving natural resources at levels sufficient to meet future needs. The rising demand due to rapid population growth has led to the expansion of conventional agriculture. However, the intensive use of chemical inputs in such systems causes environmental degradation and poses a threat to food security. As a result, environmentally friendly, resource-conserving, and food security-oriented sustainable agricultural practices have gained prominence (Kayışoğlu and Türksoy, 2023). In this context, the cultivation of leguminous crops offers substantial nutritional and health benefits to humans, while adhering to the principles of sustainability. Enhancing the economic, environmental, ecological, and social sustainability of food production requires greater attention to agricultural biodiversity. Heavy dependence on a limited number of legume species with low resilience to climate change presents a significant risk to sustainable food systems. While legumes such as soybean, common bean, and chickpea offer high economic returns and well-established market networks, they can also contribute to environmental degradation and depletion of natural resources. In contrast, species such as lupin, grass pea (*Lathyrus sativus*), and cowpea (*Vigna unguiculata*) provide ecological benefits by supporting biodiversity and increasing resilience to climate change (Vilakazi et al., 2025). Additionally, they are distinguished by their low glycemic index, low fat and cholesterol content, and their affordability as plant-based sources of protein, carotenoids, polyphenols, and energy (Foyer et al., 2016). *Lupinus mutabilis* seeds contain approximately 45% protein higher than that of beans (25%), peanuts (30%), and chickpeas (30.5%). Its oil content is similar to that of soybeans; however, due to its polyunsaturated structure and high linoleic acid content, the nutritional quality of the oil is superior (Rubatzky et al., 1997). Owing to its high oil content, *L.*

mutabilis may be considered a potential alternative to oilseed legumes such as soybean and peanut (Chongtham et al., 2022).

One of the main challenges in the livestock sector is protein deficiency in animal feed rations. This deficiency can reach up to 30% in some cases, leading to excessive feed consumption and increasing the cost of animal products by 1.5 to 2.0 times (Gaponov, 2021). Currently, the most important protein source used in feed rations is soybean. Due to its product diversity and extensive trade network, it holds a dominant position in the sector. However, considering that more than 80% of imported soybeans are genetically modified, increasing the diversity of raw materials in agricultural production becomes strategically important making lupins a valuable alternative (Gaponov, 2021). Lupins stand out due to their adaptability to various soils and climates, as well as the high digestibility of lupin-based feeds. These feeds are rich in trace elements, vitamins, and other biologically active compounds, and have low levels of anti-nutritional factors (Chongtham et al., 2022). With strategic potential in both plant-based and animal-based production, lupins can contribute significantly to ecological, economic, and nutritional sustainability by enhancing crop diversity in line with sustainable agriculture goals.

4. Factors Limiting the Cultivation and Use of Lupins

Although lupin species possess high potential for agricultural production, various environmental and biochemical factors during cultivation can adversely affect both yield and quality. Temperature is considered one of the most critical environmental factors influencing lupin cultivation. High temperatures during germination (above 27 °C) can reduce flowering, while extreme heat during the pod and seed-filling stages (around 38 °C) may lead to flower and pod abortion, ultimately resulting in reduced seed yield (Keatinge et al., 1998; Lane et al., 2019). Lupins perform best in fertile soils with a pH range between 4.5 and 7.5 (White and Robson, 1989). However, when alkaline soils with high calcium carbonate ($CaCO_3$) content are present, they can lead to significant reductions in grain yield (Ding et al., 2018; Howey, 2020). Another major constraint in lupin cultivation is the presence of alkaloids in plant tissues and seeds. Lupin alkaloids can affect the central nervous system of mammals, causing symptoms such as tremors, excitation,

seizures, and conditions characteristic of anticholinergic syndrome, including blurred vision, dry mouth, irritability, and fatigue (Kurzbaum et al., 2008). Food safety authorities have set the maximum permissible alkaloid content in lupin flours and foods at 200 mg/kg (Resta et al., 2008), while the acceptable alkaloid content in animal feeds ranges between 0.02% and 0.04%. Elevated alkaloid levels may significantly reduce protein digestibility and potentially lead to neurological disorders (Sujak et al., 2006). Understanding these limiting factors and implementing appropriate agricultural management strategies are essential for ensuring both yield performance and product safety in lupin cultivation.

5. Conclusion and Recommendations

Lupin is an important leguminous crop that originated in the Mediterranean basin and has spread to many parts of the world, adapting to diverse climatic and soil conditions. Due to its morphological and physiological characteristics, it is used in both human nutrition and animal production. Its seeds are a valuable food raw material, rich in protein, fiber, and minerals. In animal feeding, lupin can serve as an effective feed ingredient to address protein deficiencies in rations, owing to its high crude protein content and well-balanced amino acid profile. From a sustainable agriculture perspective, lupin contributes to reduced fertilizer use through biological nitrogen fixation, improves soil structure, and aids in the conservation of natural resources. Its resilience to climate change and low input requirements position it as a promising crop for strengthening food supply security. However, factors such as alkaloid content, certain soil and climatic constraints, low seed yield, and limited market demand hinder its wider adoption. To promote lupin cultivation, breeding efforts should prioritize the development of low-alkaloid, high-yielding varieties that are adaptable to diverse agroecological conditions. Thanks to its high nutritional value, low levels of anti-nutritional compounds, and favorable amino acid balance, lupin has the potential to serve as a partial or full alternative to soybean as a protein source in animal feed. Diversifying lupin-based food products, improving processing technologies, and enhancing marketing strategies will not only increase consumer demand but also raise the economic value of the crop. Within the scope of sustainable agricultural practices,

expanding the use of lupin in crop rotation systems, green manure applications, and low-input farming models can contribute significantly to the conservation of natural resources and the strengthening of food supply security.

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Chapter 11

MUNG BEAN (*Vigna radiata* L.)

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DOI: https://dx.doi.org/10.5281/zenodo.17462578

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1. General Characteristics of Mung Bean

1.1. Origin

As a self-pollinating diploid (2n = 22), the mung bean (*Vigna radiata* L.) is a member of the Fabaceae's Papilionoideae family (Diatta et al., 2024). This species is indigenous to Asia's northeastern India-Burma (Myanmar) region (Li et al., 2011). For 3500 years, mung beans have been commonly grown by Indian farmers (Shi et al., 2016). Due to its simple digestion, high nutritional value, and pleasant taste, this pulse is the most popular in India (Gayacharan et al., 2020). For almost two millennia, mung beans have been a staple in Chinese cuisine. In South East Asia, Bangladesh, India, and Western nations, mung beans are also frequently used as a fresh salad vegetable or as a staple food (Tang et al., 2014). The National Crop Gene Bank of China currently has around 5000 mung bean accessions in its gene bank (Ganesan & Xu, 2018). Also in Pakistan, mung bean is a significant summertime pulse crop (Ahmad et al., 2003). Mung bean (*Vigna radiata* var. *radiata*) is also grown in Australia and United States of America (Pandey et al., 2018). It has been also used as traditional medicine for a very long time in many countries (Hou et al., 2019).

Common names of the plant are Mug (Bengali), Green Gram (English), Mas (Nepal), Mung (India), Loctao (Peru), Frijol (Spanish), Mash (Russian) (Ganesan & Xu, 2018), Masho (Ethiopia) (Dikr, 2023) and Maş fasulyesi or Yeşil mung fasulyesi (Türkiye)

1.2. Mung bean plant characteristics

Mung beans are an annual creeping crop that can reach a height of 90 cm in warm climates up to 35°C. It is a crop with a short growing season (75-90 days), greater flexibility, and widespread growth in all soil types. It thrives in the majority of unfavorable dry and semi-arid environments. The trifoliate, alternating leaves have a light green coloring. In addition, its blossoms range in color from pale yellow to greenish yellow. Ten to fifteen ellipsoidal green, yellow, brown, or black mottled pods comprise the fruits (pods), which are pendent, glabrous, linear-cylindric, and grow up to 12 cm (Lim, 2012).



Fig. 1. Mung bean plants with pods (Ganesan and Xu, 2018).

1.3. Adaptation

Vigna radiata is grown on more than 6 million hectares in the world's warmer climates (Nair et al., 2012). The crop is grown over a broad range of latitudes (40° N or S) in areas where the growing season's diurnal temperatures are higher than 20°C (Hanumantha et al., 2016). This low-input crop has a short growth cycle (70 days) and is comparatively drought-tolerant (Dahiya et al., 2015).

Transient soil waterlogging imposed on by erratic and more frequent extreme precipitation events has a negative impact on mung bean production in Asia. Throughout their life cycle, mung beans are prone to temporary soil waterlogging, although they are particularly at risk in the early stages of growth (Kyu et al., 2024). Some varietal differences in mung bean response to transient waterlogging at the late vegetative stage have been reported (Islam et al., 2007).

1.4. Farming

About 30% of the world's yearly production comes from India and Myanmar, with China coming in second with 16% and Indonesia with 5% (Nair and Schreinemachers, 2020). Mung bean production and productivity have increased from 2.3 to 5.3 million tons and 500 to 721 kg/ha, respectively, while the total acreage has grown from 4.6 to 7.3 million ha worldwide (Nair and Schreinemachers, 2020).

Because of its agronomic significance to cropping systems and its income as a cash crop, the crop is highly important to smallholder farming families. For instance, because mung bean fixes soil nitrogen through symbiosis and aids in disrupting insect and disease cycles, it may improve the production of succeeding rice crops by up to 8%. Mungbean is extensively cultivated in Asia's lowland and upland agricultural systems as a result of these combined advantages (Herridge et al., 2019).

Similar to other legumes, mung bean and Rhizobium work together to fix atmospheric nitrogen (58-109 kg/ha), which helps succeeding crops in addition to meeting the legume's own nitrogen needs (Ali and Gupta, 2012). Because of its high nutritional content and ability to increase soil fertility, it needs comparatively less water to grow well than other legumes (Parida and Das, 2005). Mung bean is frequently grown on low-input marginal soils that are vulnerable to a variety of abiotic stressors that significantly reduce seed production (Singh and Singh, 2011). According to Dahiya et al. (2015), it survives in the majority of unfavorable dry and semiarid environments. However, it grows best on well-drained loams or sandy loam soilsat elevations of no more than 2,000 meters and in subtropical areas with average annual rainfall between 600 and 900 mm (Diatta et al., 2024).



Fig. 2. Mung bean seeds (Ganesan and Xu, 2018).

In Asia, the average mung bean yield is 0.4 t/ha, but with careful selection and management, yields of up to 2.5 t/ha can be achieved (Pandey et al., 2018). This plant is referred to as "Maş fasulyesi" and "Yeşil mung

fasulyesi" in Türkiye. Mung beans grow well in low soils and are resistant to drought. In Türkiye, it is planted as a summer crop (Akbay et al., 2020).

In Kahramanmaraş ecological conditions, emergence time of mung bean was determined as 6-15 days, 50% flowering period was 50-67 days, 50% pod setting was 57-70 days, 50% maturity period was 74-99 days, plant height was 36-42 cm, first pod setting height was 12-22 cm, pod length was 9-11 cm, pod number was 9-24 pieces/plant, number of seeds per pod was 9-10 pieces/pod and grain yield was 250-740 kg/ha, leaf number was 47-74 pieces/plant, green forage yield was 9.6-15.1 t/ha, dry forage yield was 2.3-3.2 t/ha, crude ash ratio was 13-17%, ADF ratio was 22-29% and NDF ratio was 55-56% (Akbay et al., 2020).

2. Cultivation Purposes and Nutritional Value of Mung Bean

In India, China, Bangladesh, the Philippines, Thailand, South East Asia, and western nations, mung beans and sprouts are commonly eaten as a fresh salad, vegetable, or even as a staple diet (Tang et al., 2014). Cake, sprouts, noodles, and soups evolved in oriental countries like China, the Philippines, Iran, and Thailand, while its various food products, like dhals (i.e., thick stews made from dehulled and split grains), sweets, snacks, and savory foods, evolved and became popular in the Indian subcontinent (Dahiya et al., 2015).

Because of its high protein content and hypoallergic characteristics, mung beans reduce flatulence, are well-tolerated by children, and are suggested as a supplement when making an infant's weaning diet (Ali et al., 2016).

Customers choose grains of a particular color and reject others, so the color of the mung bean grain serves as a quality indicator. Although mung bean grains are often green, they can also be different colors. Mung bean grains come in a variety of colors, including dark green, light yellow, deep green, dull, shiny, golden, and mottled yellow. While dull green mung bean variants are primarily from Korea, China, Taiwan, Türkiye, and Indonesia, the majority of shiny green varieties (49%) come from the Philippines, Vietnam, Thailand, India, Pakistan, and Afghanistan. Differences in genetic composition and storage conditions could be responsible for the grain color variance (Dahiya et al., 2015). Higher quantities of polyphenols have been found in dark-colored mung bean grains (Muhammed et al., 2010).

Grain weight and color have been found to be correlated with grain hardness (Humphry et al., 2005). According to Yildiz (2005), mung bean grains with moisture percentages of 6.7 and 18.6%, respectively, had volumes of 30 and 35 mm^3. The moisture content of the mung bean grain, which is influenced by the grain's maturity level at harvest and postharvest drying, is the parameter that explains the variance in volume. Mung bean has relatively small grains in comparison to other commonly used pulses (Nimkar and Chattopadhyay, 2001). The average weight of a thousand seeds is 36 g, with a minimum of 7 g and a maximum of 60 g (Unal et al., 2008). With a minimum of 679 kg/m^3 and a maximum of 821 kg/m^3, the average bulk density is 757 kg/m^3 (Yildiz, 2005).



Fig. 3. Pods of mungbean (Nadi, 2023).

Among the characteristics of food processing, the average water absorption capacity is 131% (minimum 79% and maximum 187%). The average cooking time is 37 minutes (with a maximum of 60 minutes and a minimum of 14 minutes) (El-Adawy et al., 2003; Ghavidel and Prakash, 2006). The average emulsification capacity is 34 milliliters of oil per gram of flour (between 20 and 48 milliliters of oil per gram of flour) (Khattak et al., 2007; Ghavidel and Prakash, 2006).

Like kidney beans (*Phaseolus vulgaris* L.) and soybeans (*Glycine max* L. Merr.), mung beans are abundant in nutrients and a good source of vitamins, minerals, and vital amino acids (Mubarak, 2005). With 20% to 25%

protein by dry weight, mung beans are known for their great nutritional value. The two main storage proteins among them are albumin (25%) and globulin (60%) (Kudre et al., 2013). Carbohydrates make up the majority of mung beans (55-65%, or 630 g/kg in dry weight). Compared to other types of legumes, mung beans have fewer flatulences because its carbohydrates are quickly digested (Nair et al., 2013). Flavonoids (isoflavones, flavones and isoflavonoids), phenolic acids (vanillic acid, gallic acid, caffeic acid, protocatechuic acid, cinnamic acid, shikimic acid, and p-hydroxybenzoic acid), and numerous other organic acids are among the numerous secondary metabolites that have been found in mung beans that have positive health effects on humans (Anwar et al., 2007).



Fig. 4. Seeds of new mungbean cultivar KUML8 (Somta et al., 2024)

According to Nair et al. (2015), mung bean sprouts and green pods are rich in vitamins and minerals. Anti-nutritional components reported in mung bean are tannins, phytic acid, hemagglutinins, polyphenols, trypsin inhibitor, and proteinase inhibitor (Fatima and Kapoor, 2006; Mubarak, 2005).

3. Contribution of Mung Bean to Sustainable Agriculture and Food Supply Security

In several regions of South Asia, conservation agriculture is becoming increasingly popular. An extra 1.0 m ha of pulse crops might be added to the Indo-Gangetic plains through system intensification with the addition of mung bean to the summer fallows of the rice-wheat cropping system (Kumar et al., 2018). In the traditional maize-wheat system of the subtropical Indo-Gangetic

plains, adding grain legumes such as mung beans over time might enhance soil health, especially soil organic carbon (Venkatesh et al., 2013).

Growing mung beans in summer fallows as part of an irrigated cereal-based cropping system provides a wealth of opportunities to implement an "ecologically intensive" cropping system (Dhakal et al., 2016). In the Indo-Gangetic plains' rice-wheat, maize-wheat, rice-potato, rice-chickpea, and rice-mustard cropping systems, the short-duration heat-tolerant mung bean crop can be readily incorporated following the winter crop, provided that irrigation facilities are available (Kumar et al., 2018).

In maize-wheat and rice-wheat rotation, long-term mungbean cultivation increased soil organic carbon by 12.0 and 12.5%, respectively, suggesting the importance of fallow management for managing soil organic carbon in tropical regions. The crop rotation was determined to be in the following order of relative effectiveness in managing soil organic carbon: maize-wheat-mung bean > pigeon pea-wheat > maize-wheat-maize-chickpea > maize-wheat (Venkatesh et al., 2013).

In rice-wheat rotation, the growing of short-duration mung bean in summer may bring up N economy up to 40-60 kg N/ha in the succeeding rice crop (Kumar et al., 2018).

In a rice-rice-rice system in Vietnam, the weedy rice seed bank decreased significantly when mung beans replaced rice during the dry season (Chauhan et al., 2010). According to long-term tests conducted in India, adding grain legumes to winter crops can reduce the spread of *Phalaris minor* and *Avena fatua*, or wild oats (Kumar and Singh, 2010). A fast-growing crop that can compete with weeds, such as mung beans, should be included in the crop rotation as an intercropping or sole crop (Meena et al., 2015).

An environmentally friendly dietary legume, mung bean lowers the requirement for inorganic nitrogen while preserving or improving soil fertility. By raising soil nitrogen levels, mung bean increases soil fertility when grown alongside grains like rice, millet, or maize. This could help future harvests and reduce the need for synthetic fertilizers (Zang et al., 2015).

Although it is still a minor grain legume in Sub-Saharan Africa, mung beans are suited for rain-fed smallholder production systems due to their short growth cycle, symbiotic atmospheric nitrogen fixation, resistance to heat and drought, and minimal input requirements. Because of its adaptability as a

short-duration crop, it is a great choice for crop diversification, giving smallholder farmers a second source of income and enhancing their ability to withstand climate change, both of which could support long-term agricultural sustainability (Diatta et al., 2024).

Just a small part of Ethiopia is used for mung bean cultivation. With an annual rainfall of 600-750 mm, the best adaptation zones for mung beans are located between 1,000 and 1,650 meters above sea level. Clay loam fluvisol, clay eutric fluvisol, and pellic vertisol soil types are most suited for mung bean production in Ethiopia. Even producer farmers in Ethiopia consume very little of it. It is exclusively grown as a cash crop in order to sell it to exporters and make profits. In Ethiopia, the maximum mungbean crop yield was 787 kg/ha. Due to its ability to withstand dry land conditions and fix atmospheric nitrogen, mung beans are becoming increasingly popular as a short-season crop that helps reduce soil nutrient depletion (Dikr, 2023).

In farming systems, mung beans have been employed as a sustainable and ecologically friendly method of controlling insects. A 50% reduction in mirid insect (*Apolygus lucorum*) (Heteroptera: Miridae) population densities was seen in cotton fields with mung bean plants (36 individuals per 100 plants) compared to cotton fields (Lu et al. 2009). Geng et al. (2012) reported similar results.

The biomass of mung beans, which can be produced as a cover crop, is added to the soil as green manure, which enriches it with nutrients and organic matter. Livestock are fed its crop remnants (leaves and stems), which provide a high-protein diet that promotes the production of meat and milk (Diatta et al., 2024).

4. Factors Limiting the Cultivation and Use of Mung Bean

Mungbean is mostly grown in rain-fed environments, and climate variability, such as high temperatures and CO_2, causes biotic stress of variable intensities in these environments, which results in a major loss of productivity (Sharma et al., 2007).

According to Islam et al. (2008), waterlogging mungbean crops affects the roots, lowers the amount of chlorophyll in the leaves, and eventually lowers grain yield. Furthermore, the N_2 fixation activity of mung bean root

nodules is decreased by the oxygen deprivation in the rhizosphere brought on by temporary soil waterlogging (Kyu et al., 2021).

Mung bean yield is significantly reduced by biotic and abiotic stressors, with fungal infections being one of the most severe. Despite the fact that physical, chemical, and biological approaches to disease management have been studied and documented in the literature, few producers have access to or have utilized these techniques. Powdery mildew, anthracnose, *Fusarium* wilt, *Cercospora* leaf spot, Rhizoctonia root rot and web blight, and *Macrophomina* charcoal rot/dry root rot and blight are among the major diseases. There are no sources of resistance to anthracnose, dry root rot, or *Rhizoctonia* root rot (Pandey et al., 2018). Fungal infections can cause a 40-60% reduction in mung bean yields (Kaur et al., 2011).

Field pests like the whitefly (*Bemisia tabaci*), black aphid (*Aphis craccivora*), leaf hopper (*Empoasca kerri*), gallerucid beetle (*Madurasia obscurella* Jacoby), spotted caterpillar (*Maruca testulalis*), stem fly (*Melanagromyza phaseoli*), lycaenid borer (*Euchrysops cnezus*), and Bihar hairy caterpillar (*Diacrisia obliqua*) can all reduce mungbean yield. Biological and chemical control methods, clean seeds, cultural techniques, and resistance cultivars are all part of integrated management strategies for mung bean pests (Dubey & Singh, 2013).

Mung bean Yellow Mosaic Virus (MYMV) is the main virus that limits mung bean productivity. MYMV is caused by Begomovirus species, which are spread by whiteflies (*Bemisia tabaci* Gennadius) and are preferred by the highest temperatures, humidity, and whitefly populations (Nair et al., 2019; Munawwar et al., 2014).

By decreasing seed germination, root and shoot lengths, fresh mass, and seedling vigor, salinity stress significantly lowers mung bean yield (Saha et al., 2010). This effect varies depending on the genotype (Misra and Dwivedi, 2004). Significant symptoms such as increased chlorosis, necrosis, and a decrease in the number of carotenoids and chlorophyll in mung bean are also brought on by salt injury (Wahid et al., 2004). NaCl stress caused a sharp decline in characteristics linked to root growth, which was more detrimental to roots than to shoots (Friedman et al., 1989).

5. Conclusion and Recommendations

More than 90% of mung bean is grown in underdeveloped nations, where there are numerous obstacles to implementing integrated management choices and small farmers lack enough expertise in integrated pest management. Plant extracts and other botanical items have also been proven to be useful in the treatment of foliar and root illnesses. Nevertheless, a large number of these investigations were restricted to greenhouse and/or laboratory settings. Therefore, in order to further leverage biological approaches and commercial applications, long-term field investigations are needed.

Although mung bean is sensitive to waterlogging, not enough germplasm has been studied for waterlogging tolerance.

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Chapter 12

PEANUT (*Arachis hypogaea* L.)

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DOI: https://dx.doi.org/10.5281/zenodo.17463083

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1. General Characteristics of the Peanut

Peanut (*Arachis hypogaea* L.) is an annual leguminous crop native to South America, with its natural distribution primarily concentrated between southern Bolivia and northern Argentina. It is believed that peanuts were introduced to Europe via North America by Spanish sailors (Pearman, 2005). Although the exact date of introduction to Türkiye remains uncertain, historical records suggest that initial cultivation occurred in the Thrace region, followed by its spread to the Aegean and Mediterranean areas (Atakişi, 1985; Arıoğlu, 2007).

Cultivated peanuts belong to two subspecies (hypogaea and fastigiata) and four varieties (hypogaea, fastigiata, hirsuta, and vulgaris). According to seed capsule structure and growth habit, peanut market types include Virginia, Runner, Spanish, Peruano, and Valencia. Virginia types exhibit semi-upright form, Runner types fully prostrate, and Spanish/Valencia types semi-to fully erect. Most cultivated varieties in Türkiye are from the Virginia group. In the Çukurova region (accounting for 95% of national production), the NC-7 variety which has a prostrate to semi-prostrate growth habit is dominant. Recently, varieties with semi-prostrate habit Osmaniye-2005, Sultan, and Halisbey have gained popularity.

Despite its broad cultivation range between 40° north and south latitudes, peanut is highly sensitive to environmental conditions. Particularly, the Virginia-type peanut requires an accumulated temperature of 2100–2500°C throughout its development. This period shortens with increasing temperatures (Banterng et al., 2003; Çalışkan et al., 2008). The vegetative stage is more susceptible to temperature stress than the generative stage. While temperatures exceeding 40°C may increase flower production during the flowering phase, they adversely affect fruit set and seed yield (Vara Prasad et al., 2000; Craufurd et al., 2002). Similarly, low temperatures delay flowering and consequently reduce yield (Talwar et al., 1999; Kumar et al., 2012).

Peanut is a self-pollinating species that contributes to soil fertility through its symbiotic relationship with Rhizobium bacteria, which enables the fixation of atmospheric nitrogen. It can provide an average of 15 kg of nitrogen per decare, thereby supporting both its own growth and that of subsequent crops in rotation (Karabulut and Tunçtürk, 2019). A substantial

degree of genetic variation exists among the cultivated peanut varieties (Singh and Simpson, 1994). However, to fully exploit this potential, appropriate varietal selection and the implementation of suitable agronomic practices are essential (Çalışkan et al., 2000).



Figure 1. Flowering of peanut plant

Accordingly, for successful peanut cultivation in new regions, it is imperative to introduce the crop to local farmers and to prioritize adaptation trials aimed at identifying regionally appropriate varieties.

Like other legumes, peanut enriches the soil by fixing atmospheric nitrogen and contributes organic matter, improving soil quality for subsequent crops. Studies have shown that peanut plants can fix approximately 4.5–15.0 kg of nitrogen per decare during a single growing season via their root-associated Rhizobium bacteria (Woodroof, 1983). As a row crop, peanut requires inter-row cultivation, which helps control weeds and aerate the soil. Thus, it is considered a valuable component in crop rotation systems.

Globally, peanut ranks fourth among oilseed crops, following soybean, cottonseed, and rapeseed (Arıoğlu, 2014). While global peanut production was 47.1 million tons in 2013, it increased to 54.3 million tons by 2023 (FAOSTAT, 2025). In Türkiye, peanut production in 2024 reached 246,796 tons over an area of 57,600 decares, with an average yield of 428 kg/da

(TUİK, 2025). Türkiye achieves an average yield approximately 2.5 times higher than the global average.

Peanut is one of the most suitable alternative crops in Türkiye's southern and southwestern coastal regions as well as in Southeastern Anatolia, due to its high yield potential and strong marketability. The majority of commercial peanut production is concentrated in provinces such as Adana, Osmaniye, Şırnak, Antalya, and Hatay (Table 1).

Table 1. Peanut planting area, production and yield amounts in Türkiye

	Adana	Osmaniye	Şırnak	Antalya	K.Maraş	Hatay	G.Antep
Planting (da)	265391	133943	84900	18732	16936	16747	14450
Production (ton)	116512	56954	36588	7487	6365	6950	6304
Yield (kg/da)	439	425	431	400	376	415	436

2. Cultivation Purposes and Nutritional Value of Peanut

Peanut (*Arachis hypogaea* L.) holds an important place in human nutrition due to its high content of oil (approximately 40–55%), protein (24–30%), and a range of vitamins and minerals (E, K, B1, Ca, Mg, P, S, K). Its tocopherol content extends its shelf life, and its high smoke point makes it a preferred oil for frying (Sarsılmaz, 2019). However, in Türkiye, it is primarily consumed as a snack. Peanut oil is widely used in India, China, and the USA and is rich in unsaturated fatty acids such as oleic (40–65%) and linoleic (20–40%) acids (Baydar, 2008).

Peanut oil is the fifth most produced and consumed edible oil globally, after soybean, palm, rape, and sunflower oils. Its high flash and smoke points mean frying equipment remains residue-free, making it highly favored worldwide for frying. In addition to oleic (40–65%) and linoleic (20–40%) acids, it contains saturated fatty acids such as palmitic (~7%) and stearic (~5%). Peanut oil is also utilized in the cosmetic industry, and in paint and soap production (Baydar, 2008). Over 90% of the world's peanut production takes place in Asia and Africa. Like the global trend, Turkish peanut production is mainly aimed at the domestic market.

The peanut shell contains approximately 6–7% crude protein, 1–2% oil, 60–67% crude fiber, 35–45% cellulose, 27–33% lignin, and 2–4% ash. Thus,

it is suitable for various uses, including particleboard production, animal feed filler, mushroom cultivation, fuel, artificial wood filling, charcoal, and as bedding in poultry and coarse forage in cattle rearing (Kadiroğlu, 2012).

After oil extraction, the remaining peanut meal contains about 45% crude protein, 24% nitrogen-free extract, and 5.5% mineral substances. Consequently, in developed countries, peanut meal is used in compound feed formulations. Being a legume, its fresh forage is directly fed to animals or baled when dried for winter feed. Its dry matter composition includes 11% protein, 5% oil, 22% crude cellulose, 42% nitrogen-free extract, 10% ash, and 10% moisture (Andrea and Palafoxdela, 1986; Eskalen and Yılmaz, 1993; Jagannathan et al., 1974).

3. Contribution of Peanut to Sustainable Agriculture and Food Supply Security

3.1. Contribution to soil fertility

As with all legumes, peanut plants fix atmospheric nitrogen in the soil through their root-associated Rhizobium bacteria. In addition to meeting their own nitrogen requirements, they enrich the soil with organic matter, benefiting subsequent crops (Coffelt et al., 1989; Suyundikov, 2020). Reports indicate that peanuts fix 15–20 kg/da and soybeans 25–30 kg/da of nitrogen via Rhizobium. While much of this nitrogen is used by the plants themselves, a portion remains available for subsequent crops, thereby enhancing soil fertility (Pattee and Stalker, 1995; Aksoy, 2016).



Figure 2. Peanut plant root, capsule image (Anonim, 2025).



Figure 3. Image of the peanut growing area

3.2. Its role in crop rotation

Although wild peanut species are perennial, cultivated peanuts are grown as annuals. As a hilling crop, they benefit soil by stimulating aeration and controlling weeds through inter-row tillage. Consequently, they prepare a clean, well-aerated seedbed for succeeding crops. Some oilseed crops with taproots also enhance nutrient availability from deeper soil layers, making them valuable in crop rotation systems (Torun and Uygur, 2019).

3.3. Usage as raw material in industry

Vegetable oils from oilseeds are used across various industries beyond food, including soap, shampoo, detergents, fabric dyes, cosmetics, pharmaceuticals, construction materials, pesticides, disinfectants, plastics, paper, adhesives, printing inks, and glass cleaner production (Arıoğlu, 2014). Peanuts are a rich source of oil, protein, carbohydrates, vitamins, and minerals, and their seeds are used for snacks, peanut butter, oil, soap, and in the bakery industry (Kadiroğlu, 2008).

3.4. Usage of post-harvest waste as green fodder

Post-harvest residues of oilseed crops like peanut are protein-rich and thus used as animal feed. Compared to wheat straw, they have higher nutritional value and are more readily consumed by livestock, contributing significantly to national animal husbandry (Wang and Huang, 2018).

4. Factors Limiting Cultivation and Usage of Peanut

The need for oil-type peanut varieties in Türkiye is rising due to a domestic oil deficit. To boost local production, production models guaranteeing purchase for industry should be encouraged, and certified seed use increased. Additionally, imports must be regulated to protect domestic farmers and preserve market balance (Sav and Sayın, 2016).

A major issue is the presence of aflatoxin-contaminated and unsafe snack peanuts, which damage the crop's image. Raising awareness at all stages—from producer to consumer—is crucial. Enhanced inspections and the proper disposal of unsafe products are necessary. Aflatoxins produced by Aspergillus species pose serious health risks (Williams et al., 2004), with improper drying and storage conditions exacerbating contamination. Therefore, hygiene standards must be strengthened, appropriate storage facilities expanded, and contaminated products destroyed. Modernizing storage to prevent conditions favorable to aflatoxin development, applying proper drying techniques, maintaining clean, disease-free warehouses, and preventing contamination during shelling are all imperative.

Quality attributes such as shape, size, color, kernel-to-shell ratio, oil and protein content, and annual fruiting consistency are critical. Varietal differences, moisture levels, and drying parameters significantly affect quality. Peanuts are highly susceptible to aflatoxin contamination, influenced by environmental factors like temperature, humidity, soil cultivation practices, and post-harvest rainfall. Protecting consumer health and farmer interests requires minimizing aflatoxin contamination, as failures impose severe economic consequences and deprive consumers of this valuable food (Williams et al., 2004).

5. Conclusion and Recommendations

A major concern in Türkiye is that aflatoxin-contaminated snacks damage the peanut's reputation. Strengthening inspection and ensuring the appropriate disposal of unsafe products are essential. Modernizing storage to control aflatoxin development, defining optimal drying methods, and maintaining clean, disease-free storage facilities are vital. Shelling processes must prevent aflatoxin formation. The low usage of certified seed among producers should be addressed certified seed production and its use should be

encouraged. To close the domestic oil gap, oilseed producers must be incentivized with guaranteed purchase models to increase production of oil-type varieties.

Türkiye faces challenges related to peanut imports. Standards should be defined, and quotas set to protect domestic producers and maintain internal market stability. Imported varieties should be assessed for adaptability to cultivation within Türkiye.

In summary, peanuts are highly valuable for Turkish agriculture due to their nutritional value, agronomic benefits, industrial applications, and role in crop rotation. Ensuring sustainable production and enhancing quality standards require focused efforts on adaptation trials, informed farming practices, varietal development, and strengthening the storage-hygiene chain.

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Chapter 13

RYE (*Secale cereale* L.)

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DOI: https://dx.doi.org/10.5281/zenodo.17463098

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1. General Characteristics of Rye

1.1. Origin and taxonomy of rye

It is thought that rye (*Secale cereale* L.) was first cultivated at least 2000 thousand years ago, or 4000 years ago according to some views, and that it spreads from Anatolia to the Balkans and Danube countries or from the north of the Black Sea to Europe. It is suggested that rye was grown in a very wide area, especially in Europe, in the Middle Ages. After the Renaissance, rye was seen as a more important crop than wheat and this continued until the 19th century. It was valuable cereal used in bread making at that time. After the 19th century, rye was rapidly replaced by wheat (Gökçora, 1969; Kün, 1988; Demir, 1983).

In Anatolia, it is widely thought that rye was a weed in wheat fields before it was cultivated as it is today. The origin of rye is considered to be Central Asia and Anatolia. There are many wild and cultivated forms of rye in Türkiye. It is accepted worldwide that Anatolia is a genetic center for rye due to its high level of genetic diversity (Kün, 1988; Yürür, 1994; Şehirali and Özgen, 1987).

The *Secale* genus belongs to the *Hordeae* tribe of the *Graminea* family. All ryes are grouped into two large groups (Kün, 1988; Yürür, 1994; Gökçora, 1969):

1) Wild ryes (*Agrestes*) group: In the rye species in this group, the fragile spike axis breaks apart and falls off at maturity. In these rye, a flower ties a grain in the spikelet. The grains are also small.
2) Culture ryes (*Cerealia*) group: This group includes transitional forms and culture forms. In rye in this group, the spike axis is not fragile. Grains are well developed and grain shedding is low. Grains are tied in two flowers in the spikelet.

Tetraploid Cultivated Ryes: Tetraploid (2n=28) rye varieties have been obtained by doubling the chromosome numbers of diploid (2n=14) rye varieties by various methods. Tetraploid rye has many agricultural advantages such as high grain yield, strong stems, low tillering and reaching maturity at the same time (Kün, 1988; Gökçora, 1969; Geçit et al., 2018).

1.2. Plant properties

Root: Rye is a plant with a hairy root system. The root system is quite strong. Rye roots go down to a depth of 2 m. Due to these root features, rye can grow better in arid and barren soils compared to other cereals. In addition, the strong root system close to the surface makes rye a good protective plant against soil erosion (Yılmaz, 2016).

Stem and Leaves: Stem is generally longer in rye than in wheat. It reaches a height of 1.1-2.0 m. Stem thickness and length vary depending on the variety with higher values especially in tetraploid cultivars (Figure 1). Stem is usually thin in dark-grained rye of Central and Western Anatolia and has 7 or 6, sometimes 5, rarely 4 nodes (Yılmaz, 2002).



Figure 1. General view of the rye plant

Leaf blade is similar to wheat leaf in terms of shape and size. However, rye leaf is narrower and more pointed than wheat. The ear is short and bare, the collar is short and blunt. Winter rye leaf is more bluish green than wheat. Leaf color, size, waxiness vary depending on whether the variety is summer or winter. Color is darker and leaves are narrower in winter forms. Winter rye shows a distinctly slanted growth form in the pre-stemming period (Yılmaz, 2016).

Spike, Spikelet, Flower: The flower group of rye is a spike (Figure 2). Sometimes spike can branched (Figure 3). The spike length is between 5-15 cm. A spikelet emerges from each node on the spike axis. The number of spikelets in a spike is approximately 30-35.



Figure 2. Spike and inflorescence in rye plant



Figure 3. Branching of the spike in rye plant

Spikelet glumes are narrow and short. There are usually 2, sometimes 3 florets in a spikelet. In cultivated rye, the bottom two of them are fertil. Hermaphroditic flowers contain three stamens, a pistil and a pair of lodicules (Yılmaz, 2016). The awn length can be 3-8 cm. Rye is a cross-pollinated plant

Grain: Rye has a naked grain that is thinner and longer than than wheat grain. The thousand seeds weight varies depending on the variety and is approximately 20-30 grams. In rye, there is a clear confusion in terms of grain

size and color. Tetraploid rye has a more uniform grain in terms of color and size.

The grain contains approximately 14% moisture, 69% N-free extract, 11% crude protein, 2% digestible fat, 2.5% crude cellulose, 1.8% crude ash. The fat ratio in the embryo is 12.4%. Hectolitre weight is 70-75 kg.

The color of rye grain can be black-purple, light and dark brown, light green, bluish-green, dark green, light and dark gray, gray-yellow or yellow. The preferred grain color is light green.

The color of grains is the result of different pigmentations and thicknesses in the aleurone, seed coat (testa) and fruit coat (pericarp) layers. It is known that dark color is dominant over light color in rye (Kün, 1988).



Figure 4. Appearance of grains on the spike of rye plant

1.3. Adaptation of rye

Many varieties of rye are quite resistant and tolerant with cold and winter, sandy, acidic or alkaline soils. For this reason, rye is mostly a cereal of northern countries and highland climates. The main planting area of rye on earth is a wide strip starting from the Ural Mountains in Russia and extending to Poland, East and West Germany and the Netherlands. Rye is also planted in certain parts of Sweden and Norway in the north of this area, in the mountainous regions of France, in the Danube and Balkan countries, in Türkiye and Iran, in the USA and Canada, and in the Southern Hemisphere in Australia, Argentina and South Africa (Kün, 1988; Yılmaz, 2016).

Climate Requirements: Rye is the type of grain with the lowest temperature and humidity requirements. The minimum germination

temperature is 1-2 ^{0}C. During the germination and initial development period, the rye plant continues to grow slowly at temperatures just above zero degrees. Rye is the most resistant to low temperatures among the cereals. There are varieties that can withstand temperatures of -30 ^{0}C and below without snow cover. Rye, which has a slow initial growth, develops quickly and quickly in the spring when the weather is just warming up. Thus, it benefits well from winter moisture and reaches maturity before other winter cereals. The total temperature requirement of winter rye during its vegetation period, which can be 250-320 days, is 2250-2950 ^{0}C (Kün, 1988; Geçit et al., 2018; Yürür, 1994).

Rye, which is more adapted to the highland climate, wants the period between tillering and heading to be cool and overcast, and the weather to be hot and dry with heading. Flowering begins when the air temperature reaches 12 ^{0}C.

Since it is a wind pollinated plant, rainfall during flowering disrupts fertilization.

Since rye has a strong root system, it can take the necessary water from the soil more easily than other cereals. Rye planted in autumn does not need much moisture for tillering and initial development. Cool weather in spring increases the yield in rye. For a good product, 350-450 mm of rainfall distributed throughout the vegetation period is sufficient (Kün, 1988; Yürür, 1994).

Soil Requirements: Rye is not selective in terms of soil requirements. Rye provides sufficient yield in low-yielding and sandy soils where other grains cannot grow. However, the best rye soils are sandy loam and silt soils.

Rye is one of the first plants to be grown in marshland cultivation. Since it is also resistant to high salt concentrations, it can grow in barren soils. Rye likes high rainfall in permeable sandy soils and does not like heavy soils. If the soil water exceeds 70% of its capacity, rye suffers from lack of air (Kün, 1988; Geçit et al., 2018; Yürür, 1994; Gökçora, 1969).

1.4. Turkish ryes

Since Türkiye is the gene center of rye, it is possible to find all wild forms in almost every region. For this reason, rye, which has a wide variety of forms in Türkiye, has been the subject of study for many local and foreign researchers.

The few studies conducted on Turkish rye until the first quarter of the 20th century were focused on collecting materials from a narrower area due to limited transportation opportunities at the time (Yılmaz et al., 1996). Extensive studies on Turkish rye began with materials collected by Zhukovsky and his colleagues in Anatolia (Kün, 1988).

Turkish rye is very diverse both phenotypically and genotypically. The richest form is seen in the Eastern Anatolian provinces. In Eastern Anatolian ryes, the spike color is yellow, red, brown, gray, black and various shades of these. In these ryes, the spike axis is brittle and the glumes are thorny. Especially in the ryes of Erzurum, Ağrı and Van provinces; the uniformity seen in terms of grain size, shape and color is important. In Central and Western Anatolian ryes, on the other hand, they generally have white spikes and solid spike axes (Kün, 1988).

The ratio of winter and spring forms is low in Turkish ryes. Since the majority of ryes have a heterozygous genetic structure; they also show a mixed situation in terms of life and development forms. Winter forms are generally seen in populations east of the Niğde-Sivas line (Kün, 1988; Yürür, 1994).

It is possible to classify Turkish rye into two groups in terms of ear and grain color:

1. Varieties with ears ranging from brown to gray-black and grains that are light dark greenish brown: The grains of these varieties are glassy, the plants are thin-stemmed and short compared to the other group. These varieties are adapted to alkaline soils. These types are found in salty sandy soils in Central Anatolia and Geçit regions.

2. Varieties with yellow, reddish yellow ears and green, gray grains: The grains of these varieties are floury. They grow mostly in the Black Sea coastal region and on mountain slopes, high plateaus, in sandy soils on the slopes of valleys with high relative humidity in Eastern Anatolia and high plateaus. They require high humidity. They are resistant to acidic soils.

Spike and grain color variation is very high in Turkish rye. In the advanced rye culture countries of the world, the spike color of rye is white and the grain color is green-grey. In Türkiye, wild and cultivated forms have been constantly mixed as a result of foreign pollination. It is not possible to get a homogeneous colored product in any rye field (Kün, 1988; Yürür, 1994; Gökçora, 1969).

2. Cultivation Purposes and Nutritional Value of Rye

12,680,515.5 tons of grain rye is produced in the world. Europe has the highest production in the world. This is followed by Asia, America, Africa and Oceania, respectively. When examined at the country level, the highest rye production is in Germany. This is followed by Russia and Poland, respectively (FAO, 2023).

In Türkiye, grain rye production is 257,000 tons. Forage rye production is 163,110 tons (TÜİK, 2024).

Rye is used as an additive to wheat for bread in Central and Eastern European countries, and as a raw material for the alcohol and whiskey industry or as animal feed in other countries.

Most of the rye produced in Türkiye is used for bread, while a small portion is used as feed. Although the biological value of protein is generally not very high in grains, rye protein has a value that should not be underestimated in terms of both quantity and quality. The protein ratio in rye grain is slightly lower than in wheat. The average protein, which is 11%, consists of 42% gluten, 42% gliadin, 8% globulin and 8% albumin. Rye bread is heavier than wheat bread. The specific gravity, which is 0.2-0.4 grams in wheat bread, is at least 0.35 grams in rye bread. While wheat bread rises well, rye bread does not rise well and gives the impression of uncooked brown dough (Anonymous, 2025a; Kün,1988; Demir, 1983; Yürür, 1969). Despite this, rye flour, which has good bread quality, has high dough and bread yield, its dough has a good and loose structure and its starch is easily kneaded (Demir, 1983).

In addition, rye bread improves digestion and fat distribution in the body, is rich in nutritional values, keeps blood sugar levels at a healthy level, and gives a feeling of fullness. It reduces the risk of cardiovascular disease and gallstone formation. In this respect, it is important. Evaluation of rye as

feed: The feed value of rye grain is quite high. It is given to animals as crushed and mixed with other grain feeds. It is also used as concentrated feed in ruminants and poultry. However, rye used as feed has sometimes been seen to be harmful to the growth of young animals. It has been understood that this damage is due to the substances in rye oil (Kün, 1988; Demir, 1983). Rye grains contain K, Ca, Mg, P, S, Zn, Cu, Fe, Mo, B, Mn (Bağcı et al., 2019; Demirbaş, 2005), Na, Pb, Ni, Cr (Kan, 2015) minerals and beta glucan (Demirbaş, 2005).

Rye is also used as roughage and concentrated feed in animal feeding. It can be used as roughage by mowing and drying hay during the grass harvest period, processing into silage or grazing in the form of rotation pasture, and the straw remaining after the seed harvest can also be used as roughage. Rye is grown alone for the purpose of hay production, as well as planted in mixtures with legumes or other cool-season cereals. When the studies are examined, it is seen that rye is planted as binary mixtures with common vetch (Kuter, 2022), Hungarian vetch (Çetin Zengin, 2022; Yolcu et al., 2009; Çopur Doğrusöz et al., 2023a), hairy vetch (Gökdemir, 2019), forage pea (Kır, 2022; Çopur Doğrusöz et al., 2023a) and wheat (Güney, 2020) from cereals. In addition, it is seen that rye is grown as a triple mixture with common vetch + wheat, as a quadruple mixture with common vetch + triticale + wheat, and as a quinary mixture with common vetch + forage pea + wheat + oats (Kuter, 2022). Some results are given in Table 1.

Table 1. Hay yield and quality of rye-legume mixtures in different locations in Türkiye

Place of study	Mixture and harvest time for highest hay yield	Hay yield (kg/da)	CP (%)	ADF (%)	NDF (%)
Kırşehir	20% Hungarian vetch + 80% rye; milk maturity period of rye	918.6	8.23	41.93	59.70
Kırşehir	20% fodder pea + 80% rye; fodder pea full bloom period	708.1	9.9	38.1	56.6
Bingöl	40% hairy vetch + 60% rye; when lower pods are formed in hairy vetch	781.9	12.93	47.3	70.1
Van	50% wheat + 50% rye; 80% wheat when in bloom	729	7.02	37.16	65.68
Gümüşhane-Kelkit	8 kg Hungarian vetch + 4 kg rye; during the milk formation period of rye	380-1288	11.66-8.84	34.69-34.07	62.40-55.90
Yozgat	80% rye + 20% Hungarian vetch; when rye spikes	1995.2	16.84	29.25	56.50
	80% rye + 20% fodder pea; when rye spikes	1953.1	17.58	32.39	59.99

(Çetin Zengin, 2022; Kır, 2022; Gökdemir, 2019; Güney, 2020; Yolcu et al., 2009; Çopur Doğrusöz et al., 2023a)

Rye is also harvested for hay production when grown as a single crop. The hay yield and hay quality values of rye at different stages in the experiments conducted in Türkiye are presented in Table 2. As it is known, the harvest time includes the development period of the plant and the climate factors experienced. Therefore, the forage yield and quality in plants vary depending on the harvest time. Hay quality decreases as growth and development progress in all plants. The decline in quality accelerates in the generative phase in cool-season cereals, so harvest timing is crucial.

Table 2. Hay yield and quality of monoculture rye harvested at different growth stages

Location	Harvest stage	Hay yield (kg/da)	CP (%)	ADF (%)	NDF(%)
Kırşehir	Booting	463.2	10.60	36.27	49.03
	Flowering	718.5	9.03	38.33	52.60
	Milking	835.1	8.07	43.47	61.57
Yozgat	Preheading	521-1350	10.13-22.1	19.03-37.10	47.25-69.42
	Full flowering	827-1718	8.14-16.5	32.21-40.61	65.74-73.47
	Post fertilization	1235-1744	8.35-14.1	31.56-41.07	63.90-76.71
	Milking	523.0-574.9	11.12-12.37	35.24-37.90	58.77-61.07
	Ear emergence	1988.2	15.66	33.24	65.02
Kelkit	Milking	506.5-1146.8	5.75-4.59	41.08-36.00	70.88-64.04
Kırşehir	Early flowering	833.3	8.5	39.5	61.3

(Çetin Zengin, 2022; Bulut, 2021; Erbaş Köse et., al., 2019; Yolcu et al., 2009; Kır, 2022; Çopur Doğrusöz ve ark., 2023a)

Rye can also be grown for silage. In the rye silage harvested at the heading stage an ensiled in vacuum bags, the pH was determined as 5.07, CP %6.44, ADF and NDF ratios as %46.83 and 74.30, respectively. However, when vetch harvested at full bloom stage was added to rye silage, it was observed that the CP and digestibility rate of the silage increased and a mixture of 75% vetch + 25% rye was recommended for silage (Görü and Seydoşoğlu, 2021). Cereals are more suitable for for silage making than legumes in terms of carbohydrate/protein content, but it is important to pay attention to the amount of air remaining in the silage when compressing the silage in cereal species with empty internodes. Possible negativities that may occur in the silage can be prevented by adding different layered materials to the silage. Adding lactic acid bacteria + enzyme inoculants to the rye grain harvested during the dough formation period increased both the fermentation and stability of the silage and the organic matter digestibility (Uğurlu, 2019).

In another study, the pH of rye silage was determined as 4.74, sucrose, CP, ADF and NDF ratios were determined as 4.50, 6.41, 39.76 and 70.72%, respectively (Çopur Doğrusöz, et al., 2023b).

The fact that there is a great deficit of quality roughage in Türkiye and that cool climate cereals are grown in large quantities causes our farmers to use cereal straw as roughage. Rye straw is also evaluated as roughage. However, its crude protein content and digestibility are quite low (Table 3). In

addition, rye straw comes last among cool climate cereals in terms of animal preference (Başaran, 2024).



Figure 5. Harvesting green grass in rye plant (before heading)

Rye can also be used in temporary pasture facilities by grazing in early spring. For example, in America, rye was planted in the fall and grazing was started when it reached 15 cm in the spring during the stem elongation period. Grazing continued until half of the grass in the plot was eaten and rested for an average of 16 days. Grazing completed when the plants flowered (Phillips et al., 2020). It is also possible to apply in Türkiye. Thus, we can also reduce the grazing pressure on the pastures.

Table 3. Some quality values of rye straw

	Dry matter (%)	Crude protein (%)	Crude oil (%)	Crude fiber (%)	N-less substance (%)	Crude ash (%)	Metabolizable energy (kcal/kg)	
	92.4	3.6	1.5	36.4	38.6	12.3	1397	
Rye straw	Organic matter (g/kg dry matter)	Crude protein (g/kg dry matter)	Crude oil (g/kg dry matter)	NDF (g/kg dry matter)	ADF (g/kg dry matter)	Lignin (g/kg dry matter)	Neutral detergent-soluble carbohydrates	Metabolizable energy (MJ/kgdry matter)
	962	25	8	844	544	55	85	5.1

(Başaran, 2024; Lopez et al., 2005.)

In addition to its consumption as bread and animal feed, rye is also used in various industrial branches. It is used in the industry in the production of spirits, the alcohol industry and whiskey. It is desired that the rye to be used in the distillation industry should be light-colored and have full grain. On the other hand, rye is also used in roofing, mattress filling, knitted hats, paper and cardboard production due to its thin, long, flexible and strong stalks.

3. Contribution of Rye to Sustainable Agriculture and Food Supply Security

Due to the effects of many factors such as misapplication of modern agricultural production techniques, monoculture farming, climate change, increasing population, misuse of quality agricultural lands, there are decreases and fluctuations in plant production and problems arise in meeting the food supply.

One way to increase crop production is to increase agricultural lands. At this point, Türkiye has no chance of adding new land to the existing land.Therefore, plant production constitutes an important resource in areas where salinity, acidity, alkalinity are experienced, in barren soils, and in regions where cold and drought are problems. Rye can grow better than other cool season cereals in areas where the problems mentioned above occur.

As a result of climate change recently, autumn is warmer and drier, and winter is generally without snowfall. These changes delay the sowing time in fall, and cause plants to spend the winter without snow.As is known, the presence or absence of snow cover in winter is of great importance for winter survival and to meet the water needs of the plants. Since rye can resist (-30) ^{0}C without snow cover, it will gain much more importance in changing climate conditions with this feature. When there is no snow, the soil temperature and air temperature have closer values. For this reason, especially in cold regions of Türkiye, rye will become an important species again with its resistance to cold during periods when there is no snow. Rye also ripens earlier in spring than the other cool climate grains. When it is considered that drought will increase even more, earliness will be a very important feature in terms of food security.

In Türkiye, approximately 4 million hectares of agricultural land are left fallow every year. While fallowing is mandatory in some regions,

fallowing is continued as a habit of farmers in some regions. Rye is a very important plant in reducing or completely eliminating fallow areas. Rye can be planted in fallow areas either alone or mixed with Hungarian vetch or hairy vetch. Whether planted alone or mixed in fallow areas, it would be appropriate to harvest the plants for seed so that the field remains covered with plants for a longer period. In addition, in these areas, it would be advantageous to apply "stubble fallow" without tilling the soil after harvest.

One of the most important areas of use of rye in plant production is its cultivation as a cover crop. Here, it is cultivated in order to prevent erosion, suppress weeds, and add organic matter and water to the soil by preventing the fields where summer crops are grown from remaining empty during the autumn-spring period. However, to grow summer crops immediately after rye as the winter cover crop, either the summer rainfall should be relatively sufficient and regular, or there should be irrigable areas. Therefore, considering the ecological and geographical conditions, and the irrigability of agricultural lands in Türkiye, using rye as a winter cover crop and its cultivation instead of fallow in fallow regions in Türkiye will both provide significant production and enable the benefits mentioned above to be utilized.

4. Factors Limiting the Cultivation and Use of Rye

As is known, the increase in the world population brings with it nutritional problems and causes the rapid depletion or destruction of natural resources. Rye, a member of the Poaceae family and cultivated worldwide, including in Türkiye, is a plant of great importance due to its fundamental role in both human and animal nutrition. Hardest changes have occurred in the cultivation areas and production amounts of rye worldwide and in Türkiye in the last 50 years. Despite technological developments and increases in agricultural productivity during this period, there have been continuous decreases in production. World rye production decreased from 27.677.000 tons in 1970 to 11.681.000 tons in 2024. Similarly, rye production in Türkiye decreased from 803.000 tons in 1970 to 305.000 tons in 2023 (Table 4). The yield increased from 1,382 kg/ha in the world in 1970 to 3.185 kg/ha in 2023. Similarly, in Türkiye, the yield increased from 1,150 kg/ha in 1970 to 3.080 kg/ha in 2023. Although the yield have approximately doubled in both the

world and Türkiye in the last 50 years, it is noteworthy that there have been significant decreases in sowing area and production.

Today, the provision of plant production required for the food and feed needs of the increasing population and animal wealth depends on increasing the yield obtained from the unit area. Yield increases can be achieved either by developing genetic potential or by reducing negative environmental factors that limit yield.

It is seen that the problems encountered in rye production in Türkiye are generally the problems experienced in farmership. Small enterprises and cultivation in very fragmented lands reduce the use of modern cultivation techniques and reduce productivity. A significant portion of small pieces are completely out of production.

Table 4. The world and Türkiye have been dealing with rye sowing areas, production and yield for many years.

Years	World			Türkiye		
	Cultivation Area (1000 ha)	Production (1000 Ton)	Yield (kg/ha)	Cultivation Area (1000 ha)	Production (1000 Ton)	Yield (kg/ha)
1970	20 027	27 677	1 382	698	803	1150
1980	16 306	25 377	1 556	443	525	1186
1990	16 815	38 193	2 271	158	240	1520
2000	9 830	20 107	2 045	147	260	1770
2010	5 021	11 916	2 373	141	366	2590
2020	4 550	15 505	3 408	104	296	2830
2021	4 385	13 476	3 073	98	200	2000
2022	4 093	13 476	3 293	98	273	2790
2023	3 981	12 681	3 185	99	305	3080
2024				91	257	2820

Source: (FAO, 2023; TÜİK, (2024)

Rye production in Türkiye is intensively carried out under rainfall, and drought and extreme temperatures experienced during sowing and heading periods cause significant fluctuations in production.

As in other field crops, pricing policies are an important factor in production in rye. The unit price given to the product and the prices of inputs cause significant changes in production by changing the size of the sowing

area or affecting the yield. Since product prices are low and inputs are expensive, the use of inputs decreases, which leads to a decrease in production and product quality. In addition, the increase in seed, fertilizer, pesticide and fuel prices increases the production cost. In the face of high costs and low prices, producers tend to produce more profitable plants.

Considering the decreasing agricultural lands in Türkiye, it is normal to be concerned about the future. Although rye yield is above the world average, it is not at the desired level. Among the elements affecting production and included in agricultural techniques, the importance of applications such as variety, seed, soil processing, fertilization, plant protection, harvesting and threshing processes has always been explained at every opportunity. However, despite the technological level generally reached by rye producers, the knowledge and experience gained on the subject, problems under these headings are still continuing at a rate that cannot be ignored (Kınacı et al., 2010).

Variety: Using high-yielding varieties is important for increasing rye production in Türkiye. It is especially important to use suitable varieties that are resistant to biotic and abiotic stress factors and certified seeds. Varieties that are highly adaptable to the ecological conditions of the region where they are grown should be preferred. The order of priority in these factors changes according to the market or producer's request or environmental conditions. A variety that is well adapted to a region, has high yield, good or sufficient quality can find a wide sowing area and reach much production amounts (Kınacı et al., 2010).

Seed: The use of quality seeds is very important in ensuring yield and production increases. Genetic structure of the seed has a special importance for yield and quality. The fact that the use of certified seeds in Türkiye has not become widespread indicates that rye producers either separate the majority of seeds from their own production or procure them from each other. Due importance should be given to breeding and adaptation studies aimed at developing new varieties that are compatible with local conditions and superior to existing varieties. With the organizations to be made between the relevant institutions, it is necessary to produce sufficient certified seeds for the rye varieties recommended according to the regions. In order to increase the planting areas of these varieties more rapidly, small sample studies should be

conducted in comparison with local varieties under farmer conditions, the recommended varieties should be better introduced to farmers and their superiority should be demonstrated.

Soil processing and planting: The main purpose of soil processing is to provide the most suitable environment for plants to grow, develop and produce products. For this, it is very important to use the most suitable tools correctly at the most suitable time.

In places where dry farming is done in Türkiye, a significant number of farmers apply fallow. They think that the main purpose of fallow is to rest the soil. However, they unfortunately do not know that the main purpose of fallow is to store water in the soil as much as possible during fallow and to protect it as much as possible, and therefore the selection of soil tillage methods and ploughing tools to be used during fallow time and fallow is very important. In areas where the wheat-fallow system is applied, the first soil tillage should be done in spring when the soil is mellow, but it is sometimes delayed until the end of June. In addition, superficial soil tillage such as doubling and tripling, which should be done according to the weeding status of the field, is neglected. In Türkiye, depending on the region, the first tillage in fallow lands should be done in March-April when the soil is mellow, with a plough with a reduced ear, 15-20 cm deep, parallel to the leveling curves (perpendicular to the slope) and without turning over the soil (tearing it). The field should be checked at certain intervals, especially after spring rains, and when approximately half of the field surface is covered with weeds, doubling should be done with a cultivator at a depth of 8-10 cm. In the event that weeds develop again in the field, the depth of the tripling to be done with the cultivator should be 5-8 cm (Bulut, 2017).

For high yield, sowing time has a special importance among cultural practices. The importance of sowing time is widely known by farmers. Farmers are well aware of the relationship between sowing time, sowing depth and the critical moisture content for germination. Rye is generally sown in winter in Türkiye. Although the sowing time varies by region, it is done in September - November. It does not cause any problems.

Sowing is usually done with a drill. Sometimes broadcast sowing is done on sloping lands and in small farms. When drilling, plant density and sowing depth can be adjusted, less seed is used, fertilizer can be given to the

seed bed, the more uniform germination and a good plant establishment and higher yields are obtained. Therefore, broadcast sowing should not be used unless necessary.

One of the important factors determining the yield in rye is the seeding rate and, accordingly, plant density. In sparse sowing, the field cannot be utilized sufficiently, the weed problem increases and the yield decreases (Akkaya 1994). Seed count in Türkiye is 500-600 seeds/m^2, and although it varies depending on the seed size, seeding rate generally equiponderates to 16-18 kg/da of seed (Erbaş Köse and Mut, 2022). Sowing depth of 2-3 cm is sufficient.

Plant nutrition: Plants need to sufficient and correct nutrients in order to grow, develop and crop. Since plants largely obtain their nutrition from the soil, nutrients removed from the soil or lost in various ways need to be replenished to the soil.Due to the high fertilizer prices in Türkiye, not enough fertilizer is used or especially in small farms, no fertilizer is used at all. This significantly reduces production. In this respect, rye is an important cereal. Rye does not require much fertilizer. Rye has a good ability to scavenge residual soil nutrients. The main nutrient intake occurs during the stem elongation period. Excess nitrogenous fertilizer should be avoided in the spring. Excess nitrogen causes lodging. Phosphorous fertilizers provide a significant increase in the yield in rye. In fields where the pre-crop is fertilized, rye does not need to be fertilized. 4 kg nitrogen (N) and 4-6 kg phosphorous (P_2O_5) can be applied per decare. All phosphorous and half of the nitrogen can be given at sowing and the rest of the nitrogen during the stem elongation period.

Plant Protection: Rye is not affected much by diseases and pests that cause significant damage to other cereals. Rye spur (*Clavicepspurpurea*) is the most important disease of rye. The disease agent is a fungus. Instead of a grain on the spike, it creates a long, spur-shaped protrusion that is larger than the purple-black grain. The disease can be prevented by using clean seed and not sowing rye in the ergot infected field for a few years.

Input Use and Capital Status: To obtain higher yield and higher quality crops in plant production, new and necessary technological inputs must be used. However, the widespread use of new technology and inputs is possible if farmers have sufficient capital and technical knowledge. The fact that the

vast majority of agricultural enterprises in Türkiye are small scale and family-owned enterprises, the small and fragmented lands, and the inadequacy of capital in enterprises restrict the timely and sufficient use of inputs such as mechanization, fertilization, agricultural control, etc. in agriculture, and this situation causes decreases in quantity and quality in rye production as well as in grain production. Agricultural support provided to farmers should be increased, and the supply of basic inputs such as cheap fuel oil, agricultural implements and machinery, fertilizers and pestidices should be facilitated. In addition, costs should be reduced by establishing joint use of agricultural machinery among unions, cooperatives and small farmers in the village. In this way, mechanization in agriculture is increased.

Educational Status: The educational status and age of farmers are very important in adapting to new technology and production techniques and changing conditions. Since an effective relationship cannot be established between agricultural research aiming to achieve high yields and agricultural publication activities aiming to convey the results to farmers and other users, the expected benefits from these researches cannot be obtained. Restructuring in relevant institutions and ‘‘research and publication’’ activities should be handled together, farmers’ problems related to production should be continuously conveyed to researchers, and a mechanism should be established where research results are rapidly conveyed to farmers by giving importance to trials under farmer conditions. In farmer training, the Agriculture and Veterinary Faculties of Universities with extensive research and knowledge and the Research Institutes of the Ministry of Agriculture and Forestry are not assigned/recruited. Farmer training is only provided by technical staff in the Provincial Directorates of the Ministry of Agriculture and Forestry. These staff also provide theoretical training in villages and coffeehouses that do not have an educational environment (Bulut, 2017). This is not enough. In addition to theoretical knowledge, practical training should also be provided to farmers by technical staff who are experts in the field.

5. Conclusion and Recommendations

Rye, cultivated worldwide and also in Türkiye, has a great importance due to its fundamental role in both human and animal nutrition. On the other hand, rye is quite resistant and tolerant of cold weather and winter, sandy acidic or alkaline soils, and is also quite easy to grow. Despite this, it is seen that the necessary importance is not given to rye production. Cultivation areas and production are decreasing day by day. At this point, the fact that rye farming is very similar to wheat farming and the abundance of local varieties appear as important advantages in increasing rye production in Türkiye. When the increasing population and changing climate conditions are considered together, it is clear that especially in Türkiye, rye production should be self-sufficient and even exportable. For this, the protection of cultivation areas, reduction of production costs, development of varieties suitable for ecologies, and prevention of product losses are among the main issues that need to be emphasized. Plant and animal production; It is a profession and science that is socially, environmentally and economically indispensable and whose importance is expected to increase.

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Chapter 14

SAFFLOWER (*Carthamus tinctorius* L.)

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DOI: https://dx.doi.org/10.5281/zenodo.17463107

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1. General Characteristics of Safflower

Safflower (*Carthamus tinctorius* L.) is an annual industrial plant belonging to the Asteraceae family with a chromosome number of 2n=24. Wild safflower species have also been discovered in many parts of the world, including Turkiye. The diploid chromosome numbers of these wild species have been determined to be 20, 44, and 64 (Knowles, 1958). The Latin name Carthamus is thought to have originated from the Arabic words “quartum” or “qurtum.” The meaning of this Arabic-derived word refers to the orange-red color obtained from its flower (Singh and Nimbkar, 2006). The origin of the safflower plant has not been fully determined. In the past, according to Kupzow, the origin of safflower’s was based on three gene centers (India, Abyssinia, and Afghanistan) (Kupsow, 1932). Today, however, the boundaries have been expanded to include the Arabian Peninsula within the circle of origin (Ruyvaran et al., 2022). The systematics of the safflower plant are as follows; Kingdom: Plantae (Plants)

Division: Magnoliophyta (Angiosperms)

Class: Magnoliopsida (Dicotyledons)

Order: Asterales (Composite Flowers)

Family: Asteraceae

Genus: Carthamus

Species: *Carthamus tinctorius* L.



Figure 1. Safflower plant (Anonymous, 2025)

To date, 25 different species of safflower have been taxonomically recorded worldwide. However, the species cultivated for agriculture is *Carthamus tinctorius* L. Wild safflower species include *Carthamus lanatus, Carthamus oxyacanta,* and *Carthamus flavescens Spreng,* which was discovered within the borders of Turkiye (Anonymous, 2022; Ashri and

Knowles, 1960; Hanelt, 1961; Singh and Nimbkar, 2006). Additionally, these wild species are important as genetic material in breeding studies (Ahlawat, 2008). Breeding studies are very important for increasing yield and quality, but there are many factors that affect yield. For example, when the planting, sowing, cultivation, or harvesting and threshing of plant groups with underdeveloped mechanization cannot be adapted to mechanization, breeding is also necessary to adapt the plant material to agricultural methodologies. For example, the formation and breeding of thorny and thornless forms of the flax plant over the years can be cited as an example.

The thistle plant belongs to the class of plants from which oil is obtained from the seeds. In addition, due to its many uses, it is one of the plants cultivated worldwide for various purposes. As a result of these various uses, it has been named in different ways around the world. Its most common name worldwide is "Kusum-Kusumbha," which originated in India and spread across the globe (Dajue and Mündel, 1996). The flavonoid derivatives carthamin (orange-red) and carthamidin (yellow) found in safflower flowers are responsible for the red-orange color. Because of this feature, it has been associated with saffron (*Crocus Sativus* L.). So much so that the dried and ground flowers of the safflower plant are often used as an adulterant in cheap saffron sold on the market. Due to its similarity to saffron, safflower is known in Europe as "American saffron," "dyer's saffron," and "Mexican saffron." In Turkiye, it is generally known as safflower, but in different regions it is known as haspir, haspur, kır safranı, zaferan, and sahte safran (Taşlıgil and Şahin, 2016).

1.1 Origiand history of the safflower

The safflower plant, known worldwide as false saffron and dyer's saffron, is a plant native to Asia. It is believed to have spread throughout the world from this continent. Archaeological excavations have revealed that safflower was first cultivated in Egypt around 3500 BC. In addition to these findings, it was cultivated in Japan, India, China, and Iran; in the Middle Ages in Spain, France, and Italy; and after the discovery of the American continent in Mexico, Colombia, and Italy. These countries cultivated the plant for dye, food, and medicinal purposes. It is also known that it was later cultivated for its oil. The safflower plant was brought to Anatolia by Turks migrating from

Central Asia. It was first cultivated in the province of Balıkesir between 1940 and 1945. The first varieties brought were thorny varieties. In many regions, the Turkish people referred to safflower as zerdeçal, haspir, and thorny Safflower.

In Chinese, Pakistani, Bangladeshi, and Egyptian medicine, tea made from safflower flowers was used to relieve menstrual pain, bloating, and edema, as well as for heart and vascular diseases and to lower blood pressure. They prepared ointments by mixing safflower seed oil with mustard oil to heal wounds. In these countries, they consumed all parts of the plant for different purposes, benefiting from it both as food and for medicinal purposes. In particular, they used the yellow-red colors of the flowers to dye the foods they consumed and the fabrics they wove. Today, it is frequently used for this purpose in foods, and even dried safflower flowers are added as an adulterant to saffron purchased from herbalists. In the textile industry, safflower flowers are used for dyeing fabrics only by the local populations of some Asian countries.

The first cultivation techniques and breeding studies for safflower in our country were initiated in the 1920s at the Sazova Seed Improvement Station in Eskişehir; however, these studies were interrupted due to World War II. In 1936, the first studies yielded results, and our first thornless variety, named "Yenice 1813," was registered. The oil deficit in our country has increased over the years. In 1958, Safflower cultivation and breeding studies were brought back to the agenda in order to close this deficit. Safflower reached its golden age in our country in the 1970s, with the highest level of cultivation area reaching 2,200 ha (anonymous, 2006).

1.2 . Morphologıcal characterıstıcs of the safflower plant

1.2.1. Root

The safflower plant has a strong taproot system. Safflower roots can reach a depth of approximately 2-3 m in the soil (Anonymous, 2025b; Günal, 2001). Thanks to this strong root system, safflower is cultivated both in summer and winter. The root system plays a significant role in nutrient uptake and surviving harsh conditions, especially during the winter season. Additionally, the root system makes it a suitable plant for utilizing barren and fallow lands, as safflower is drought- and cold-tolerant. It requires less

nutrients compared to many oil crops. Furthermore, its strong root system aerates the soil, regulates microbial activity, maintains soil moisture balance and capacity, holds the soil firmly, preserves its aggregate structure, prevents erosion, and improves soil quality. With these characteristics, Safflower is a valuable plant in terms of both economic and ecological sustainability (Anonymous, 2025b; Yıldırım, 2021).

Studies have shown that the roots of the Safflower plant exhibit allelopathic effects on subsequent plants (Day, 2016; Kulan et al., 2020). Allelopathic effects can be described as chemical substances secreted by plants into the soil through their organs. These substances can negatively affect the growth of other plants and weeds in the soil. These chemical substances can limit plant growth or even cause death by affecting the plant's energy production, protein, fat, and carbohydrate synthesis, hormone synthesis, nutrient uptake, stomatal condition, and water absorption (Li et al., 2010). According to research, stubble remaining in Safflower fields has been found to have an allelopathic effect on sunflower (*Helianthus annuu*s L.), rapeseed (Brassica napus L.), chickpea (*Cicer arietinum* L.), and bread wheat (*Triticum aestivum* L.) cultivated in the following season. The chemicals responsible for the allelopathic effect in saffflowers have been identified in the stems (2-naphthalenemethanol, lauryl alcohol, and cylooctadiene) and roots (1-pentadecene, 2-naphthalenemethanol, and caryophyllene oxide) (Bonamigo et al., 2013; Day, 2016).

1.2.2. Stem

Safflower is a shrub-like plant with a well-developed ability to adapt to arid and cold climatic conditions. These characteristics are closely related to its morphological structure. One of these structures, the stem, supports all parts of the plant, including flowers, leaves, and seeds, and provides resilience to harsh climatic conditions.

The stem of safflower is herbaceous in structure, and the base of the stem thickens during development. This enables it to withstand harsh climatic conditions. Additionally, the stem can be spiny or non-spiny. Spiny genotypes have evolved to prevent water loss and are more tolerant to arid conditions. The plant's height ranges from 60 to 100 cm on average. The stem is cylindrical in structure and greenish-gray in color. As the stem of the

Safflower plant grows longer, it becomes thinner, and lateral branches 15-20 cm long form on the stem (Balcı et al., 2007; Koç et al., 2010; Bolükbaşı, 2018). The average number of lateral branches per plant varies between 2.9 and 9.8 (Kırıcı and Meral, 1998). However, for each of the morphological, physiological, and chemical characteristics, genotype, environment, and cultivation practices are important factors affecting yield.

1.2.3. Leaves

The characteristics of amaranth leaves may vary depending on the genotype. Leaves may be spiny or spineless, like stems. The average length of amaranth leaves is 10-15 cm, while their width varies between 2.5 and 5 cm (Bolükbaşı, 2018). The edges of safflower leaves have a serrated structure. safflower is generally a salt-tolerant plant. However, safflower grown in salty soils has leaves that are thicker and smaller in form and take on a darker green color compared to the general population. Additionally, the stoma structures degenerate, and the cell structures are damaged (Bassil and Kaffka, 2002; Sadeghi, 2011). It also negatively affects the number of leaves per plant (Toprak and Tunçtürk, 2018). Although salinity is a factor that limits yield, changes in the number and morphology of leaves are closely related to the plant's adaptive capacity. This is because an excess of leaves also means more water consumption. In this case, the salt taken into the plant with water can cause toxicity and loss of intracellular turgor pressure, leading to the plant's death by preventing the uptake of more saline water and plant nutrients. However, thanks to the adaptation ability developed by the plant, it can prevent this situation through structural differentiation. Additionally, a study has demonstrated a significant positive correlation between the number of leaves and seedling height, root length, root dry weight, and above-ground dry weight (Kaya et al., 2001).

1.2.4. Flower structure and pollination characteristics

safflower is a plant belonging to the Asteraceae family. This family includes approximately 110 genera and 2,500 species. In Turkiye, there are 133 genera and 1,156 species. The safflower plant is mostly self-pollinating. In terms of pollinators, they are entomophilous plants. That is, they are plants that require insects such as bees or other insects for pollination. They have a clustered flower structure, rarely a single-flowered structure, and their flowers

are sessile (Seçmen et al., 1998; Tanker et al., 1998). safflower is hermaphroditic, with male and female reproductive organs present in the same flower, and self-pollination (autogamy) is common. However, cross-pollination may occur depending on environmental factors. It has been reported that the cross-pollination rate can reach up to 60-70% (Li and Mündel, 1996).



Figure 2. Safflower's flower (Anonymous, 2025)

The number of flower heads per plant of the safflower plant varies between 12.7 and 30.6, depending on the genotype and environmental conditions (Tunçtürk et al., 2000). The width of a flower head is between 1.5 and 3.5 cm. There are between 20 and 80 flowers on each head. The flowers are covered by bract leaves, which have a differentiated leaf structure. The flower organs are located within the corolla tube formed by the fusion of five-parted petals. This structure also includes the ovary, which will form the seed. The ovary consists of three main parts: the stigma, the style, and the ovule. Additionally, it contains five male organs, and the male pollen cells can only maintain their viability for about one day. The outer part of the Safflower has 1-3 rows of sterile flowers. These flowers can produce pollen but cannot be fertilized because the ovary is dormant. The flowers in the inner part are fertile and can be fertilized to form new seeds. safflower flowers do not bloom simultaneously. First, the flowers connected to the main stem at the top bloom, followed by the second and third rows of flowers. The development of the flowers on the flower row occurs from the outside toward the center (Esendal, 1988; Kayaçetin et al., 2012).

The flower color of Safflowers is classified in a wide range. Safflowers can have yellow, orange, red, and, to a lesser extent, white flowers. Only two rows of flowers on the disk open each day, and it can take up to seven days for all the flowers on the disk to open. It can take up to one month for all the disks on a plant to open. After the flowers open, the fertile ones are pollinated. Approximately 1-1.5 months after pollination, the seeds mature (Esendal, 1988; Knowles, 1982).

1.2.5. Seed characteristics

Safflower is a valuable oil plant and is cultivated for its seeds. Safflower seeds are similar to Safflower seeds. The safflower flower reaches maturity 30-35 days after pollination; however, it requires an additional 15 days for harvest (Knowles, 1982). The seeds are white in color with black stripes and contain 25-45% oil. The length of safflower seeds ranges from 7.18 to 8.35 mm, and their width ranges from 3.9 to 4.33 mm. The thickness of the seeds ranges from 3.24 to 3.69 mm. The weight of 1,000 seeds ranges from 40 to 50 g (Kobuk et al, 2019). Some studies on oil content indicate that seeds obtained from summer sowing have higher oil yields (Bayraktar, 1991), while other studies indicate that oil yields are higher in winter sowing (Coşkun, 2014). This means that the genotypes under study should be well understood and continued with consideration of their ecological characteristics. Additionally, it has been proven that delaying the planting time reduces oil yield (Baydar and Turgut, 1993). All the parameters mentioned may vary depending on the interaction between the environment and the genotype, as well as the cultivation conditions.



Figure 2. Safflower's seed (Anonymous, 2025)

Approximately 90% of safflower seed oil consists of unsaturated fatty acids (Baydar and Erbaş, 2016). In addition, it contains 14-15% protein, 32-34% sugar, 5-8% moisture, and 2-7% ash (Coşge et al., 2007). The oil composition of the safflower plant can be examined under two headings depending on its genetic characteristics; it can be classified as oleic acid-rich or linoleic acid-rich. Studies have shown that there is a very significant negative correlation (-0.97) between these two fatty acids (Bartholomew, 1971).

Tocopherols (vitamin E and its derivatives) are molecules synthesized only by plants. Although this vitamin is found in all green parts of the plant, it is mainly concentrated in the seeds (Altıner et al., 2017). Safflower oil contains high levels of tocopherols and their derivatives. Safflower oil, which is particularly rich in α-tocopherol, is notable for its average total tocopherol content of 340 mg g-1 (Herting and Drury, 1963). For this reason, it is also used in cosmetic products.



Figure 3. Safflower's oil (Anonymous, 2025)

The results of studies conducted in different ecologies regarding the fatty acid profile values of different genotypes are shown in Table 1.

Table 1. Fatty acid composition of some local and foreign safflower genotypes investigated

Genotype	PalmiticAcid (C16:0)	StearicAcid (C18:0)	OleicAcid (C18:1)	Linoleic Acid (C18:2)	literature
797pı	5.21	2.09	13.4	76.8	(Johnson et al., 1999)
Morlin	5.71	2.61	8.5	80.8	(Johnson et al., 1999)
Montolo 2001	5.4	1.6	82.1	9.90	(Cazzatoet al., 2001)
Hybr.GW9022	8	2.2	10.0	78.8	(Cazzato et al., 2001)
Benno	7.1	2.2	19.3	70.3	(Cazzato et al., 2001)
Bacum	10.60	6.6	52.5	30.30	(Cazzato et al., 2001)
Esfehan	20.2	9.7	9.5	23.5	(Cazzato et al., 2001)
Dinçer5-118	5.83	2.38	13.35	78.24	(Kobuk et al., 2019)
Remzibey-05	6.8	2.4	11.46	79.17	(Kobuk et al., 2019)
Balcı	6.32	2.92	16.68	73.83	(Kobuk et al., 2019)
Lolas	5.15	2.23	67.0	23.18	(Kobuk et al., 2019)
Linas	6.32	2.92	16.68	73.83	(Kobuk et al., 2019)
Remzibey	6.1	2.55	24.7	66.16	(Kurt et al., 2017)
Dinçer	8.75	3.34	8.6	78.76	(Kurt et al., 2017)
Average	7.68	3.20	23.15	61.71	

The owners of registered varieties of safflower in Turkiye are classified in Table 2 as prickly or non-prickly.

Table 2. Registered safflower varities in Türkiye

Variety	spikiness	Registrant
Yenice 5-38	Dikensiz	Transıtıonal Zone Agrıcultural Research Instıtute
Dinçer (5-18-1)	Dikensiz	
Remzibey 05	Dikenli	
Balcı	Dikenli	
Yekta	Dikenli	
Göktürk	Dikenli	Trakya Agricultural Research Institute
Olas	dikenli	
Linas	Dikenli	
Olein	Dikenli	Isparta University of Applied Sciences
Askon 42	-	Utek Agriculture Construction Food Industry Trade Ltd.Co..
Hasankendi	Dikenli	Field Crops Central Research Institute
Servetağa	-	Selcuk University Faculty of Agriculture
Koç 42	dikenli	Bahrı Dagdas Internatıonal Agrıcultural Research Instıtute
Asol	dikenli	
Safir	Dikenli	Gap Agrıcultural Research Instıtute

(TTSM, 2025)

Table 3. Upon examination, production areas with the highest production are, in order, Kayseri Isparta, Konya, Nevşehir, and Kırşehir provinces. In terms of production quantities, Kayseri Isparta, Konya, Aksaray, and Nevşehir come first (TUİK, 2025).

When looking at global safflower seed production values, Kazakhstan, the Russian Federation, India, Mexico, and the United States rank in the top five, respectively. Turkiye ranks sixth (FAO, 2023).

Table 3. Safflower yields by province in Turkiye in 2024

No	City	Production Area (da)	Production Quantity (t)
1	Kayseri	91770	10191
2	Isparta	38330	4274
3	Konya	26196	3441
4	Nevşehir	16972	1953
5	Aksaray	13309	1821
6	Kırşehir	11112	1098
7	Ankara	9516	894
8	Sivas	6942	734
9	Çankırı	6713	754
10	Yozgat	5806	630
11	Afyonkarahisar	3940	487
12	Karaman	3334	356
13	Bursa	3039	198
14	Çorum	2374	397
15	Kırıkkale	2360	275
16	Balıkesir	2295	285
17	Elazığ	1698	245
18	Amasya	1471	215
19	Uşak	1111	82
20	Adana	1250	133
21	Kütahya	1090	99
22	Eskişehir	1045	112
23	Bolu	470	38
24	Samsun	415	79
25	Niğde	350	53
26	Kahramanmaraş	342	41
27	Tokat	266	34
28	Çanakkale	185	31
29	Denizli	120	8
30	Diyarbakır	93	11
31	Malatya	55	4
32	Edirne	46	7
33	Antalya	42	6
34	Burdur	33	1
35	Kastamonu	27	3
36	Ağrı	17	2
37	Muş	14	3
38	Bitlis	12	1
39	Tekirdağ	10	3
40	Bilecik	5	1
Toplam		254175	29000

(TUİK, 2025)

Table 4. Safflower seed production values worldwide in 2023

No	Country	Production Quantity (t)
1	Kazakhstan	242171,96
2	Russia	137957,24
3	İndia	90002,46
4	Mexico	65760,24
5	USA	59230
6	Turkiye	39000
7	China	34028,18
8	Mainland China	34028,18
9	Tanzania	14334,04
10	Ethiopia	9386,03
11	Kyrgyzstan	6474
12	Tajikistan	5860,29
13	Uzbekistan	5727,84
14	Arjentina	5401
15	Iran	4813,29
16	Australia	3615,68
17	Ukraine	108,99
18	İsrael	2,28
19	Palestine	1,38
equals		758.930,08 (t)

(FAO, 2023)

1.3. Safflower cultivation and ecology

Safflower is not a soil-selective plant. However, it grows well in loamy, neutral soils with good surface drainage. Since Safflower roots can penetrate deep into the soil, the soil should be deeply tilled (spring-fall). Before sowing, the soil should be prepared for sowing by tilling with a disc harrow.

The fertilizer requirement for Safflowers should be determined based on soil analysis. However, the plant requires 12-15 kg/da of pure nitrogen. Before sowing, 3-5 kg/da of phosphorus should be applied to the soil to initiate plant growth. Potassium is not required in large quantities in Turkish soils. For this reason, compound fertilizers such as 20-20-0 or 15-15-15 can be preferred.

The Safflower plant is an oil plant that can be planted both in summer and winter. The most suitable planting time for summer cultivation varies

from region to region, but it is generally March and April, while the suitable planting time for winter cultivation is September and October. The planting time is of great importance for yield and quality. Otherwise, the plant becomes stunted, has fewer branches, and has a lower oil content, resulting in yield losses. The recommended row spacing for Safflowers is 15 to 20 cm, and the recommended inter-row spacing is 40 to 60 cm. It is important to adjust the row spacing and inter-row spacing according to ecological and topographical characteristics. Otherwise, weed problems may arise, leading to both mechanical and economic issues. The first 3-4 weeks after emergence are critical for safflowers, and weed control during this period is essential. Otherwise, yield losses may occur.

The seed rate per acre for safflowers is 4 to 6 kg. The sowing depth should be between 2 and 5 cm. Depending on climatic conditions, Safflower seeds can germinate in 7 to 21 days. Growing Safflower plants that have reached the rosette stage are quite resistant to cold (-12°C) during this period and their growth is relatively slower. During the stem elongation stage, they are more sensitive to cold than during the rosette stage. During the head formation stage, the plants can withstand high temperatures (40-45°C) (Anonymous, 2022).



Figure 4. Safflower's field (Anonymous, 2025)

Safflower is a plant that tolerates barren and arid lands. For this reason, it does not require as much water as other oil crops. However, irrigation during certain periods has a significant positive effect on yield. These periods correspond to the rosette stage, budding, and flowering stages. If the plant

does not receive enough rainfall during these periods, yield is negatively affected (Anonymous, 2022).

The most important criterion for harvest is when the leaves turn brown and the seeds turn white. This period generally corresponds to approximately 1.5 months after flowering. A combine harvester can be used for harvesting. In addition, in Safflower cultivation, there is no need for any mechanization system specially designed for safflowers; however, it is important to note that the speed of the combine harvester must be adjusted correctly to prevent seed breakage. The moisture content of the harvested seeds should be around 14 to 15%, and the moisture content for storage should not exceed 8 to 10% (Anonymous, 2022).

2. Cultivation Purposes and Nutritional Value of Safflower

The safflower plant has been used for various purposes throughout human history. Initially used for medicinal purposes, such as reducing fever, alleviating menstrual pain, and treating wounds and swollen tissues, the safflower plant has since been cultivated for oil production. Today, different genotypes are evaluated for different applications based on their varying oil compositions. Safflower oil is not used as a table oil but primarily in the margarine production industry. The oleic type of safflower is more similar to Safflower oil in terms of taste and aroma. safflower oil is not only used for food purposes but also for various industrial applications. Safflower is also a valuable energy crop. Fossil fuels, which are currently used as an energy source, are insufficient to meet the increasing energy demand; moreover, the damage they cause to the environment has reached such a large scale that people have begun to turn to cheaper and renewable energy sources. The use of Safflower oil for biodiesel production has increased in recent years. Research has shown that the Safflower plant yields better results than the soybean plant. It has been reported that 45 kg of diesel fuel and 15 kg of gasoline can be obtained from 100 kg of Safflower oil (Kıraç, 1938).

After oil is extracted from Safflower seeds, the remaining residue is used as meal. The protein content of the residue ranges from 22% to 24%. Additionally, Safflower seeds are an essential component of bird feed due to their rich content (Babaoğlu, 2005).



Figure 5. Some uses of the safflower plant (Anonymous, 2025)

Thanks to the substances carthamin and carthamidin give safflower flowers their yellow-red color, they have been used to color fabrics and foods from ancient times to the present day. However, with the widespread use of inexpensive synthetic dyes, the use of dye plants has significantly decreased; yet, in recent days, conscious consumers have begun to prefer products that are organic and sustainable. For this reason, the use of dye plants such as safflower has once again come to the forefront.

Safflower flowers are used as ornamental plants, especially some wild species, due to their showy appearance. They are commonly used in landscaping, particularly in parks and gardens. In addition to food use, safflower leaves are also highly valued. They are used as tea, especially in Asian countries, to reduce swelling. Additionally, safflower leaves are also used in salads (Taşlıgil and Şahin, 2016).

3. The Contrıbutıon of Safflower Sustainable Agriculture and Food Supply Security

3.1. Contribution to food and oil supply and agricultural systems

Oils are absolutely essential compounds for the survival of living organisms. They form the raw materials of organisms. Organic compounds form the basis of living structures by contributing to the structure of cells and organelles. In addition, oils are the primary energy source for living organisms. Furthermore, oils are important molecules that support the structure of the body and contribute to its aesthetic appearance. Fats have two different sources: animal and plant. Plant-based fats contain certain special compounds that cannot be synthesized by animals but are essential for life.

The absorption of these essential fats plays a vital role. For this reason, the cultivation of oil plants worldwide and the fats obtained from them are not only economically important but also highly significant for health.

The safflower plant is well adapted to arid and salty soils. It is an oil plant with a high adaptability to extreme ecological conditions. Safflower's low water requirements and adaptation to arid areas greatly facilitate its cultivation. It is a plant that should be considered, especially in arid areas. In this regard, safflower is a plant with both ecological and economic advantages. Additionally, safflower is quite economical due to its low input requirements, does not require pesticides or insecticides in its cultivation, can be grown in marginal areas, has high oil yield and composition, and has a wide range of applications. These characteristics distinguish safflower from other oil plants.

Among the leading countries in oil production worldwide, China, Indonesia, and Malaysia are at the forefront. The primary source of refined vegetable oil produced globally is palm oil. Additionally, it is both financially viable and has a long shelf life, making it one of the most imported oils worldwide. Approximately 40% of the world's palm oil production is carried out by Indonesia and Malaysia (Anonymous, 2024). Turkiye, however, is among the countries that cannot meet their own vegetable oil production needs. In fact, it only meets approximately 25% of its oil consumption, with the remainder being imported, primarily Safflower oil. The main reasons for the oil deficit in our country can be summarized as follows: oil crop production patterns are not properly planned, the right genotypes are not adapted to the right ecotypes in yield and breeding studies, alternative oil crops are not sufficiently recognized by farmers and there are prejudices, input costs are high, and sustainable agricultural systems have not been developed due to drought and climate change.

There are 4.2 million hectares of fallow land in Turkiye where no cultivation is carried out (Yavuz et al., 2020). These idle areas can be converted into productive agricultural areas by determining the right crops and agricultural methodologies. Soil structure and organic matter content can be improved, and economic development can be enhanced both regionally and nationally by creating employment and new job opportunities in the region. safflower is a crop suitable for such areas. It is an oilseed crop with the ability

to adapt to saline and arid soils and low-rainfall ecosystems. Considering Turkiye's oil supply and its capacity to meet this demand, Safflower production has the potential to reduce dependence on imports to a certain extent. Additionally, the uses of Safflower oil were discussed in the previous section. Safflower cultivation in the region will not only support the agricultural economy but also has the potential to provide raw materials for many industries. It is also very important for the continuity of living organisms and biodiversity in the ecosystem. In particular, thanks to its striking flowers, the bee population will increase, supporting the agricultural and ecological characteristics of the region. For this reason, it is very important to evaluate fallow lands with oil crops such as safflower.

Various oil crops that directly or indirectly contribute to the oil sector are cultivated in Turkiye. For this purpose, Safflower is the most widely cultivated oil crop, followed by cotton. The list of oil crops produced in Turkiye, along with their production values, is shown in Table 5.

Table 5 shows that safflower is the most widely cultivated oilseed crop in 2024, with 8.5 million decares. It is followed by cotton, with 4.6 million decares. Production volumes are directly proportional to cultivated areas, and the ranking remains the same. Safflower and hemp seed production are relatively niche products and are not widely cultivated.

Table 5. Acreages and production quantities of oilseed crops grow in Turkiye in 2024

Oil Plants	**Planted Area (da)**	**Production Quantity (t)**
Soybean	437.113	180.000
Cottonseed	4.669.272	1.345.800
Canola	295.194	101.200
sunflower	8.549.239	1.855.000
Hemp seed	7206	556
safflower	254.175	29.000

(TUİK, 2025)

Table 6. Turkiye's vegetable oil import values by year

	Years	**Foreign Trade Import Quantities (Kg)**	**Foreing Trade Import Values ($)**
Vegetable Oil İmport Values	2024	2.225.630.802	2.172.613.856
	2023	2.560.603.335	2.606.978.089
	2022	2.599.861.613	3.641.709.638
	2021	1.857.519.688	2.161.218.612
	2020	1.789.453.008	1.320.872.413
	2019	919.236.456	1.400.605.571
	2018	912.065.090	1.228.827.246
	2017	1.239.470.672	1.435.592.082
	2016	1.430.595.677	1.495.966.141
	2015	1.530.760.270	1.610.113.330

(TUİK, 2025)

Table 6. shows Turkıye's imports of vegetable oils. 2022 was the highest year for imports in terms of both quantity and price. The main reason for the decline in imports after 2023 may be due to policies to increase domestic production or the effect of exchange rates.

The safflower plant is a deep-rooted plant thanks to its taproots. With this deep root system, it can make good use of the soil's moisture. Due to this feature, it prevents erosion and plays a major role in improving soil structure. It is effective in the organic matter cycle by maintaining the microbial balance of the soil. Due to these characteristics, Safflower is a valuable oil plant for sustainable agriculture. It holds an important place among the measures that can be taken against global warming, a global catastrophe. For this reason, the integration of Safflower into the production system is important in global agriculture. Such a diverse agricultural product must be included in food security.

3.2. Factors limiting the cultivation of safflower

Safflower (*Carthamus tinctorius* L.) is a highly valuable plant in terms of its use in both oil and various industries. Due to its high content of unsaturated fatty acids and tocopherols, it has strong potential in the food, pharmaceutical, biofuel, and cosmetic industries. However, despite its high economic and industrial value, safflower is not a widely cultivated crop worldwide. One of the main reasons for this is the insufficient development of agricultural awareness and consciousness at the producer level (Singh and Nimbkar, 2006). Additionally, the lack of technical knowledge regarding Safflower cultivation, the limited availability of modern agricultural methods, and the inadequacy of advisory services for farmers also pose significant barriers to production.

On the other hand, another important factor in the insufficient evaluation of the economic potential of the flax plant is the inadequacy of marketing. Unfortunately, the flax trade network remains limited, and its promotion is insufficient at both the national and international levels. This situation reduces the product's value in the market. However, with proper planning and dissemination strategies and producer training, production volume can be increased.

Another factor limiting safflower cultivation is the low grain yield of safflower both globally and in Turkıye. The failure to properly implement the cultivation technique package significantly reduces the yield required to achieve economic viability from safflower. Therefore, breeding efforts are important for increasing yield (Kurt et al., 2017).

4. Results and Recommendatıons

- Safflower (Carthamus tinctorius L.) is a plant belonging to the Asteraceae family, originating in Asia, and has many uses. Throughout history, it has been developed for different purposes and found new uses. Thanks to its strong and deep root system, the plant is tolerant to arid and salty soils. Morphologically, the plant structures have diversified through natural selection to adapt to these regions.
- Wild forms of the safflower plant exist. These wild forms are valuable materials for breeding studies.

- Safflower contains high levels of unsaturated fatty acids (oleic and linoleic acids). This property is particularly important for human health, especially in preventing cardiovascular diseases.
- In Turkiye, numerous studies have been conducted on the safflower plant to improve agricultural methodologies. In addition, different saffflower varieties rich in both oleic and linoleic acids have been registered as a result of studies conducted in our country.
- The evaluation of fallow lands is very important for increasing agricultural productivity and ensuring the sustainability of soil resources. The safflower plant improves soil structure thanks to its root system. It can be cultivated especially in arid and low-yield fallow regions. This way, idle fallow lands can be converted into agricultural lands.
- The utilization of fallow lands with the safflower plant will create new job opportunities in rural areas, providing employment for many people. This will play an important role, especially in youth and women's employment and regional development.
- Globally, the physical and chemical structure of soils is being degraded due to environmental and human factors such as improper agricultural practices, irrigation methods, global climate change, and inadequate drainage systems. As a result of these negative processes, the accumulation of ions such as sodium (Na^+) and chloride (Cl-) in the soil increases, leading to salt stress in plants. Today, approximately 20% of agricultural land that meets the food needs of the rapidly growing world population is facing salinity issues, and this percentage is increasing every year. Since this situation threatens the sustainability of agricultural production, it is essential to determine the resistance levels of plants to salinity and develop salt-tolerant varieties based on this information (Toprak and Tunçtürk, 2018). Safflower is a very important plant in terms of evaluating these areas.
- Safflower is understood to be an important alternative for closing Turkiye's oil deficit. In particular, the evaluation of marginal areas and the inclusion of Safflower cultivation are of great importance. Our comparison of domestic and foreign Safflower varieties shows

that Safflower varieties registered in our country can be produced domestically without dependence on foreign sources, with high and high-quality oil yields.

- It is necessary to improve the quality of existing safflower varieties and develop new varieties for different industrial applications. Therefore, we must diversify our existing variety range using both traditional and modern breeding technologies.
- Safflower plants should be introduced to producers, and public institutions should provide awareness-raising activities such as training programs. In addition, the marketing of the products obtained and their integration into industry must be ensured.
- safflower should be included in national and even international agricultural strategies in the context of climate change, which threatens all living things on a global scale.

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Chapter 15

SAINFOIN (*Onobrychis sativa* Lam.)

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DOI: https://dx.doi.org/10.5281/zenodo.17463133

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1. General Characteristics of the *Onobrychis* Genus

1.1. Origin and biogeographical distribution of the *onobrychis* genus

The genus *Onobrychis* comprises more than 170 taxonomically classified species, all of which are confined to the Palaearctic phytogeographical zone. The genus exhibits a broad longitudinal distribution, extending from the western Mediterranean, including the Iberian Peninsula, through the Caucasus and Zagros Mountains, reaching Central Asia, and extending as far east as Siberia (Yildiz et al., 1999). The taxonomic and genetic diversity of *Onobrychis* is particularly concentrated in a region encompassing Western Asia, Central Asia, and South-eastern Europe (Burton and Curley, 1968; Carbonero et al., 2011). Within this core area, Turkey, Iran, the Caucasus, and Central Asia represent hotspots of species richness and endemism (TUBİVES, 2025). These regions serve not only as primary centres of natural distribution but are also regarded as evolutionary and phylogeographical centres of diversification for the genus, playing a crucial role in its speciation and adaptive processes.

A significant revision of the genus *Onobrychis* in the context of the Turkish flora was conducted by Hedge (1970). Following this, Huber-Morath (1982), Kit-Tan and Songer (1986), and Duman and Vural (1990) added seven new *Onobrychis* species to the Turkish flora. The most comprehensive revision of the genus in Turkey was later performed by Aktoklu (1995), who reported a total of 60 taxa representing 52 species. More recently, two new species have been described and incorporated into the Turkish flora: *Onobrychis mehmetchiquii* by Aybeke and Dane (2017) and *Onobrychis silvanensis* by Aytac et al. (2020).



Figure 1. *Onobrychis cornuta* (L.) Desv. from the section *Dendobrychis*. a: General view of the species; b: Leaves and flowers; c: Flowers and spiny structure; d: Fruits with clearly visible spines.

Based on the comprehensive studies of Davis (1970–1988), the genus *Onobrychis* in the Turkish flora is represented by two subgenera: Onobrychis and Sisyrosema. The subgenus Onobrychis typically exhibits pink flowers and is further divided into three sections: *Dendobrychis* (perennial, semi-woody species, Figure 1), *Lophobrychis* (annual herbaceous species, Figure 2), and *Onobrychis* (perennial herbaceous species, Figure 3). Conversely, the subgenus Sisyrosema predominantly comprises species with yellow flowers, occasionally cream or white, and is subdivided into two sections: *Heliobrychis* (Figure 4) and *Hymenobrychis* (Figure 5). Despite the considerable species diversity of the genus Onobrychis both globally and within Turkey, agricultural production is predominantly focused on *Onobrychis sativa* Lam. (syn. *Onobrychis viciifolia* Scop.,) and *Onobrychis transcaucasica* Grossh., which are the primary species cultivated for forage purposes

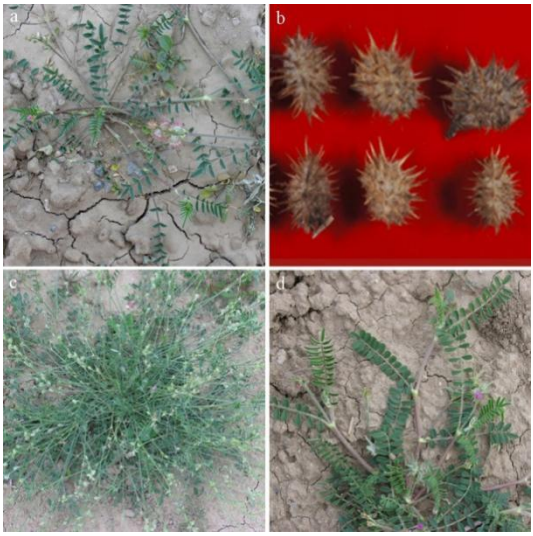


Figure 2. Species from the section *Laphobrychis*. a, b: *Onobrychis caput-galli* (L.) Lam.; c: *Onobrychis aequidentata* (Sibth Et Sm.) D'urv.; d: *Onobrychis crista-galli* (L.) Lam.



Figure 3. Species from the section *Onobrychis*. a: *Onobrychis elata* Boiss. Et Bal.; b: *Onobrychis montana* DC. subsp. cadmea (Boiss.) P. W. Ball.; c: *Onobrychis argaea* Boiss. Et Ball.; d: *Onobrychis occulta* Hedge Et Hub-Mor.



Figure 4. Species from the section *Heliobrychis*. a: *Onobrychis atropatana* var. *grandiflora* Aktoklu nov.; b: *Onobrychis huetiana* Boiss.; c: *Onobrychis argyrea* Boiss. subsp. *argyrea Boiss.*; d: *Onobrychis ornata* (Willd.) Desv.



Figure 5. Species from the section *Hymenobrychis*. a: *Onobrychis albiflora* Hub-Mor.; b: *Onobrychis galegifolia* Boiss.; c: *Onobrychis hypargyrea* Boiss.; d: *Onobrychis meschetica* Grossh.

1.2. Morphological and fenological characteristics of sainfoin (*Onobrychis viciifolia* Scop.)

Sainfoin (*Onobrychis viciifolia* Scop.) is a perennial forage legume belonging to the *Fabaceae* family, characterized by its semi-erect growth habit and deep-rooted system (Figure 6e). The plant typically produces numerous branched stems, reaching heights of 40 to 80 cm. Its well-developed taproot system enables efficient access to deep soil moisture, thereby conferring notable drought tolerance and allowing the species to thrive even in nutrient-poor soils. Additionally, sainfoin enhances soil fertility through symbiotic *Rhizobium* bacteria in its roots, fixing atmospheric nitrogen at levels comparable to alfalfa under favourable conditions (Provorov and Tikhonovich, 2003). This trait makes it a valuable species in crop rotation systems.

The leaves are compound and exhibit a slightly pubescent surface. Leaflets are arranged oppositely, generally oval or lanceolate in shape, with smooth margins and pointed apices. The number of leaflet pairs on basal leaves varies among populations, ranging from 8 to 16. Sainfoin flowers are of the papilionaceous type, typical of the *Fabaceae* family (Figure 6a). The flowers are usually pink with darker pink veining and measure approximately 11–13 mm in length. Each flower consists of three main components: a standard (banner), two wings, and a keel. The wings are shorter than the keel (Figure 6b). The inflorescences are racemose, approximately 6–7 cm long, and are located on the upper parts of the stems (Figure 6e). The fruit is a legume but differs from classical legumes in that it does not dehisce at maturity. It typically contains a single seed and has a thick-walled, spiny structure with hooked projections along the margin (Figure 6c). Seeds are yellowish-brown, compressed, and oval in shape (Figure 6d). Unlike many legume species, sainfoin seeds generally lack a hard seed coat, which facilitates water absorption and germination.



Figure 6. Morphological Characteristics of *Onobrychis viciifolia* Scop.: Flower (a), floral parts (b), fruit (c), seed (d), and general plant appearance (e)

The phenological development stages of sainfoin consist of key phases such as flowering, fruit set, yellowing, and senescence. These stages reflect the plant's responses to environmental conditions and genetic traits. Observations indicate that there are notable differences in the timing of the onset and completion of these stages among different sainfoin populations (Figure 7). In general, the flowering phase begins in the first weeks of May and continues until the end of the month. This is followed shortly by the fruit set phase, which typically lasts until early June, suggesting a rapid transition of sainfoin into the generative phase. The yellowing stage marks the plant's

progression into senescence and generally begins between late May and mid-June. The senescence (drying) phase occurs from the end of June through late July, indicating the completion of the plant's life cycle.

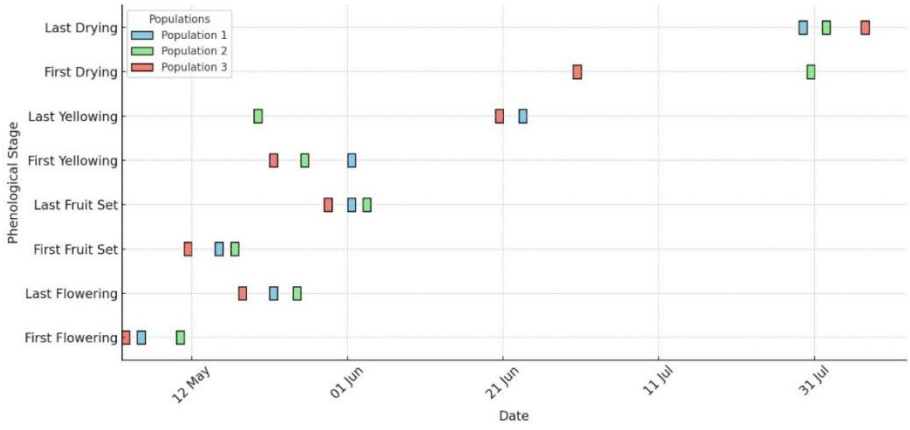


Figure 7. Comparison of phenological stages in different sainfoin (*O. sativa*) populations (Avcı, 2010)

1.3. Ecological adaptation of sainfoin to climate and soil conditions

Sainfoin is a perennial forage legume that can be successfully cultivated in semi-arid and arid climates due to its broad ecological adaptability. Its tolerance to high temperatures and low precipitation regimes makes it a promising alternative species in the context of climate change adaptation (Sebastià et al., 2024). The deep and extensively branched root system enhances the plant's ability to access soil moisture during summer droughts, facilitating survival under dry conditions and prolonging its green period throughout the year (Mora-Ortiz & Smith, 2016). These traits enable sainfoin to play a significant role in sustainable agricultural systems, both as a pasture legume and a hay crop.

In terms of soil requirements, sainfoin is relatively non-selective and well-adapted to a wide range of soil types. It performs best in calcareous, slightly alkaline, and well-drained soils, while its growth is limited in acidic, heavy-textured, and poorly drained soils. The species typically prefers soils with a pH range of 6.0 to 8.0 for optimal development. Although sainfoin is

considered moderately sensitive to salinity (Özaslan Parlak, 2008), recent studies have reported the existence of certain ecotypes with greater tolerance to salt stress (Uzun et al., 2017; Beyaz et al., 2018).

Sainfoin also demonstrates wide altitudinal adaptability and can be cultivated successfully across a broad elevation range, generally between 400 and 1800 meters above sea level (Mora-Ortiz & Smith, 2016). It is naturally and agriculturally widespread in temperate climate zones and, thanks to its winter hardiness, can also be grown in high-altitude areas. Sainfoin seedlings demonstrate superior cold tolerance during early developmental stages when compared to *Medicago sativa*, allowing for more robust establishment under low-temperature conditions (Meyer and Badaruddin, 2001). This inherent resilience is further enhanced as the plant progresses through its growth stages, ultimately facilitating successful overwintering in harsh climatic environments.

1.4. Vernacular nomenclature of *Onobrychis sativa*

Onobrychis sativa is a forage legume species that has been cultivated and utilized across various geographical regions for centuries. As a result of its long-standing role in traditional agriculture and animal husbandry, the species is known by a diverse array of vernacular names in different cultures. In Turkey, it is commonly referred to as "korunga," though a number of regional names also exist, including "geyik yoncası" (deer clover), "kenger otu,""kara yonca" (black clover), "eşek otu" (donkey herb), "evliya otu" (saint's herb), and "goringe," particularly in eastern provinces. These local names are often derived from morphological similarities with other species or reflect traditional uses and cultural perceptions of the plant.

At the international level, *Onobrychis sativa* is identified by distinct vernacular terms in various languages (see Table 1).

Table 1. Common vernacular names for *Onobrychis sativa* in different languages and their descriptions

Language	Name	Description
English	*Sainfoin*	Derived from Old French, meaning "healthy hay"; commonly used for drought-tolerant forage crops.
French	*Esparcette*	A traditional term referring to forage legumes cultivated in dry and mountainous regions.
German	*Esparsette* or *Saat-Esparsette*	"Esparsette" refers to sainfoin in general; "Saat-Esparsette" specifies cultivated varieties.
Spanish	*Esparceta*	Borrowed from the French term; used widely for forage legumes in arid regions.
Italian	*Sulla comune* or *Sulla coltivata*	"Sulla" is a general term for sainfoin-like legumes; "comune" means common, "coltivata" means cultivated.
Russian	*Эспарцет посевной (Esparcet posevnoy)*	"Esparcet" denotes sainfoin; "posevnoy" indicates sown or cultivated types.
Persian (Farsi)	*Esparseteh*	A traditional local name for sainfoin used in Iranian agriculture and forage crop terminology.

These local names are largely shaped by the agricultural terminology and botanical literature specific to each region. In some countries, the species is further distinguished from other *Onobrychis* species through descriptors such as "true sainfoin" or "cultivated sainfoin." The diversity of vernacular names reflects not only linguistic differences but also the species' agricultural significance and cultural prevalence in various regions. In this context, understanding how *Onobrychis sativa* is named across different languages and regions is crucial for international agricultural research, seed trade regulation, and the documentation of plant genetic resources.

1.5. Sowing, utilization, and seed production of sainfoin

Successful cultivation of sainfoin necessitates the preparation of a seedbed characterized by a light, friable, and well-drained soil structure, coupled with balanced nutrient availability and rigorous weed management. As a perennial legume, sainfoin allocates significant resources to root system

development during its initial growing season, which consequently results in relatively slow shoot growth. During this critical establishment phase, the presence of competing weeds can markedly inhibit seedling vigor and density. Therefore, pre-sowing soil tillage is essential not only for optimizing seedbed conditions but also for suppressing weeds seed germination. In scenarios of elevated weed infestation, implementing early mowing practices following satisfactory seedling establishment can enhance the efficient utilization of essential growth factors such as water, nutrients, and light, thereby facilitating improved crop development and yield potential.

Sainfoin is generally sown in early spring due to the susceptibility of seedlings to winter damage, as field observations have shown that over 50% of seedlings can be adversely affected by harsh winter conditions (Unpublished data). The appropriate sowing time varies depending on climatic conditions; however, periods when the soil temperature reaches 5–7 °C are typically preferred. The recommended sowing depth is 2–3 cm, as deeper sowing may hinder seedling emergence. Uniform seed distribution and proper seeding density are essential for achieving optimal yield. For hay production in the Southern Marmara Region or ecologically similar areas in Turkey, sainfoin should be sown at a seeding rate of 160–200 kg ha^{-1} with 15–30 cm row spacing (Türk and Çelik, 2006). However, in inland regions characterized by lower precipitation and higher drought risk, the seeding rate may be reduced to 80–120 kg ha^{-1} to optimize resource use and ensure adequate plant establishment.

Inoculating sainfoin seeds with *Rhizobium* bacteria prior to sowing is a crucial practice that enhances the plant's biological nitrogen fixation capacity, thereby effectively improving both yield and forage quality (Prévost et al., 1987; Tufenkci et al., 2006). However, in some cases, nitrogen deficiency symptoms have been observed despite inoculation, primarily due to variability in the efficiency of the *Rhizobium* strains forming symbiotic relationships with sainfoin. Studies focusing on *Rhizobium* strains capable of effective nodulation in sainfoin remain limited. In this context, Asrafi et al. (2022) identified two novel *Rhizobiales* species isolated from sainfoin root nodules. *Mesorhizobium onobrychidis* exhibits plant growth-promoting traits and is capable of fixing both nitrogen and carbon dioxide, while *Onobrychidicola muellerharveyae* shows potential as a symbiont in reducing biotic stress.

Therefore, further investigation and utilization of these newly identified *Rhizobiales* species offer significant potential to enhance sainfoin's nitrogen fixation capacity and stress tolerance.

Sainfoin, self-intolerant (allelopathic) in nature, should not be sown in the same field until at least 10–12 years have passed (Gençkan, 1992). It exhibits superior performance and adaptability compared to *Medicago sativa* and *Trifolium repens* under low-fertility soil conditions, highlighting its suitability for marginal agricultural lands (Carbonero et al., 2011; Demdoum, 2012). Sainfoin's relatively low phosphorus demand is attributed to the efficient uptake capacity of its roots, which possess a high cation exchange capacity, as evidenced by the reduced response to phosphorus fertilization in subsequent cereal crops grown on soils previously cultivated with sainfoin (Fox and Kacar, 1964). In fertilization practices, nitrogen and phosphorus applications at rates of 40 kg ha^{-1} and 39 kg ha^{-1}, respectively, have been demonstrated to be optimal for enhancing plant height, forage yield, and nutrient uptake in sainfoin cultivation (Tufenkci et al., 2006). These results underscore sainfoin's potential as a resilient forage crop for low-fertility soils, where targeted nutrient management can significantly improve both productivity and nutrient utilization efficiency.

The highest forage quality of sainfoin is attained when harvested at the onset of flowering, a phenological stage characterized by the highest protein content and digestibility (Sakhraoui et al., 2024). The nutritional composition of sainfoin at the flowering stage demonstrates significant variability contingent upon cultivation conditions, with crude protein content reported between 11.39% and 17.70% (Kaplan, 2011). In a comprehensive evaluation conducted in Southeastern Anatolia, Turkey, dry matter yields of *Onobrychis viciifolia* genotypes were observed to range from 4.74 to 9.63 t/ha, with the Lütfibey and Özerbey-03 genotypes exhibiting superior agronomic performance (Sayar et al., 2022). As a perennial forage legume, sainfoin remains productive for approximately 3 to 5 years under appropriate management. It is a valuable forage species that can be cultivated either as a monoculture or in mixtures with the perennial legume *Medicago sativa* and grass species such as *Festuca arundinacea*, *Festuca prantensis*, *Bromus inermis* and A*gropyron cristatum*, offering significant potential for pasture and meadow establishment. Mixtures of *O. viciifolia* with grasses generally

outperform monocultures of either component in terms of forage yield and quality. For instance, Liu et al. (2006) reported a dry matter yield of 9.1 t/ha from a mixture of *O. viciifolia* and *Festuca pratensis* sown at a 2:1 ratio, compared to 7.5 t/ha obtained from *O. viciifolia* grown alone.

Sainfoin has emerged as a valuable forage crop in sustainable livestock systems due to its beneficial effects on animal health, primarily attributed to its condensed tannin content. Tannin concentrations in sainfoin have been reported as 4.37%, 4.62%, and 2.88% in fresh, hay, and silage forms, respectively (Scharenberg et al., 2007), and these levels may vary between 4.19% and 9.95% depending on ecological conditions (Kaplan, 2011). The condensed tannins in sainfoin contribute to reducing the risk of bloat by inhibiting biofilm formation in the rumen (Wang et al., 2006) and minimizing excessive ammonia accumulation through reduced proteolysis (Lagrange et al., 2020). Furthermore, due to its high content of non-structural carbohydrates, sainfoin hay supports ruminal fermentation by supplying essential carbon skeletons for microbial protein synthesis (Lagrange et al., 2021; Villalba et al., 2021). Notably, feeding regimens in which fresh sainfoin leaves comprise 10–20% of the diet have been reported to reduce bloat incidence by approximately 27% compared to diets consisting solely of alfalfa (McMahon et al., 1999). Furthermore, a newly developed sainfoin population capable of providing 25–30% biomass over a three-year period has been demonstrated to effectively reduce the risk of bloat in cattle grazing alfalfa pastures, despite steers showing a preference for alfalfa over sainfoin (Sottie et al., 2014).

Sainfoin has emerged as a potential biological control agent against gastrointestinal parasites commonly found in livestocks (Arroyo-Lopez et al., 2014; Desrues et al., 2016; Desrues et al., 2017). This antiparasitic effect is primarily attributed to its rich content of bioactive compounds, notably condensed tannins and flavonol glycosides. These compounds are known to disrupt the life cycle of parasites within the digestive tract, inhibit larval migration, and suppress egg development (Komáromyová et al., 2022; Rodríguez-Hernández et al., 2023). Notably, parasitized sheep have been observed to preferentially consume sainfoin, a behavior interpreted as a form of self-medication (Gaudin et al., 2019). All available evidence suggests that sainfoin should be considered a valuable natural and functional forage plant in

livestock nutrition, with potential not only for controlling parasitic infections but also for supporting overall animal health.

The success of sainfoin seed production depends on the integrated management of environmental and agronomic factors such as adequate pollination conditions, balanced use of irrigation and nutrients, weed control, and optimal row spacing. As an obligate cross-pollinated species, sainfoin produces pollen- and nectar-rich flowers that attract up to ten times more bees than *Trifolium repens* and *Medicago sativa*, with effective pollinators like *Apis mellifera* and *Megachile rotundata* increasing seed yield by over 30% (Pankov, 2013; Goplen et al., 1991). Seed production typically begins in the second year, and yield is influenced by factors such as climate, irrigation, plant density, row spacing, mineral nutrition, and weed control. Weed control is a critical agronomic factor directly influencing seed yield, and chemical weed management using herbicides such as imazamox has been reported to enhance seed production by 24–28% (Dimitrova, 2010). An optimal row spacing of approximately 50 cm, irrigation level of 200 mm, and boron application at 0.6% have been shown to maximize yield (Stevovic et al., 2012; Chen et al., 2024). Germination rates are influenced by seed size and maturity, with larger seeds exhibiting higher germination and faster seedling development (Avcı and Kaya, 2013). While average seed yield ranges between 500–900 kg/ha, it may reach up to 1100 kg/ha under favorable environmental conditions and appropriate agronomic management (Goplen et al., 1991; Prosperi et al., 1994). In seed production, timely harvest and appropriate techniques are essential due to irregular pod maturation and the risk of seed loss. Seeds are harvested manually or mechanically and should be dried carefully to prevent quality deterioration.

2. Cultivation Purposes and Nutritional Value of Sainfoin

2.1. Utilization

Sainfoin is a valuable perennial legume species that occupies a significant role in both agricultural and livestock systems owing to its diverse range of applications. Owing to its nitrogen-fixing capability, it serves as an effective green manure and cover crop, improving soil fertility and contributing to erosion control—particularly in degraded or sloped terrains susceptible to desertification (Heuzé et al. 2020). Its deep-rooted system

confers substantial drought tolerance, allowing it to thrive in poor, alkaline soils. As a forage legume, sainfoin is distinguished by its high content of condensed tannins, which effectively reduce the incidence of ruminal bloat and exhibit strong anthelmintic properties by disrupting the life cycle of gastrointestinal parasites, thereby providing a natural alternative to chemical antiparasitic treatments (Wang et al. 2015; Desrues et al. 2016; Greiffer et al. 2022). Furthermore, the high tannin content in sainfoin enhances protein utilization efficiency, thereby promoting daily weight gain and improving carcass quality, while its superior palatability leads to a preference by both small and large ruminants over other leguminous forages such as alfalfa (Baila et al., 2022; Baila et al., 2024)

In addition to its forage value, sainfoin contributes significantly to pollinator support due to its prolonged flowering period and abundant nectar production, thus aiding in biodiversity conservation (Goplen *et al.*,1991; Carbonero et al., 2011). It can be harvested for high-quality hay or used in pasture systems either as a monoculture or in mixtures with other forage species (Doğrusöz et al., 2024). Recent studies have highlighted the nutritional potential of sainfoin seeds in human diets, reporting high levels of crude protein (38–42%), dietary fiber (45–48%), crude fat (7–9%), and essential minerals (Craine et al. 2024; Andaç et al. 2025). These values are comparable to conventional legumes such as soybean, lupin, and chickpea. However, the presence of antinutritional compounds warrants further evaluation; various thermal processing techniques have been shown to reduce these compounds, enhancing the safety of sainfoin seeds for human consumption. Collectively, these characteristics position sainfoin as a multifunctional species with potential utility in both sustainable animal production systems and future human nutrition.

2.2. Phytochemical composition and nutritional values

Sainfoin is considered a valuable forage crop in ruminant nutrition due to its rich phytochemical composition and biologically active phytochemical contents. The nutrients found in its herbage and seeds include high levels of protein, a balanced amino acid profile, fibre fractions, fats, vitamins, and both macro- and microelements. These components are of great importance for

enhancing feed efficiency and supporting metabolic functions in animal nutrition.

Sainfoin is regarded as a valuable protein source in ruminant nutrition due to its high crude protein (CP) content and well-balanced amino acid profile, which contribute positively to growth and milk production (Waghorn, 2008; Kapp-Bitter et al., 2021). CP concentration decreases significantly with plant maturity, ranging from 19.5–19.8% during the vegetative stage to 11.4–17.7% at flowering, underscoring the importance of early harvest to optimize nutritive value (Bal et al., 2006; Kaplan, 2011). The presence of condensed tannins in sainfoin plays a crucial role in enhancing protein utilization by protecting dietary protein from ruminal degradation, thereby increasing the flow of essential amino acids to the small intestine and resulting in 10–21% higher plasma amino acid concentrations (Scharenberg et al., 2007). Furthermore, sainfoin silage exhibits lower levels of soluble non-protein nitrogen and free amino acids compared to alfalfa silage, reflecting reduced proteolysis during ensiling and improved protein efficiency (Albrecht and Muck, 1991).

The fibre fractions in sainfoin, particularly digestible components such as hemicellulose and cellulose, provide a favourable fermentation environment for ruminal microorganisms, thereby enhancing overall feed digestibility and energy efficiency. They are highly influenced by developmental stage and environmental conditions, which in turn affect its forage quality. During the vegetative stage, acid detergent fiber (ADF) and neutral detergent fiber (NDF) concentrations are at their lowest (ADF: 28.6–33.4%, NDF: 37.8–46.1%), indicating superior digestibility and higher nutritional value (Bal et al., 2006; Türk et al., 2011). As the plant progresses to the flowering stage, fiber content increases (ADF: 34.3–43.3%, NDF: 43.3–47.6%), and continues to rise during the grain-filling stage (ADF: 33.8–40.2%, NDF: 44.6–55.7%), reflecting a decline in forage quality (Kaplan, 2011; Bal et al., 2006). However, after 42 days of regrowth, fiber levels (ADF: 33.7–39.7%, NDF: 36.5–45.4%) return to values similar to those in early growth stages, suggesting a potential recovery in nutritive value (Azuhnwi et al., 2012).

Sainfoin dry matter contains fat ranging from 3.11% to 4.20%, which is within the optimal 3–5% range recommended for ruminant nutrition,

providing sufficient energy without negatively impacting rumen microbial populations (Palmquist & Jenkins, 1980; Vuckovic et al., 2006). Its ash content, varying between 8.94% and 10.26%, aligns with the advised 7–10% range for dried forages, reflecting an adequate mineral supply to fulfil ruminant nutritional requirements (Van Soest, 1994; Vuckovic et al., 2006; McDonald et al., 2010). Moreover, sainfoin contains pyridoxine and riboflavin at levels of 3.14 mg/100 g and 2.35 mg/100 g, respectively, which are consistent with typical forage vitamin concentrations and sufficient to support ruminant metabolic functions (FAO, 1990; McDonald et al., 2011; NRC, 2001; Seylgazina et al., 2017).

The macro- and micronutrient composition of sainfoin is influenced by both genotype and environmental factors. Nonetheless, macro-elements such as potassium (K), magnesium (Mg), and calcium (Ca) are generally present in concentrations adequate to fulfil the nutritional requirements of dairy cattle. In contrast, phosphorus (P), sodium (Na), and zinc (Zn) are frequently reported at suboptimal levels (Vuckovic et al., 2006; Özköse, 2018; Sayar & Han, 2023). Although the calcium-to-phosphorus (Ca:P) ratio is conventionally considered optimal at 2:1, in sainfoin this ratio typically ranges between 4.7 and 5.5. This elevated Ca:P ratio has not been associated with negative health outcomes in animals provided with sufficient vitamin D. Furthermore, the potassium-to-calcium plus magnesium ratio (K:(Ca+Mg))—an indicator of grass tetany risk—ranges between 0.9 and 1.1 in sainfoin, remaining well below the critical threshold of 2.2 and thus indicating a low risk of tetany-related disorders (Sayar & Han, 2023; Çaçan & Kökten, 2024).

Sainfoin is distinguished by its rich phytochemical profile, with condensed tannins playing a significant role in the plant's antibacterial, antioxidant, and protein-binding properties (Hayot Carbonero et al., 2011; Sakhraoui et al., 2024). They reduce ruminal protein degradation, thereby increasing the amount of amino acids absorbed in the intestines and improving nitrogen utilization efficiency, which consequently enhances milk yield and quality, as well as the nutritional and functional properties of dairy products (Waghorn, 2008; Girard et al., 2016; Naumann et al., 2017). Additionally, condensed tannins have been reported to modulate ruminal microbial populations and suppress methanogenic activity, thereby reducing methane emissions, improving animal performance, and supporting

environmental sustainability. (Cardoso-Gutierrez et al., 2021; Min et al., 2021). The effects of tannins on animal performance are dose-dependent; although high concentrations can negatively impact digestion, condensed tannin levels in sainfoin typically range between 4% and 8%, a range considered beneficial for ruminant nutrition (Mueller-Harvey, 2006). Recent studies have revealed significant variation among sainfoin genotypes in tannin concentration, structure, and degree of polymerization, which influence tannin-protein interactions and digestive effects, thereby directly affecting forage quality and nutritive value (Hatew et al., 2016; Wang et al., 2024). Consequently, characterizing sainfoin genetic resources based on tannin profiles is crucial for optimizing the nutritional benefits in ruminant feeding.

2.3. Technological characteristics

Sainfoin is a versatile leguminous species that has historically played a significant role in both natural and cultivated grasslands, as well as in forage crop mixtures. Beyond its traditional use in animal husbandry, recent advancements in processing technologies and biotechnological approaches have highlighted the potential of both its herbage and seeds for diverse applications. In particular, sainfoin seeds—rich in high-quality protein and various bioactive compounds—have emerged as a promising alternative plant-based protein source not only for animal nutrition but also for human consumption (Craine et al. 2024).

Sainfoin is utilized in various forms—green forage, hay, silage, and pellets—within animal feed processing systems, providing both feed diversity and flexibility in livestock nutrition. Due to its rapid post-harvest drying capability, sainfoin offers significant advantages in hay production, while its ability to retain high nutritional value during ensiling renders it a promising source of high-quality forage (Tarasenko et al., 2015; Rufino-Moya et al., 2019; Sheppard et al., 2019). Pelleting represents a suitable processing method for sainfoin, as its high fiber content enhances feed digestibility. Although elevated drying temperatures during pelleting may reduce the reactivity of certain amino acids—particularly lysine—the bioactivity of sainfoin's condensed tannins is largely retained, preserving its functional benefits (Pellikaan et al., 2023).

Nutritionally and biochemically, sainfoin presents a rich composition, including high-quality protein, dietary fiber, and a lipid profile abundant in bioactive compounds, making it a valuable raw material for functional foods, dietary supplements, and pharmaceutical applications (Tarasenko et al., 2015). These properties enhance its potential not only as a forage for ruminants but also as a protein supplement in human and monogastric animal nutrition (Craine et al., 2024).

In summary, sainfoin stands out as a multifunctional forage legume with expanding relevance beyond traditional livestock systems—its unique nutritional profile and technological adaptability position it as a promising candidate for sustainable animal feeding strategies and innovative applications in human nutrition.

3. Contribution of Sainfoin to Sustainable Agriculture and Food Supply Security

Sainfoin is a leguminous forage species of strategic relevance to sustainable agriculture and global food security. Owing to its multifunctional agroecological traits, sainfoin contributes significantly to the preservation of natural resources, enhancement of soil fertility, maintenance of agrobiodiversity, improvement of water-use efficiency, and mitigation of greenhouse gas emissions through carbon footprint reduction. Collectively, these attributes reinforce environmental sustainability and support the long-term resilience and productivity of agricultural systems.

3.1. Conservation of biodiversity and ecosystem services

One of the most significant contributions of sainfoin to biodiversity is its provision of a continuous and abundant source of nectar and pollen throughout the growing season (Kells, 2001; Harris ve Ratnieks, 2022). These floral resources are vital for pollinators such as bees, which face increasing threats from habitat loss, pesticide use, and climate change (Potts et al., 2010; Goulson et al., 2015). By supporting the sustainability of pollinator populations, sainfoin plays an indirect yet crucial role not only in the reproduction of wild plant species but also in enhancing the productivity of pollinator-dependent agricultural crops such as fruits and vegetables.

Furthermore, the integration of sainfoin into mixed forage systems reduces the dominance of monocultures, thereby enhancing ecosystem

diversity within agricultural landscapes and strengthening ecological resilience (Altieri, 1999). Diverse plant assemblages in agricultural systems create buffering effects against environmental fluctuations (Andow, 1991), reduce pest and disease pressures (Gurr et al., 2004), and support a broader range of beneficial organisms, including predatory insects, birds, and soil microorganisms (Altieri, 1999).

The diversity of species and varieties within the *Onobrychis* genus significantly enhances its ecological importance (Avcı, 2010; Avcı et al., 2014, 2016). Variations in phenology, growth patterns, and chemical composition among different sainfoin types enable a wide array of ecosystem functions, including nitrogen fixation, soil coverage, and control of livestock parasites (Malisch et al., 2015; Avcı et al., 2016; Legendre et al., 2017). These multifunctional characteristics make sainfoin a key species in the development of agroecosystems that seek to harmonize agricultural productivity with ecological sustainability.

Sainfoin plays a crucial role in enhancing belowground biodiversity by stimulating microbial activity in the rhizosphere through the production of secondary metabolites and contributing to the stabilization of soil aggregates (Clemensen et al., 2020). These biological interactions facilitate the physical improvement of soil structure, promote more effective sequestration of organic carbon, and accelerate nutrient cycling, thereby supporting the maintenance of long-term soil fertility and reinforcing the ecological sustainability of agricultural production systems (Xiang et al., 2024).

3.2. Role in soil fertility and improvement

Crop production mainly depends on inorganic nitrogen fertilizers to replace nutrients lost during harvest and other processes, but these fertilizers have low efficiency and high environmental costs. Sainfoin, a leguminous species, enhances soil fertility by biologically fixing atmospheric nitrogen through symbiotic relationships with *Rhizobium* bacteria in root nodules—enabling nitrogen fixation rates of up to 168 kg N/ha—and thereby substantially reducing dependence on synthetic N fertilizers (Baimiev et al., 2007; Malisch et al., 2017). The inoculation of sainfoin with specific *Rhizobium* strains improves nitrogen fixation efficiency and supports the production of high-quality forage under low-input agricultural systems

(Prévost et al., 1987; Baimiev et al., 2007; Re et al., 2014). Consequently, sainfoin cultivation offers economic benefits to farmers while mitigating environmental impacts associated with synthetic fertilizer use, including greenhouse gas emissions, soil acidification, and water eutrophication (Olivares et al., 2013; Sakhraoui et al., 2024). Given these attributes, sainfoin plays a critical role in promoting sustainable agriculture and addressing the challenges posed by climate change.

Moreover, sainfoin possesses a deep and extensive root system that contributes to the physical and chemical improvement of soil. The root architecture enhances soil porosity and promotes better aeration and water infiltration, which are essential for maintaining healthy soil microbial communities and preventing waterlogging (Frame et al., 1998; Jia et al., 2024). This root activity also facilitates the redistribution of nutrients from deeper soil layers to the surface, making them more accessible for subsequent crops (Yan & Ghezzehei, 2022).

Sainfoin roots contribute substantial organic residues to the soil, which, upon decomposition, increase soil organic matter content (Sariyildiz and Savaci, 2020; Xiang et al., 2024). Elevated organic matter improves soil cation exchange capacity, nutrient retention, and moisture-holding capacity, thereby fostering a fertile and resilient soil environment (Lal, 2004). The root biomass of sainfoin, along with associated microbial exudates, plays a critical role in stabilizing soil aggregates, thereby reducing vulnerability to erosion by wind and water; this aggregation is essential for maintaining soil structure, which supports sustainable crop production by mitigating surface crusting and compaction (Six et al., 2004; Yüksek & Yüksek, 2015; Blanco & Lal, 2023).

Furthermore, the cultivation of sainfoin improves soil physical properties, thereby enhancing water movement and retention within the soil profile, which in turn increases water availability, supports plant growth under water-limited conditions by improving water use efficiency, and plays a vital role in maintaining or enhancing soil moisture dynamics—an especially important attribute for sustaining agricultural systems in drought-prone regions (Ben-Salem et al., 2018; Blum, 2005; Martlew et al., 2023).

Taken together, the biological nitrogen fixation capability, soil-enhancing root traits, and organic matter contributions of sainfoin underscore its vital role in fostering soil health, reducing environmental burdens, and

advancing the sustainability and resilience of agroecosystems, particularly under low-input and climate-stressed conditions.

3.3. A High-Quality forage resource in livestock production and a potential contributor to human nutrition

Sainfoin is a multifunctional forage legume recognized for its high nutritional value, unique phytochemical profile, and positive impacts on animal health and productivity. Its high crude protein content, favourable digestibility, and the presence of condensed tannins (CT) confer multiple advantages in ruminant nutrition (Theodoridou, 2010; Wang et al., 2015;Besharati et al., 2022). These tannins, when present at optimal concentrations, reduce ruminal protein degradation, thereby enhancing amino acid absorption in the intestines and improving overall nitrogen utilization (Theodoridou et al., 2010; Wang et al., 2015; Loregian et al., 2023). Additionally, CTs have been shown to reduce methane emissions, contributing to the environmental sustainability of livestock systems (Hatew et al., 2016; Aboagye & Beauchemin, 2019; Lazzari, 2022). As a result, sainfoin consumption is associated with increased milk and meat yields and reduced reliance on synthetic additives such as antibiotics and anthelmintics (Sakhraoui et al., 2024).

Beyond its nutritive value, sainfoin exhibits natural anthelmintic and anti-bloat properties, which are particularly beneficial in pasture-based ruminant production systems (Wang et al., 2006; Heckendorn et al., 2006; Hayot Carbonero et al., 2011). These attributes not only promote animal welfare and productivity but also support the long-term sustainability of forage-based livestock operations, particularly in low-input or organic farming contexts.

In recent years, growing attention has been directed toward the potential use of sainfoin seeds in human nutrition. Sainfoin seeds are rich in plant-based protein, dietary fiber, phenolic compounds, and antioxidants, suggesting their suitability as a functional food ingredient (Wijekoon et al., 2021; Sura et al., 2023; Craine et al., 2024). As global demand for alternative protein sources rises—driven by environmental concerns, dietary shifts, and food security challenges—sainfoin presents a promising, underutilized option for diversifying plant protein sources. Its nutritional profile positions it as a

valuable ingredient for vegetarian and vegan diets, as well as for addressing protein deficiencies in regions with limited access to animal-sourced foods.

The dual utility of sainfoin as a high-quality livestock forage and a prospective source of human nutrition highlights its role in integrated and sustainable agri-food systems. Further research into its agronomic traits, processing potential, and bioactive compound functionality will be essential to fully realize its multifaceted contributions to food and feed security.

3.4. Mitigating the agricultural carbon footprint

Sainfoin, a perennial forage legume, plays a significant role in mitigating the environmental impacts of agricultural systems, particularly in the context of carbon footprint reduction. Its multifunctional ecological attributes—such as biological nitrogen fixation, soil carbon sequestration, and improved soil health—make it a promising component of climate-smart agriculture (Sakhraoui et al., 2024).

One of the most direct contributions of sainfoin to reducing greenhouse gas emissions is its ability to fix atmospheric nitrogen through symbiotic associations with *Rhizobium* spp. This process diminishes the need for synthetic nitrogen fertilizers, the production and application of which are major sources of CO_2 and N_2O emissions (Snyder et al. 2009). Since nitrous oxide has a global warming potential approximately 300 times higher than carbon dioxide (NOAA, 2024), decreasing its emissions through reduced fertilizer use constitutes a crucial climate mitigation strategy.

Beyond nitrogen fixation, sainfoin's extensive and deep root system enhances soil organic matter accumulation and stimulates microbial activity, contributing to the long-term stabilization of organic carbon in soils (Sariyildiz ve Savaci, 2020; Xiang et al., 2024). These below-ground carbon inputs not only improve soil structure and fertility but also facilitate the sequestration of atmospheric carbon, thereby lowering the net carbon emissions from agricultural land (Lal et al., 2007; Lal, 2008).

Additionally, sainfoin's perennial nature ensures continuous soil cover throughout the year, which not only minimizes soil erosion and nutrient leaching but also promotes deeper carbon deposition in the soil profile (Martlew et al., 2023; Xiang et al., 2024). Its cultivation has also been associated with improved water retention and erosion control, indirectly

supporting carbon conservation by preventing soil degradation (Yüksek & Yüksek, 2015; Ben-Salem et al., 2018; Sariyildiz ve Savaci, 2020).

In conclusion, sainfoin's integration into farming systems offers both agronomic and environmental benefits. Its ability to reduce reliance on synthetic inputs, sequester carbon in soils, and enhance overall soil health underscores its potential as a strategic crop in efforts to reduce agriculture's carbon footprint. Consequently, sainfoin should be recognized as a key species in the formulation of sustainable agricultural practices and climate change mitigation policies.

3.5. Water management and drought mitigation

Sainfoin emerges as a valuable crop in sustainable agricultural systems due to its notable drought tolerance and efficient water management capabilities. Its resilience to water stress enables successful cultivation even in semi-arid and arid regions where water availability is limited (Carbonero et al., 2011; Sebastià et al., 2024). This trait is increasingly critical for enhancing agricultural resilience in the face of escalating water scarcity and irregular precipitation patterns driven by climate change.

The water use efficiency of sainfoin is underpinned by its physiological and morphological adaptations. Sainfoin's deep root system enables access to moisture from deeper soil layers (Irani et al., 2015; Malisch et al., 2016), while its long-lived leaves, strong turgor maintenance capacity, and high light interception efficiency (Sheehy & Popple, 1981) collectively contribute to its characterization as a drought-resilient forage legume. These adaptations optimize water utilization, allowing the plant to maintain growth and survival under water-deficit conditions.

Beyond the plant's intrinsic water use characteristics, sainfoin positively influences soil properties that enhance water retention (Ben-Salem et al., 2018; Sheppard et al., 2019). The accumulation of organic matter and stimulation of microbial activity improve soil structure, increasing its capacity to retain water for longer periods (Bronick & Lal, 2005; Fageria, 2012; Murphy, 2015). Consequently, this improves water availability during drought periods, benefiting both sainfoin and neighbouring crops, and strengthening overall agroecosystem resilience.

In summary, sainfoin's drought tolerance and superior water management traits represent critical factors supporting the sustainability of agricultural production under increasing water stress conditions associated with climate change. Therefore, promoting the cultivation of sainfoin in arid and semi-arid areas should be considered a strategic priority for conserving water resources and maintaining agricultural productivity.

4. Factors Limiting the Cultivation and Use of Sainfoin

In recent years, sainfoin cultivation in Turkey has been on a continuous decline. Cultivation area and production data clearly demonstrate this. There are various reasons for the decline in sainfoin cultivation. This section evaluates the factors that negatively impact sainfoin cultivation.

Sainfoin prefers well-drained, calcareous (pH 6.5-7.5) soils rich in organic matter. Acidic soils (pH < 6.0) or heavy clay soils negatively affect root development and nodulation (Frame et al., 1998). Waterlogging causes root rot (Undersander et al., 2011). Unsuitable soil conditions reduce germination rates and yields. Soil amendments (liming, drainage) are necessary, which increases costs.

Although sainfoin is drought-tolerant, it requires sufficient moisture during germination and early development (Peel et al., 2004). Irregular rainfall or lack of irrigation reduces plant density and yield. The risk increases in regions without irrigation infrastructure. Over-irrigation can trigger root diseases. Sainfoin should not be planted in water-logged lands with high water table (Tıknazoğlu, 2009).

Although sainfoin is a perennial plant, field preparation, seed costs, and maintenance require high initial investments (Undersander et al., 2011). Farmers' technical knowledge of sainfoin cultivation is often limited. Low awareness and high costs hinder its widespread use. Training and support programs are necessary.

Sainfoin provides yield for 3-5 years under suitable conditions, but overgrazing or late harvesting reduces the field's regeneration capacity (Frame et al., 1998). Yield declines are observed in aging fields. Regular field maintenance and rotation planning are necessary, which requires long-term planning and cost. Kara et al. (2009) reported that problems encountered during the harvest of sainfoin include rainy weather, moles, field mice, and

bees. Additionally, dodder and a lack of tools and equipment were also cited as problems.

The slow growth of sainfoin in the first year causes weeds (especially broadleaf weeds and meadow weeds) to become dominant (Blaser et al., 2006). The limited availability of selective herbicides for sainfoin makes weed control difficult. Mechanical or chemical weed control is necessary, but these treatments are costly and require technical expertise.

Sainfoin is susceptible to fungal diseases such as root rot (Fusarium spp.), leaf spot (Ascochyta spp.), and anthracnose, as well as pests such as aphids and spider mites (Gray et al., 2006). These pests reduce yield and forage quality. Despite subsidies, significant increases in sainfoin acreage have not occurred. The most important reason for the lack of a consistent increase in sainfoin production areas is that rootworms cause premature thinning in this plant. Because sainfoin fields are thinned early, our farmers likely prefer alfalfa and vetch, depending on field and climate conditions (Yolcu and Tan, 2008).

The thin and delicate leaves of sainfoin tend to fall off during drying or baling, resulting in a loss of nutritional value (15-20% protein) (Cash et al., 2002). If not harvested at the appropriate moisture content (15-20%), the risk of mold increases. Careful harvesting techniques and appropriate storage conditions (dry, airy areas) are necessary.

Alfalfa is recommended for irrigated lands and sainfoin for arid lands, and it has been noted that sainfoin is an ideal forage crop for arid conditions (Serin and Tan, 1996). Kara et al. (2009) reported that the reasons for not planting sainfoin are due to a lack of irrigated land, the high cost of seed, and insufficient land. It has been reported that 7% of farmers do not plant sainfoin because it is cut early. Imperfect utilization methods and the use of inappropriate seed shorten the sainfoin's lifespan (Tıknazoğlu, 2009).

While sainfoin cultivation in Türkiye has occasionally experienced minor fluctuations, overall significant progress has not been achieved. The primary reasons for this include the fact that sainfoin is mostly cultivated in regions with limited yields, producers prefer local populations over genetic diversity, the plant's long establishment process, its inadequate resistance to waterlogging, and the inability to produce the required amount of seed.

Sainfoin cultivation is practiced in a limited region of the world, primarily in Turkey, Iran, and Russia. Because sainfoin is rarely cultivated in developed countries, where research, development, and breeding efforts are intense, research on this plant has also been limited. Considering that sainfoin is often cultivated in adverse conditions, sufficient high-quality varieties tolerant to various adverse conditions have not been developed.

In recent years, it has been observed that the intensity of damage caused by certain pests affecting sainfoin has increased. This situation causes serious yield losses and prematurely ends the sainfoin's economic life. However, sufficiently effective control methods have not yet been developed.

4.1. Sainfoin root worm (*Bembecia scopigera* Scop.)

Although sainfoin has many pests, the most common species that cause the plant to quickly lose its economic life are the sainfoin rootworm (Bembecia scopigera Scop.) and Sphenoptera carceli Cast. and Groy.

In years when the insect population is high, the sainfoin plant becomes extremely sparse in its second year and rapidly ceases to produce an economic crop. The first significant study on the sainfoin rootworm, which is frequently seen, was a doctoral thesis completed in 1988. Initial observations showed that the adult larvae hatch from eggs laid on the stems of the sainfoin, particularly near the ground level, and then burrow into the root zone, creating galleries. The adult insect resembles a butterfly bee (Figure 8). It is reported to be seen in late June or early July and has a flight period of two months. Adults begin mating upon emergence, and a female lays 350-500 eggs. Depending on the temperature, an average of 20 eggs hatch per day. The larvae, first seen in mid-July, enter the roots and buds near the roots and feed in these areas until late November and early December (Figures 9 a and b). They overwinter as larvae and begin feeding again in the spring (Tamer and Özer, 1990). It has been reported that up to 28 sainfoin rootworm larvae were counted in a sainfoin root in a sainfoin plant where the pest population was dense (Uzun et al., 2007).

4.2. Sphenoptera carceli cast. and groy

Information on another pest, Sphenoptera carceli Cast. and Groy, which causes similar damage to the sainfoin rootworm, is extremely limited (Figures 9 c and d). Observations indicate that, although varying from year to year, it is

at least as prevalent as the sainfoin rootworm. Although uncommon, it also causes damage on the same roots as the sainfoin rootworm (Bembecia scopigera Scop.) (Figure 9-e).



Figure 8. Sainfoin rootworm adult

4.2.1.Control with cultural measures

Crop rotation is the most effective cultural measure in sainfoin fields with high insect infestation. According to our observations, the first sainfoin plant established in the late 1990s at the Konya Altınova Agricultural Enterprise, after sainfoin cultivation was suspended for approximately 6-8 years due to high insect infestation, yielded an economic crop for three years. However, the following year, the plant became too sparse to produce an economic crop, so the field was plowed.

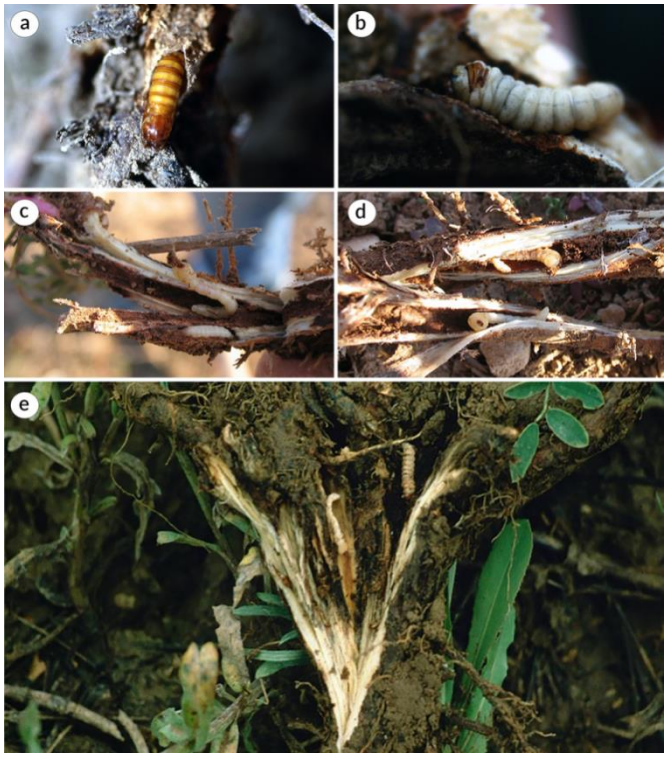


Figure 9. a) Sainfoin rootworm (*Bembecia scopigera* Scop.) pupa, b) Sainfoin rootworm (*Bembecia scopigera* Scop.) larva, c and d) *Sphenoptera carceli* Cast. and Groy. Larvae causing damage inside the sainfoin root, e) *Bembecia scopigera* Scop. and *Sphenoptera carceli* Cast. and Groy larvae seen simultaneously in the sainfoin root.

The second cultural measure that can be implemented in sainfoin plants is to regulate planting density. Because sainfoin is planted too densely with wheat planters while it is still fruiting, the plant roots compete with each other and cannot grow thicker. This causes the larvae of the pest to enter the roots, causing rapid damage to the root system and ultimately leading to plant death. Instead, wide spacing between and within the rows will encourage both lower fruit yields and the development of a larger root system. Even if larvae are present in the roots, the sainfoin plant can tolerate the disease for at least one year longer due to its extensive and robust root system.

4.2.2. Chemical control

There are no effective chemical control methods.

4.2.3. Biological control

Preliminary studies on the egg parasitoid (Trichogramma evanescens), which parasitoidally controls sainfoin pests, have shown promise. The TÜBİTAK 1507 SME R&D project (Production, Release, and Determination of the Effectiveness of Biological Control Agents Against the Sainfoin Rootworm (Bembecia Scopigera)) is currently underway.

4.2.4.Plant breeding

Elçi and colleagues have shown that single plants with strong root systems, selected over many years through selective breeding, are more tolerant to sainfoin pests. Similarly, according to Gül and Tan (2024), in their study "Determination of dry matter yield, some morphological characteristics, and rootworm infestation in local sainfoin populations," new cultivars with insect tolerance can be developed by utilizing local sainfoin genotypes.

It is possible to obtain insect-tolerant plants using transgenic plant technology. In his 2019 doctoral dissertation, Çöçü conducted gene transfer studies using A. tumefaciens lines carrying the cry genes (cry1Ac, cry1Ab, cry2A, cry1C, and the cry1Ba/cry1Ia hybrid gene SN19), which encode insect resistance in plants. Shoots resistant to the antibiotic kanamycin were obtained as a result of gene transfer studies. These shoots were rooted in MS nutrient medium and placed in a climate cell. Two months later, a total of 37 transgenic sainfoin plants carrying different cry genes expected to be resistant to insects were identified through PCR analysis of the NPT-II gene. Because the cultivation of transgenic plants is prohibited in Turkey under the national biosafety law, field studies on these plants were discontinued.

5. Conclusion and recommendations

Sainfoin is considered a valuable forage crop in ruminant nutrition due to its rich phytochemical composition and biologically active phytochemical contents. The nutrients found in its herbage and seeds include high levels of protein, a balanced amino acid profile, fibre fractions, fats, vitamins, and both macro- and microelements. These components are of great importance for enhancing feed efficiency and supporting metabolic functions in animal

nutrition. Sainfoin is utilized in various forms—green forage, hay, silage, and pellets—within animal feed processing systems, providing both feed diversity and flexibility in livestock nutrition. Sainfoin stands out as a multifunctional forage legume with expanding relevance beyond traditional livestock systems—its unique nutritional profile and technological adaptability position it as a promising candidate for sustainable animal feeding strategies and innovative applications in human nutrition.

The root biomass of sainfoin, along with associated microbial exudates, plays a critical role in stabilizing soil aggregates, thereby reducing vulnerability to erosion by wind and water; this aggregation is essential for maintaining soil structure, which supports sustainable crop production by mitigating surface crusting and compaction. Taken together, the biological nitrogen fixation capability, soil-enhancing root traits, and organic matter contributions of sainfoin underscore its vital role in fostering soil health, reducing environmental burdens, and advancing the sustainability and resilience of agroecosystems, particularly under low-input and climate-stressed conditions.

Sainfoin has emerged as a potential biological control agent against gastrointestinal parasites commonly found in livestocks. This antiparasitic effect is primarily attributed to its rich content of bioactive compounds, notably condensed tannins and flavonol glycosides. In addition to its forage value, sainfoin contributes significantly to pollinator support due to its prolonged flowering period and abundant nectar production, thus aiding in biodiversity conservation.

Sainfoin's drought tolerance and superior water management traits represent critical factors supporting the sustainability of agricultural production under increasing water stress conditions associated with climate change. Therefore, promoting the cultivation of sainfoin in arid and semi-arid areas should be considered a strategic priority for conserving water resources and maintaining agricultural productivity.

Sainfoin is a leguminous forage species of strategic relevance to sustainable agriculture and global food security. Owing to its multifunctional agroecological traits, sainfoin contributes significantly to the preservation of natural resources, enhancement of soil fertility, maintenance of agrobiodiversity, improvement of water-use efficiency, and mitigation of

greenhouse gas emissions through carbon footprint reduction. Collectively, these attributes reinforce environmental sustainability and support the long-term resilience and productivity of agricultural systems. The dual utility of sainfoin as a high-quality livestock forage and a prospective source of human nutrition highlights its role in integrated and sustainable agri-food systems. Further research into its agronomic traits, processing potential, and bioactive compound functionality will be essential to fully realize its multifaceted contributions to food and feed security.

In conclusion, sainfoin's integration into farming systems offers both agronomic and environmental benefits. Its ability to reduce reliance on synthetic inputs, sequester carbon in soils, and enhance overall soil health underscores its potential as a strategic crop in efforts to reduce agriculture's carbon footprint. Consequently, sainfoin should be recognized as a key species in the formulation of sustainable agricultural practices and climate change mitigation policies.

Eventhough lots of benefits, in recent years sainfoin cultivation in Turkey has been on a continuous decline. Cultivation area and production data clearly demonstrate this. In order to stop this decline and increase sainfoin cultivation, it is necessary to develop new varieties tolerant to different stress conditions, increase support, and transfer growing packages and other technological features to producers.

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Chapter 16

SESAME (*Sesamum indicum* L.)

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DOI: https://dx.doi.org/10.5281/zenodo.17463145

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1. General Characteristics of Sesame

Sesame (*Sesamum indicum* L.) belonged to Pedaliaceae family, which is known due to its oil content, flavor and delicious aroma and also known as the queen among oilseed crops (Jhonson et al., 1979; Myint et al., 2020). Primarily, sesame domesticated by the Harappan civilization and then spread to Mesopotamia before 2000 BC, reaching other parts of India by the late 2nd millennium BC (Kenoyer, 1998). According to previous studies, sesame was originated in South Asia from wild populations, particularly Pakistan and Western India. Much later its cultivation was occurred in Africa (Fuller, 2003). According to previously reported evidences about origin of sesame, the debate continues that sesame was originated in India and South Africa (Bedigian, 2004; Yol and Uzun, 2012; Kurt, 2018). During the ancient times, sesame was initially grown in Mesopotamian, Anatolian and Harappan eras for edible oil and seed (Bedigian, 2004). Currently, sesame is grown in more than 60 countries (Kurt, 2018). It is commonly known as hu ma in Chinese, sesame in French, til in Hindi, goma in Japanese, ajonjoli in Spanish, gergelim in Portuguese and susam in Turkish (Anilakumar et al., 2010; Konyalıgil et al., 2025).

In 2023, world sesame production was 6.788.881 tons, from which Türkiye produced 16.190 tons (FAO, 2023). Sesame is a semi-erect, self-pollinating annual plant which bears height 0.6 to 1.2 meters. Leaves of the plants vary in shape (lanceolate or ovate). However, lower are divided into three lobes while upper leaves have serrated edges with irregular shape. Its flowers (Figure 1) are bell shaped of purple or yellow color. Sesame is adapted to many soil types (Bedigian, 2010) but grows best in well-drained soils having pH between 5.5 and 6.8, and it is well adapted to warm, temperate tropical climates as a drought-tolerant crop (Rauf et al., 2024). Reported temperature for sesame life lies between 11°C and 35°C (Bedigian, 2010) but optimum temperature for best growth ranged between 24 to 27ºC (Gebregergis et al., 2024). Due to this vast range of temperature adaptability, sub-topical and humid regions can be grown also (Naturland, 2000; Gebregergis et al., 2024).



Figure 1. Sesame flowers

Capsule (Figure 2) is the most important organ of sesame related to productivity, so number of capsule per plant is one of the most used selection criteria in sesame breeding (Gnanasekaran et al. 2008; Yol and Uzun 2012). Long and dense capsule characteristics have a great impact on seed yield in sesame by enabling plants to produce more capsules and seeds (Sarwar et al. 2007).



Figure 2. Sesame capsules

2. Cultivation Purposes and Nutritional Value of Sesame

Being rich in nutrients sesame seeds are used in different foods and confectionery around the globe. Due to low sugar content, it is used in preparation of low glycemic confectionaries like cookies and biscuits (Dega and Barbhai 2023). Sesame leaves consumed as vegetable (Bedigian, 2018; Aworth., 2018) and flowers used to make cologne and perfumes in African countries i.e., Ivory Coast and Uganda (Pusadkar et al., 2015). In Western and Asia countries its oil is used as flavor additive and cooking purpose (Pastorello et al., 2001). In Türkiye, sesame seeds are used to prepare different bakery and other items such as cakes, crackers, simit (Türkish bagels) and bread. Halva and tahin (sesame butter) are also made with seed in Türkiye and other Middle East countries (Kurt et al., 2018).

Due to presence of minerals, carbohydrates, fibers and proteins in high amount, sesame is highly recommended for human diet. When sesame leaves are consumed as food, phenolic compounds and flavonoids present in them act as antioxidants (Mbaebie et al., 2010; Lin et al., 2017). Previous studies have reported its health benefits and cosmetic uses (Hsu and Parthasarathy, 2017; Chinweuba and Chendo, 2017; Majdalawieh and Mansour, 2019). Its oil helps to moderate the blood pressure (Sudhakar et al., 2011; Wacal et al., 2024), reduces osteoarthritis effect in knees (Eftekhar Sadat et al., 2013), contains anti-ulcer properties (Mishra et al., 2019), possess antibacterial and antifungal properties for wounds treatment (Shittu et al., 2019) and sesamol and sesamin present in oil serve as anti–carcinogenic (Majdalawieh et al., 2017). Sesame seeds are also used to feed chicken, fish and other animals or livestock (Dernekbaşı et al., 2017).

Sesame is a rich source of dietary components like carbohydrates, crude protein and fats (Wada et al., 2021; Zebib et al., 2015). Averagely, seeds contain 9.12% carbohydrates, 24.79% crude protein and 49.81% fats (Wacal et al., 2024). Similarly, among minerals seeds contain Ca 779.02 mg, Zn 6.97 mg, P 597.83 mg, Mg 408.95 mg, K 623.84 mg, Mn 3.16 mg, Fe 9.03 mg, and Cu 1.51 mg in per 100 g serving (Deme et al., 2017; Wacal et al., 2019). Plant based lignans sesaminol, sesamolin and sesamin are also present in sesame. It contains about 0.37 mg/g sesamol, 1.08 mg/g of sesamolin and 6.15 mg/g of total lignans (Wacal et al., 2024). Wacal et al. (2024) also reported the average fatty acids content in seeds from different studies like linoleic

41.16%, oleic 39.56%, palmitic 8.42%, stearic 5.55%, linolenic and arachidic 0.6%. In seeds most essential amino acids are methionine, histidine, valine and threonine which composed 1.45%, 1.29%, 2.01% and 2.32% of seeds, respectively (Nweke et al., 2011;Mustafa and Hüseyin, 2023).

Shells of sesame seeds can be found in different colors such as brown, black, yellow and white (Batu, 2020). Generally, sesame seeds are in light and dark colors. Some studies reported that light colored seeds better oil quality (Were et al., 2006; Kanu, 2011; Kim et al., 2014) but black seeds have higher carbohydrates, vitamins, protein and oil contents (Kim et al., 2014; Gebregergis et al., 2024). About 16-18% carbohydrates, 35-60% oil contents, 44-54% fats and 17-40% protein contents (more than cereals and nuts) are present in sesame seeds (Uzun et al., 2008; Akin, 2018; Bassogog et al., 2020; Batu, 2020). Its seeds are rich source of important fatty acids, amino acids, vitamin E and B1 and minerals like, magnesium, calcium, iron zinc, phosphorous, manganese, copper and potassium (Alyemeni et al., 2011; Kanu, 2011; Bakal, 2022).

3. Contribution of Sesame to Sustainable Agriculture and Food Supply Security

Sesame needs limited amount of water and fertilizers, and can thrive well in harsh environment without using any kind of pesticides due to natural resistance against pathogens (Myint et al., 2020). As a resilient crop sesame has number of benefits and well adapted to various cropping patterns. Different studies reported the benefits like improvement of soil fertility, intercropping, crop rotation and use of whole plant or plant parts for different purposes (Hussain et al., 2017; Couch et al., 2017). Sesame leaf extract controlled the weed growth such as purple nutsedge (*Cyperus rotundus*) (Hussain et al., 2017). Due to presence of lignans and various organic acids like phenols, flavanoids and saponins in plant, it could be use as insecticide (Andargie et al., 2021) particularly cotton leaf worm (*Spodoptera litura*) (Laurentin et al., 2003). By intercropping of sesame in maize, sunflower and peanut, it enhances crop growth and yield (Olowe and Adeyemo, 2009; Ijoyah et al., 2016). By intercropping with cotton, it has been reported to reduce the root–knot nematode effect. It also manages the pathogenic fungi and promotes the growth of arbuscular mycorrhizal fungi in soil which enhance stress

resistance and nutrients uptake in plants (Syed et al., 2015; Gupta, 2020). It is also recommended to incorporate the soil sesame residues in soil to maintain soil fertility and replenishment of nutrients (Wacal et al., 2024). By using all discussed approaches sesame plant can be used to increase crop yield and promote sustainable agriculture.

Malnutrition of micronutrients is growing swiftly in developing nations and became a growing issue around the globe (WHO, 2002). Malnutrition of micronutrients cause significant economic losses and become the cause of multiple diseases (White and Broadley, 2005). As we discussed, sesame is a rich source of various micronutrients such as copper, zinc, calcium, iron, potassium and more. Several researches like Kurt et al. (2020), Pandey et al. (2017) has been conducted to study the effects of micronutrients in different cultivars collected from different regions. These studies proved that, sesame has the ability to overcome the growing malnutrition of micronutrients and food security issues in the world. By giving proper attention and focusing on proper growth of sesame can help to fight against food security and malnutrition issues.

4. Factors Limiting the Cultivation and Use of Sesame

Sesame can thrive in hard environments like limited water and fertilizers but its yield varies according to cultural practices, cultivars and growing environment. Areas with salinity and drought stresses lemmatize its productivity (Myint et al., 2020). Drought mainly affects vegetative stage and low production was observed due to drought in semiarid regions (Boureima et al., 2012). Drought significantly effects yield and oil quality (Myint et al., 2020). Moreover, chilling and water also affect sesame production (Tripathy et al., 2019). Due to poorly drained soils, waterlogging reduces leaf axils per plant, photosynthesis, plant growth and ultimately affects seed yield (Uçan et al., 2007). Insect pests approximately cause 25% production losses globally (Myint et al., 2020), from which charcoal rot, wilting, leaf blight,*Cercospora* leaf spot and powdery mildew are among the most devasting diseases in the world and Türkiye (Adorada et al., 2025). Due to lack of knowledge and interest, farmers adapt new cultivars very slowly due to that reason, they have to face poor yield and make current cultivars susceptible to diseases, which limit the sesame production in the world

(Tripathy et al., 2019). Inappropriate harvesting either by mechanically or manually leads the seed losses up to 50% (Weiss, 1971). In many countries, especially Türkiye, inappropriate care of the crop during growth, lack of industrial interest and lack of the labor for harvesting most of the sesame production goes to be unused, get wasted and ultimately cause yield losses. Due to those reasons, farmers lack interest in sesame cultivation which continuously affecting the sesame production year by year.

Capsule shatter at harvest is considered one of the most significant problems in sesame agriculture worldwide as it caused seed loss at harvest up to 50% seed loss. Capsule shattering renders sesame unsuitable for mechanized harvesting. Therefore, it is being intensively addressed in breeding efforts. The development of new sesame varieties fully suited to mechanized harvesting could be a key factor in improving sesame crops.

5. Conclusion and Recommendations

Sesame belongs among one of the most ancient oilseeds crops and holds significance importance in agriculture due to economical, medicinal and nutritional values. It was originated from South Asia and due to cultivation of multiple ancient civilizations owns diverse soil conditions and climatic adaptability. Sesame seeds are rich in oil and have vital nutrients like carbohydrates, vitamins, proteins, antioxidants and fats which significantly fulfil the human dietary needs. In preparation of different traditional medicines and cosmetics, sesame is used widespread in the world, including Türkiye. In field, sesame suppress weeds growth, improves soil fertility and manages pests via intercropping system in sustainable means. Despite these benefits, sesame cultivation lemmatizes by different biotic and abiotic stresses and late adaptability of new cultivars due to farmers unawareness. Breeders should have to introduce new sesame cultivars with potential to produce more yield, tolerant to different stresses and adaptable to climatic variations. Domestically, it is dire need to give awareness to farmers about sesame production and health benefits of the crop, so that they focus properly and provide essentials to crop. Conclusively, sesame can potentially contribute to meet the nutritional and food security, rural livelihoods and sustainable agriculture issues. Policy support and strategic research can overcome currently facing issues to improve its position among oilseed crops.

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Chapter 17

SINGLE-FLOWERED VETCH (*Vicia articulata* Hornem.)

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DOI: https://dx.doi.org/10.5281/zenodo.17463152

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1. General Characteristics of Single-Flowered Vetch

Single-flowered vetch (*Vicia articulata* Hornem) is native to the Mediterranean region (Laghetti et al., 2000). Its natural forms are distributed in the Western Mediterranean, the Near East and the Mediterranean and Eurosiberia (López Bellido 1992].

Single-flowered vetch is self-pollinating (Zhang and Mosjidis, 1995), annual, climbing, herbaceous plant with angular stems (Figure 1), up to 50 cm tall. Leaves are 2.5-4.5 cm, 1-2 x 0.3 cm, and consist of 8 to 14 asymmetrically arranged leaflets Single flowers are bluish-white or yellowish (Figure 2a), with a calyx 5-6 mm in diameter and a petal up to 1.4 cm long. Pedicel 2-4 cm long, longer than the flower. Pod 2.5-3 x 0.7 cm long, slightly compressed (Figure 2b), with two to four 5 mm seeds, ellipsoidal, compressed, with a yellowish background color and large black-brown spots (Figure 3a), some small and punctate (Tardio et al., 2018). When the seed coat is peeling off, the inside of the seed (cotyledon) is yellow colors (Figure 3b), which is probably why it is known as yellow lentils.

It adapts well to low fertility soils and is resistant to all types of soils, but prefers light clayey and low calcareous soils. it tolerates poor, acidic or calcareous soils (Tardío et al., 2018), poor, light, sandy, stony and hillside soils (Sabaté Bel, 2011). it is known to be very resistant to drought and can grow under very low rainfall (± 300 mm) (Francis et al., 2000) It is also quite resistant to autumn and winter drought and to low temperatures (Van de Wouw et al. 2001). Cultivated varieties are quite heterogeneous populations adapted to different environments. In Spain, two types of single-flowered vetch are distinguished according to the background color of the seed coat: from yellowish-grey tones in the white varieties to blackish-brown in the black varieties. However, both have black dots on the background color (Laghetti et al., 2000), and the black forms are more cultivated in this country (López Bellido 1992).

In Türkiye, single-flowered vetch is known as "sarı mercimek (yellow lentil in English)" by farmers and is sold under this name in the market (Uzun et al., 2011). In addition, among the farmers, the plant is also called "kara mercimek (black lentil in English)" and "tek çiçekli fiğ (one flowering lentil in English)". Başaran (2024) reported that the single-flowered vetch populations originating from Türkiye were divided into two groups in terms

of plant height and phenological characteristics; one of them was late-flowering and short, the other was early and taller. These two groups show a difference of about one week in flowering. The populations started flowering on average 69-75 days after planting and reached harvest maturity in 117-122 days. No significant difference was detected between them in terms of characteristics such as flower color and seed color. The author also determined the grain yield as 1.47 - 2.41 t ha^{-1} and the protein content as 26.08 – 27.90% in single-flowered vetch populations. The general view of the vegetative and generative parts of a single-flowered vetch originating from Türkiye is given in Figures 1, 2 and 3.



Figure 1. General view of single-flowered vetch at the vegetative stage.



Figure 2. General view of flower (a) and pod (b) of single-flowered vetch.

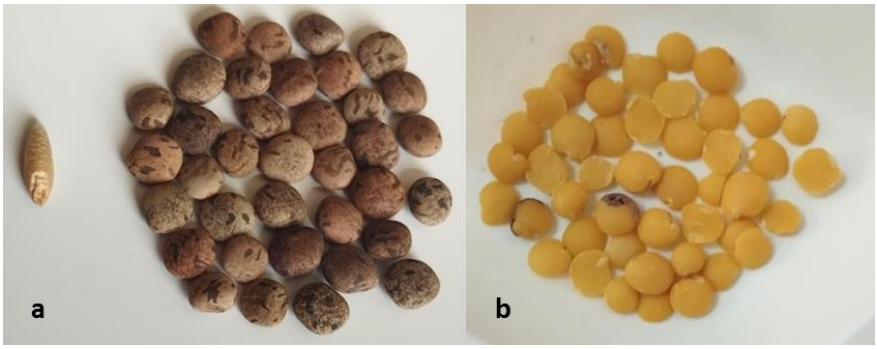


Figure 3. General view (a) and cotyledon color (b) of single-flowered vetch seeds.

2. Cultivation Purposes and Nutritional Value of Single-Flowered Vetch

The single-flowered vetch is one of the few vetch species used as food, but due to its similarity to lentils (*Lens culinaris*), information about its history is not clear. There is also confusion in archaeobotanical findings. Because it can be easily confused with other legume species such as lentils and common vetch (*Vicia sativa*) when charred (Pierogiovanni and Taranto, 2005). However, it can be easily distinguished from both lentil and vetch in the vegetative stage (Figure 4).

Single-flowered vetch is widespread mainly in south Europe, in west Asia and Australia for forage, green manure and human food (Laghetti et al., 2000). Its cultivation continues today in Spain, France, Southwestern Germany, Austria, Italy, Greece, Türkiye and Syria; however it is in danger of extinction in many regions (Laghetti et al., 2000; Van de Wouw et al., 2001).

Research indicates that its cultivation decreased significantly in the 1950s in all countries where it was grown. This situation is also seen in many neglected products. Because the developments in agriculture after the Second World War caused significant changes in cropping patterns, and crops with low economic value and not suitable for mechanization not preferred.

In Spain, it has been traditionally grown on dry lands in various regions as pulse and animal feed (Tardío et al., 2018). It is reported that single-flowered vetch once had the largest cultivation area in Spain after chickpeas. In this country, the cultivation area and production were 216.000 hectares and 109.300 t in 1930, but it has decreased significantly to 2000 hectares and 2.270 t in 2019, with an average yield of 1.046 t/ha (Rueda et al., 1999).

Being a climbing plant that tends to lodge, it was often planted with some cereals such as barley or wheat, for example with 10–20% rye in the Sierra Norte region of Madrid, to prevent lodging and facilitate mechanized harvesting

A single-flowering vetch was widely grown in Greece until the 1950s. However today it is grown only on the island of Santorini in the Aegean Sea and is therefore reported as an endangered species (Sarpaki et al., 2022). Similarly, it was still grown in Italy in the 1950s. However, since no records of it being grown later have been found, it is reported that it may be one of the lost crop species (Laghetti et al., 2000). This crop is still grown and consumed locally in Italy, but it has disappeared or is on the verge of extinction in some regions. It is called "black lenticchia nera" because of the similarity of its seeds to lentils (Piergiovanni, 2021). Although there are some negative opinions about its taste, Italian farmers state that single-flowered vetch is more productive and resistant to pests than lentils (Piergiovanni, 2021). The cultivation and consumption of single-flowered vetch continues in one village (in Calasetta) of S. Antioco, a small island in the southwest of Sardinia (Laghetti et al., 2000) and in three villages in the south of Apulia (Corigliano d'Otranto, Soleto and Martano (Accogli et al., 2012). Evidence of single-flowered vetch cultivation has been found in different villages in Sicily, but it has been determined that the cultivation of the plant has recently disappeared in these areas (Maly et al., 1987; ISPRA, 2013).

Single-flowered vetch is grown as a grain legume in Türkiye, but there is very little information about this plant. Since there are no official statistics about the crop, it is not possible to determine the production area and amount. In addition, in some regions, it is known by different species names such as *Vetch* and *Lens*, making difficult to obtain real data. However, field studies and farmers' feedback show that it is grown in significant amounts in the inner parts of the Aegean Region of Türkiye (Uşak, Manisa and Kütahya) and mostly in high altitude regions.



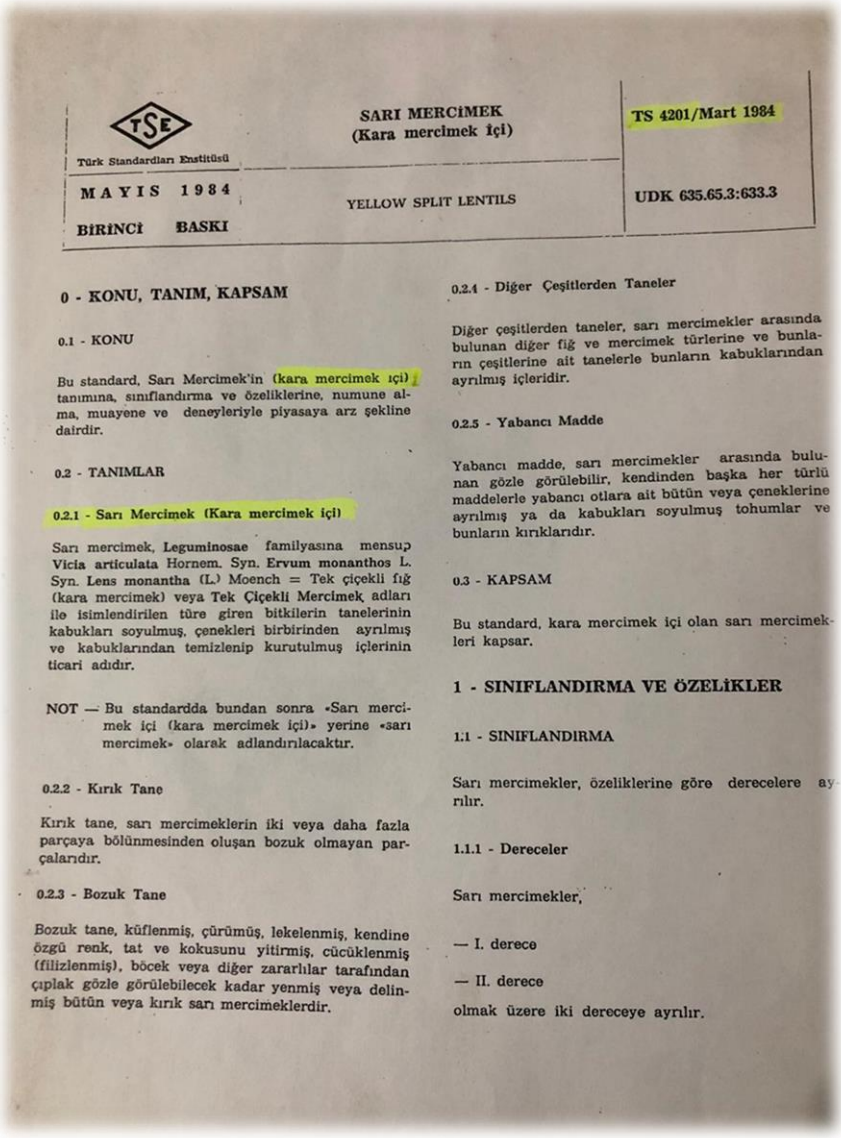
Figure 4. Visual differences of single-flowered vetch from lentil and common vetch.

Although the plant belongs to the vetch genus taxonomically, it is known and consumed as lentil. In fact, this issue was clarified with the Turkish Standards Institute (TSE) report (in Turkish) dated 1984 (Figure 5). According to this report titled "Sarı Mercimek (Kara mercimek içi)"; *Vicia articulata* Hornem is called in Turkish as "tek çiçekli fiğ", "kara mercimek"

and "tek çiçekli mercimek"). Also the report stated that after seed coats are removed and splitted, it is officially known as "sarı mercimek" (in English yellow lentil). This report developed standards for the trade of "yellow lentil" and provided a legal basis its uses as food in Türkiye. However, its production has continued to decline, possibly due to low yields or more economical alternative products. Growing in marginal areas and with low input does not make high yields possible. In addition, the use of populations as genetic material, the lack of academic studies, and problems in breeding and marketing may also be the reasons for the decline.

As reported by Başaran (2024), farmers state that the plant has been cultivated for a long time, its cultivation is decreasing today, but if they produce it, they can sell it at a higher price than red lentil. According to the farmers' statements, it is understood that the cultivation of the crop increased significantly within the scope of the "Reduction of Fallow Areas" project initiated by the Ministry of Agriculture and Rural Affairs, and then began to decrease significantly. This project was carried out in the 1980s and provided a very significant increase in lentil cultivation areas in Türkiye. Today, single-flowered vetch cultivation continues to decline, probably due to low yields, lack of labor, mechanization problems or more economical alternatives. Therefore, single-flowered vetch cultivation is in danger of extinction.

The grain yield of single-flowered vetch was reported between 0.65 - 1.1 t ha^{-1} in different regions of Spain (Rubiales and Flores, 2020). Single-flowered vetch seeds, like other legumes, are a good source of plant protein with an average content of 22 - 26% (Francis et al., 2000) and balanced amino acid composition (Pastor-Cavada et al., 2011). In Türkiye origin populations, protein content was determined as 26.08 - 27.90%, grain yield as 1.47 - 2.41 t ha^{-1} and 1000-grain weight 47.7 - 55.2 g (Başaran, 2024). The plant should be harvested when the pods are fully mature. Moreover, since the problem of pod shedding or cracking is not very intense, there is considerable flexibility in the harvest date.



Türk Standardları Enstitüsü

SARI MERCİMEK
(Kara mercimek içi)

TS 4201/Mart 1984

MAYIS 1984
BİRİNCİ BASKI

YELLOW SPLIT LENTILS

UDK 635.65.3:633.3

0 - KONU, TANIM, KAPSAM

0.1 - KONU

Bu standard, Sarı Mercimek'in (kara mercimek içi) tanımına, sınıflandırma ve özeliklerine, numune alma, muayene ve deneyleriyle piyasaya arz şekline dairdir.

0.2 - TANIMLAR

0.2.1 - Sarı Mercimek (Kara mercimek içi)

Sarı mercimek, Leguminosae familyasına mensup Vicia articulata Hornem. Syn. Ervum monanthos L. Syn. Lens monantha (L.) Moench = Tek çiçekli fığ (kara mercimek) veya Tek Çiçekli Mercimek adları ile isimlendirilen türe giren bitkilerin tanelerinin kabukları soyulmuş, çenekleri birbirinden ayrılmış ve kabuklarından temizlenip kurutulmuş içlerinin ticari adıdır.

NOT — Bu standardda bundan sonra «Sarı mercimek içi (kara mercimek içi)» yerine «sarı mercimek» olarak adlandırılacaktır.

0.2.2 - Kırık Tane

Kırık tane, sarı mercimeklerin iki veya daha fazla parçaya bölünmesinden oluşan bozuk olmayan parçalarıdır.

0.2.3 - Bozuk Tane

Bozuk tane, küflenmiş, çürümüş, lekelenmiş, kendine özgü renk, tat ve kokusunu yitirmiş, cücüklenmiş (filizlenmiş), böcek veya diğer zararlılar tarafından çıplak gözle görülebilecek kadar yenmiş veya delinmiş bütün veya kırık sarı mercimeklerdir.

0.2.4 - Diğer Çeşitlerden Taneler

Diğer çeşitlerden taneler, sarı mercimekler arasında bulunan diğer fiğ ve mercimek türlerine ve bunların çeşitlerine ait tanelerle bunların kabuklarından ayrılmış içleridir.

0.2.5 - Yabancı Madde

Yabancı madde, sarı mercimekler arasında bulunan gözle görülebilir, kendinden başka her türlü maddelerle yabancı otlara ait bütün veya çeneklerine ayrılmış ya da kabukları soyulmuş tohumlar ve bunların kırıklarıdır.

0.3 - KAPSAM

Bu standard, kara mercimek içi olan sarı mercimekleri kapsar.

1 - SINIFLANDIRMA VE ÖZELİKLER

1.1 - SINIFLANDIRMA

Sarı mercimekler, özeliklerine göre derecelere ayrılır.

1.1.1 - Dereceler

Sarı mercimekler,

— I. derece

— II. derece

olmak üzere iki dereceye ayrılır.

Figure 5. The Turkish Standards Institute (TSE) report dated 1984: This report states that the single-flowered vetch is consumed by humans in Türkiye under the name of yellow lentil and determines the principles regarding its trade (the report is 7 pages, the 2nd page is shown).

3. Contribution of Single-Flowered Vetch to Sustainable Agriculture and Food Supply Security

Single-flowered vetch is an ancient grain legume that is well adapted to the arid agricultural systems of the Mediterranean and Southwest Asia (Enneking, 1995). It is easy cultivated and can grow under low rainfall (± 300 mm), has relatively high seed yield, heigh protein content, and low or moderate toxic compounds (Francis et al., 2000).

This crop is generally preferred in areas that are not suitable for growing other products, and is grown without fertilization and irrigation. In fact, poor quality soils are considered more suitable for seed production. Because in fertile soils the plant develops very well but grain yield decreases (Tardio et al., 2018). It is a low-cost and economical crop in terms of input requirements and, as a legume, it is a source of nitrogen for the soil, thus reducing the need for mineral fertilizers (Tardío et al., 2018). It is also very suitable for use as a green manure in the improvement of poor soils (Romero Molina et al., 2011). Single-flowered vetch is self-pollinating; its seeds do not lose their quality and can be used for a long time. However, there are findings that the plant cannot tolerate itself; some farmers in Spain reported that when they planted this product in the same place for two years, the plant did not bloom and took on a different appearance, like a weed (Remmers, 1998).

Undoubtedly, in the past, farmers have made selections based on yield and different morphological characteristics in single-flowered vetch. However, single-flowered vetch has not been subject to modern breeding to date, which is indicating that it has been protected from human-induced genetic interventions and its natural structure has been preserved. Therefore, perhaps the most important feature of single-flowered vetch is that it is one of the rare cultivated plants that has not been subjected to human intervention and has remained natural with its genetic structure and chemical content. Also it is mostly grown in marginal areas with low input so does not pose a risk of chemical pollution (Başaran, 2024). All this shows that single flowered vetch is a nutritious and safe crop and has significant potential for sustainable agriculture and food production.

4. Factors Limiting the Cultivation and Use of Single-Flowered Vetch

Single flowered vetch is a plant with low or moderate toxic components (Francis et al., 2000). As with some other legumes, the presence of L-canavanine is a limiting factor in its consumption. A non-protein amino acid, L-canavanine competes with arginine in many enzymatic reactions, causing both toxic effects and reduced feed intake in non-ruminant animals (Laghetti et al., 2000: Sánchez Vioque et al. 2009). In terms of human consumption, it is possible to reduce the toxic effect; soaking the seeds in water before cooking has been shown to be a highly effective method of deactivating L-canavanine and making it safe to eat (Laghetti et al., 2000).

Spanish farmers have made different observations about the resistance of this plant to pests. In Contraviesa, farmers reported that they had almost no problems with pests or diseases, while in Segovia, it was very sensitive to Bruchus **(**Tardío, 2018**),** and in Extremadura, the problem of Orobanche was mentioned and even shown as one of the reasons for abandoning the plant's cultivation (Acosta and Díaz Diego 2008). In Türkiye, we also detected intensive Bruchus damage in collected and experiment seed. Therefore, measures may need to be taken to combat these pests in order to spread the cultivation of the plant.

4. Conclusion and Recommendations

Single-flowered vetch is an ancient legume of the Mediterranean ecology with low input requirements and high nutritional and economic value. Its seeds are also quite valuable in terms of human nutrition. It is consumed with pleasure and even preferred by people and its quality is quite high. It does not contain any significant negative effects regarding its consumption. It can also make significant contributions to the evaluation of marginal areas and poor soils and the improvement of the soil.

What is surprising is that such a valuable legume is at risk of extinction or completely extinct in all countries where it is cultivated. The reasons for this are; a) the product is not sufficiently recognized, b) its taxonomic differences are not fully known, it is confused with vetch and lentil, c) high-yield and high-quality commercial varieties have not been developed, d) there is a lack of information regarding its agronomy, e) weed control and

harvesting are still based on human labor, f) lack of sufficient regulations regarding trade and product standards. With the improvements made in these areas, this historical legume can be made widespread and thus a significant advantage can be gained in terms of sustainable agricultural food supply security and healthy nutrition.

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Chapter 18

Sorghum [*Sorghum bicolor* (L.) Moench]

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DOI: https://dx.doi.org/10.5281/zenodo.17463164

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1. General Characteristics of Sorghum

Sorghum (*Sorghum bicolor* (L.) Moench) is a self-pollinating, summer plant belonging to the Gramineae family, Panicoideae subfamily, Andropogoneae tribe, *Sorghum* genus, and *Sorghum bicolor* species (Wang et al., 2016). The genus is diverse, with species found in Africa and Asia (Clara W. Mundia et al., 2019; Faye et al., 2021; Endalamaw et al., 2025). Wild progenitors of the subspecies (subsp.) *vericilliflorum* are thought to have given rise to modern farmed Sorghum (Vavilov, 1951; Wang et al., 2016).

Sorghum is an annual or perennial C_4 cereal crop belonging to the Poaceae family (Tiryaki, 2005; Wang et al., 2016). It is a basic source of energy and nutrition for people living in semi-arid and arid regions of Africa and Asia. The proximate nutritional composition of Sorghum whole grain is similar to wheat whole grain (Stefoska-Needham et al., 2015). It also has various industrial applications such as animal feed, alcohol production and biofuel (Salvati et al., 2024). Sorghum's tolerance to drought, high temperatures and low nutrient levels makes it an even more important crop in today's world where the effects of climate change are increasing. This chapter aims to provide a comprehensive evaluation of Sorghum, shedding light on its origin, genetic diversity, areas of use, agronomic utilization and cultivation practices.

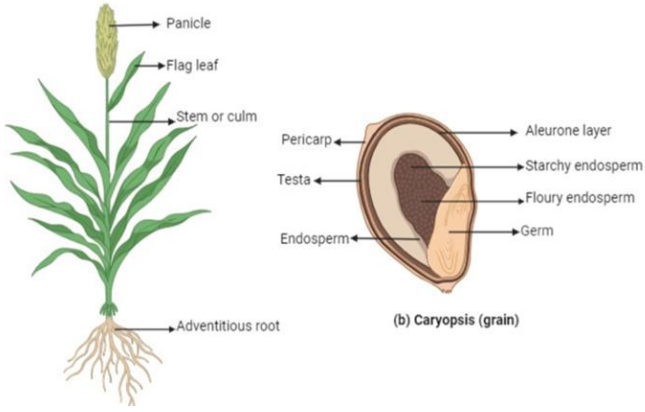


Figure 1. Sorghum plant and grain structure (Anonymous, 2025a)

1.1. Sorghum production in the world

Sorghum is farmed worldwide and ranks fifth in global cereal production, after maize, rice, wheat, and barley (Rao-P et al., 2015; Clara W. Mundia et al., 2019; Zhang et al., 2025a) (Figure 2 and 3). The United States is the global leader in maize and Sorghum production (Figure 3). World total Sorghum production in 2025 was reported as 61.788 million tons (USDA-FAS, 2025). The average production share of Sorghum by region from 2017 to 2022 showed that Sorghum is actively cultivated in America (28.4%), Africa (51.3 and Asia (14.4%). (Figure 4). In 2025, the United States will account for around 17% of global total production, followed by Nigeria (14%), India (13%), Mexico (11%), Sudan 5%, and Argentine 5%, and (Figure 5) (USDA-FAS, 2025).

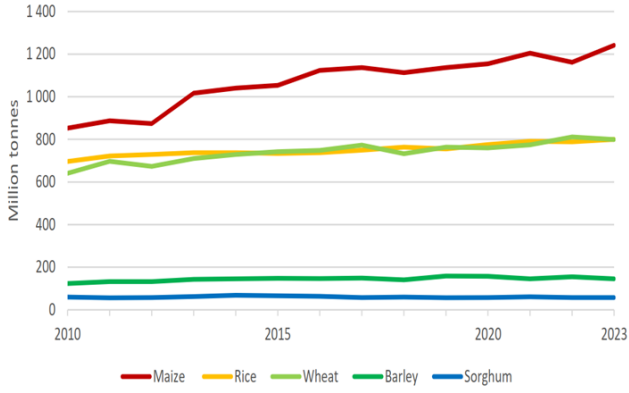


Figure 2. Crops and livestock production between 2010-2023

Sorghum, referred to as “Darı” or “Kocadarı” in Türkiye, has garnered the interest of Turkish farmers for both feed production and industrial applications, including ethanol generation (Table 1). Despite a 433.3% increase in Sorghum production from 2023 to 2023, the extent of global Sorghum cultivation and production remains inadequate for inclusion in FAO statistics. Another uncertainty regarding Sorghum production in Türkiye is that Sorghum is also considered as part of “Darı” in local. This scenario may induce ambiguities in the production and yield metrics of Sorghum within the “Darı” category and other Sorghum derivatives aside from grain Sorghum. On the other hand, *Sorghum bicolor* is also known as milo in USA and has been

called the “great millet” in Africa, where it originated (Mayers, 2018). However, the term "Darı" also refers to “Millet” and is generally used to introduce to a number of small-seeded annual grass species (Mayers, 2018). C4 millets, including foxtail millet (S*etaria italica*), barnyard millet (*Echinochloa frumantacea* and *E. esculenta*), proso or common millet (*Panicum milaceum*) and pearl millet (*Cenchrus americanus*) (Nikee Shrestha et al., 2023). The introduction and dissemination of these plant species from both taxonomic and agronomic viewpoints will allow for more accurate processing of plant production statistics across Türkiye, as well as the development of production plans based on this knowledge. Farmer training and demonstrations of the aforementioned production targets will lay the groundwork for Sorghum production planning in Türkiye. This will further increase Sorghum production, which can easily meet the growing animal feed demand through silage Sorghum in Türkiye. In today's world of changing dietary patterns, gluten-free Sorghum is also likely to find a place in human nutrition through a variety of products.

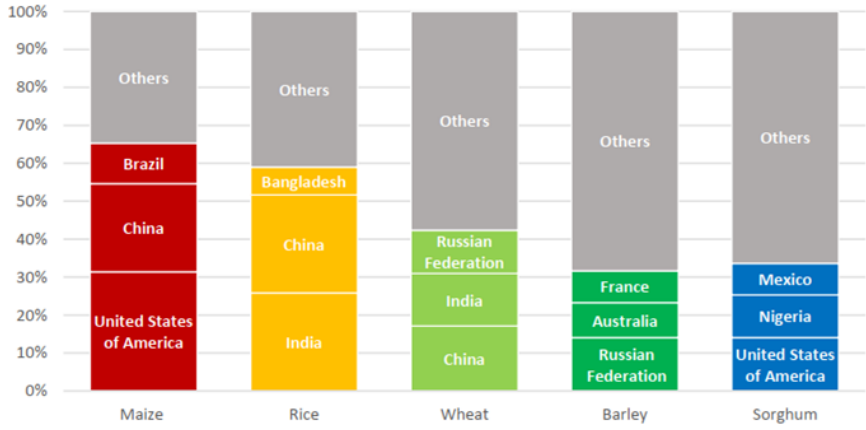


Figure 3. World production of top cereals. (FAOSTAT, 2024c).

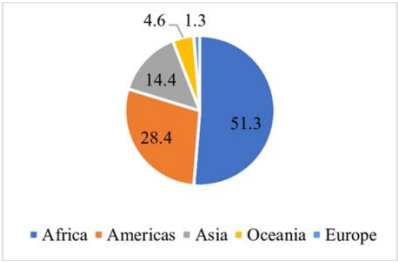


Figure 4. Production share of sorghum by continent 2017-2022 (FAOSTAT, 2024a).

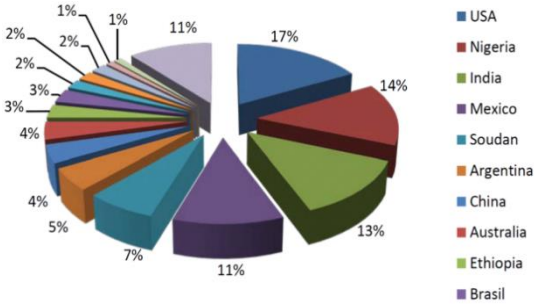


Figure 5. Sorghum production by country in 2025 (USDA-FAS, 2025)

Table 1. Production of cereals and other crops in Türkiye, 2023-2024.

Crops	Production (Tones)				
	2023	Share (%)	2024	Share (%)	Change (%)
Total	79 449 572	100.0	75 476 989	100.0	-5.0
Cereals	42 198 659	53.1	39 022 509	51.7	-7.5
Wheat	22 000 000	27.7	20 800 000	27.6	-10.0
Maize	9 000 000	11.3	8 100 000	10.7	13.2
Rice	900 000	1.1	1 019 000	1.4	-12.0
Barley	9 200 000	11.6	8 100 000	10.7	-15.7
Rye	305 000	0.4	257 000	0.3	-4.9
Oats	410 000	0.5	390 000	0.5	-16.2
Spelt	2 818	0.0	2 361	0.0	-8.0
Millet	4 101	0.0	3 774	0.0	53.2
Canary grass	4 192	0.0	6 422	0.0	0.0
Triticale	370 000	0.5	341 000	0.5	-7.8
Sorghum	18	0.0	96	0.0	433.0
Buckwheat	2 530	0.0	2 856	0.0	12.9

(TUİK, 2025).

1.2. Origin and evolution of sorghum

Sorghum originated in Northeast Africa, particularly the region between Ethiopia and Sudan, approximately 5000-8000 years ago (Wendorf et al., 1992; Kimber, 2000). Archaeological and genetic evidence suggest that this region was the main center of Sorghum evolution and diversification (Wendorf et al., 1992; Kimber, 2000). Hybrid forage Sorghum, often known as forage Sorghum, can reach heights of 1.8-3 m and have rather high stem diameters (Getachew et al., 2016). However, modern cultivars have been created to be smaller and easier to harvest (Getachew et al., 2016). In Africa, however, traditional tall Sorghum is still planted, and the stalks are used for a number of purposes (such as fuel or construction) (Getachew et al., 2016). Cultivated Sorghum (*Sorghum bicolor* subsp. bicolor), which evolved from its wild ancestor *Sorghum bicolor* subsp. *verticilliflorum*, spread from there to Africa, Asia, America and Australia over time (Tiryaki, 2005).

Sorghum landraces adapted to a variety of climates (Tiryaki, 2005; Wang et al., 2016). The geographical spread of Sorghum and its adaptation to different environmental conditions have resulted in a wide genetic diversity (Gebre et al., 2025; Teklewold et al., 2025). This diversity is evident in morphological traits (plant height, cluster structure, grain color), physiological traits (drought and salinity tolerance, maturation time) and genetics (Gebre et al., 2025). Genetic studies have identified five main races of Sorghum (bicolor, caudatum, durra, kafir and guinea) and numerous subraces resulting from hybridization between these races (Chaturvedi et al., 2023). This genetic richness constitutes an important resource for Sorghum breeding.

1.3. Genetic diversity

The Sorghum belongs to the Poacea family of Andropogonae order (Tiryaki, 2005). The Poaceae is characterized by a panicle-shaped inflorescence and grain, spikelets borne in pairs, and extensively branching roots (Wang et al., 2016). Its wild and cultivated species are under bicolor (L) Moench (formerly *vulgare*) (Chaturvedi et al., 2023). Sorghum can be broadly categorized into two types: forage and grain (Getachew et al., 2016). The forage Sorghum is further classified into four types: 1) hybrid forage Sorghum; 2) Sudangrass; 3) Sorghum x Sudan hybrids (sometimes called Sudan hybrids); and 4) sweet Sorghum (Getachew et al., 2016). All Sorghum

species are believed to have evolved from a diploid ancestral genome with n = x = 10. Genome Evolution in the genus *Sorghum* discovered 25 species classified into five subgenera: *StipoSorghum,EuSorghum*, *ChaetoSorghum*, *HeteroSorghum* and *ParaSorghum* (Garber, 1950). Price et al. (2005) defined twenty-one species of Sorghum (Table 2). Species in the genus exhibit chromosome numbers of 2n = 10, 20, 30, or 40 (Garber, 1950; Lazarides et al., 1991). StipoSorghum section consists of ten species found in northern Australia (De Wet, 1978; Lazarides et al., 1991.). EuSorghum section includes cultivated Sorghum (*S. bicolor* and subspecies *drummondii* and *arundinaceum*), as well as wild species *S. almum* Parodi, *S. propinquum* (Kunth) Hitch., and *S. halepense* (L.) Pers. (De Wet, 1978; Price et al., 2005). Sections ChaetoSorghum and HeteroSorghum are monotypic and native to the Australo-Pacific region, while ParaSorghum has seven Asian, Australian, and Central American species (Price et al., 2005).

Sorghum was also classified as *Sorghum bicolor var*. bicolor in terms of plant cultivation and divided it into five races: durra, kaffir, guinea, bicolour and caudatum (Harlen and de Wet, 1972). All of these main races originate from Africa and are widely cultivated in these regions for different purposes (Harlen and de Wet, 1972). Subspecies *bicolor* and subspecies *drummondii* (Steud), a wild African complex, are examples of cultivated Sorghum species (Price et al., 2005). On the other hand, there are three species in the species classification of Sorghum: (1) *Sorghum halepense* (L.) Pers., a perennial tetraploid (2n = 4x = 40) species that forms a rhizome and is found in the regions covering South Asia and Europe (Price et al., 2005; Wang et al., 2016). Polyploidy of *S. halepense* resulted from hybridization between diploid species. Polyploids often have increased adaptability and environmental tolerance but may be less fertile. (2) *Sorghum propinquum* (Kunth) Hitch, diploid forms (2n = 2x = 20), rhizomes and has a wide distribution covering South India, Sri Lanka and the islands of Southeast Asia. (3) *Sorghum bicolor* (L) Moench are all annual and constitute a widely cultivated diploid (2n = 2x = 20) Sorghum species (Endalamaw et al., 2025). The presence of 5 and 10 *Sorghum* species calls into question the genus' base number, as genetic and molecular studies imply that *Sorghum bicolor* (n = 10) is a tetraploid, contrary to popular assumption (Price et al., 2005; Endalamaw et al., 2025). Although *Sorghum bicolor* is a diploid (2n = 2x = 20) species,

the ancestral chromosomal number (x = 5 vs. x = 10) remains unknown (Price et al., 2005). Sorghum is divided into two lineages: one with 2n = 10 species with large chromosomes and related polyploids (2n = 20, 30, and 40), and another with 2n = 20 and 2n = 40 species with smaller chromosomes (Price et al., 2005). Overall, intra-racial and inter-racial hybrids contribute to significant phenotypic and genotypic diversity that underlies the species' adaptation to different agroecological zones (Price et al., 2005).

Sorghum is sexually compatible with all wild relatives in the Sorghum section, such as *S. halepense* (Johnsongrass), *S. propinquum*, *S. bicolor* ssp. *drummondii, S. bicolor* ssp. *arundinaceum*, and its four races (*aethiopicum, virgatum, arundinaceum, and verticilliflorum*) (Wang et al., 2016). These examples demonstrate how new types can replace landraces in crop plants. The loss of crop landraces is particularly severe in wealthy countries (Wang et al., 2016). Modern cultivars have largely replaced landraces in North America and northwest Europe (Wang et al., 2016).

The main types of Sorghum were also classified as grain, forage, biomass, and sweet (Hossain et al., 2022). Grain Sorghum comes in a variety of colors including red, orange, bronze, tan, white and black (Figure 1) (Teferra and Awika, 2019; Endalamaw et al., 2025). Red, orange, and bronze variants are widely used in the Sorghum business, whereas tan, cream, and white varieties are mainly processed into flour for the backing industry (Hossain et al., 2022; Endalamaw et al., 2025). Black and burgundy types are rich in antioxidants and are commonly employed in food applications. Forage and biomass Sorghum are commonly utilized in cattle and biomass businesses (Getachew et al., 2016; Fu et al., 2025). Sweet Sorghum can be used as a substitute to table sugar and is commonly utilized in brewing alcoholic beverages (Salesse-Smith et al., 2025).



Figure 6. Color of grain sorghum (Teferra and Awika, 2019)

1.4. Growth stages

The life cycle of the Sorghum (Figure 7) plant can be classified into three growth stages, namely vegetative (GS-1), reproductive (GS-2), and grain fill (GS-3), with about a third of the life cycle spent in each (Roozeboom and Prasad, 2019; Mamo et al., 2023).

Growth Stage I (GS I) occurs between planting and panicle initiation, lasting 33-45 days (Vanderlip and Reeves, 1972). Vegetative growth can be classified as emergence (S0), third leaf collar (S1), and fifth leaf collar (S2) (Roozeboom and Prasad, 2019). Hybrids initiate panicles 7 to 10 days earlier than types. During this stage, the majority of leaves begin to form. Water and temperature stresses during this period cause poor crop stem and postpone the initiation of floral development. Photoperiod has a significant impact on leaf formation and panicle initiation at this stage (Roozeboom and Prasad, 2019).

Growth Stage II (GS II) occurs between Panicle Initiation (PI) and Anthesis (or 50% flowering), lasting 35-45 days. GS II is essential for panicle formation and differentiation. Reproductive growth begins when the terminal meristem differentiates into panicle structures rather than new leaves (S3).

Reproductive growth is separated into two stages: flag leaf appearance (S4) and boot (S5) (Roozeboom and Prasad, 2019). Water, temperature, and photoperiod significantly affect spikelet and floret development. During this stage, stem elongation occurs simultaneously. Water stress during GS II affects the final output due to seed number reduction. As a result, from floret differentiation to early bloom, or the early boot stage, Sorghum is extremely vulnerable to water stress (Karaer et. al., 2024a; Endalamaw et al., 2025). Around two to three weeks after PI (the floret differentiation stage), a temperature of five degrees Celsius above ambient also results in a 28 percent decrease in seed number and a 30% decrease in yield. As a result, the length of GS II affects both yield and seed number. Reproductive growth shifts to grain filling at half bloom (S6), when plant height and leaf area are at their peak and around half of the total aboveground dry matter has been gathered (Roozeboom and Prasad, 2019).



Figure 7. Life cycle of sorghum (Anonymous, 2025b)

Growth Stage III (GS III) marks the transition from anthesis to physiological maturity, characterized by the creation of a black coating at the base of grains (Roozeboom and Prasad, 2019). Grain fill is split into soft dough (S7) and hard dough (S8), with physiological maturity (S9) occurring when dry matter accumulation ceases (Roozeboom and Prasad, 2019). The duration typically spans from 40 to 45 days, depending on genotype and environment. Water stress and hot temperatures can limit grain dry weight buildup. This stage is crucial for maximizing sink capacity and yields (Roozeboom and Prasad, 2019).

1.5. Sorghum farming

Sorghum farming varies according to the variety to be grown, climate conditions, soil type and agricultural techniques applied. It generally includes the following stages (Tiryaki, 2005).

Soil preparation: Sorghum has the advantage of being able to grow in a wide range of soil types (Getachew et al., 2016). For example, sweet Sorghums outperformed other fodder crops in terms of soil salinity tolerance (Vasilakoglou et al., 2011; Getachew et al., 2016). Sorghum thrives on deep, fertile, well-drained loamy soils, but is also more resilient to shallow soil and drought conditions than corn (Vasilakoglou et al., 2011; Getachew et al., 2016). Sorghum prefers well-drained, loamy or sandy-loam soils (Getachew et al., 2016). The most frequent soil cultivation strategy for Sorghum is early plowing, which eliminates weeds and levels the soil so that enough moisture is retained in the upper layers in the spring before sowing Sorghum on the prepared soil (Tiryaki, 2005; Butchee et al., 2012). Traditionally, Sorghum has been planted on soils with pH > 6.5, however soil acidity (pH 5.42) reduced grain production by 10% (Butchee et al., 2012).

Sowing: Sorghum seeds germinate at 10 °C, and the ideal temperature for seed germination, growth, and development is between 25 and 30 °C (Tiryaki and Andrews, 2001). For grain Sorghum, the average daily temperature at a depth of 10 cm ranges between 14 and 16 °C. Seeds are usually planted in spring when the soil temperature is suitable. Planting depth and distance between rows are adjusted according to the variety and the purpose of cultivation (Tiryaki and Andrews, 2001; Tiryaki, 2005). Planting densities range from 30,000 to 150,000 plants/ha in dryland systems,

depending on rainfall, and from 150,000 to 250,000 plants/ha in irrigated systems (Berenguer and Faci, 2001; Staggenborg et al., 2013). Higher densities increase soil coverage, which increases the utilization of solar radiation within the crop canopy (Benson et al., 2025). Planting at lower densities conserves soil moisture and closes yield gaps, which are generally linked to decreased planting rates and tiller output (Benson et al., 2025). Sustainable Sorghum farming practices aim to protect soil health, optimize water use, support biodiversity and minimize input use. Practices such as crop rotation, cover crops, minimum tillage and integrated pest management can be evaluated in this context (Tiryaki, 2005).

Irrigation: Although Sorghum is a drought-resistant plant, it needs sufficient water, especially in the early development and flowering periods. Irrigation is regulated according to variety, soil type, season, fertilizer application and rainfall (Endalamaw et al., 2025). Water-saving methods such as drip irrigation may be preferred (Tiryaki, 2005; Roncucci et al., 2014).

Fertilization: Basic nutrients such as nitrogen, phosphorus and potassium can be supplemented according to soil analysis (Ajeigbe et al., 2018). Delaying fertilizer application based on forecasted and observed rainfall might increase Sorghum grain yield and minimize input losses (Ganyo et al., 2019). Organic fertilizers can also be used to improve soil health (Ajeigbe et al., 2018; Karaer et al., 2024b; Wang et al., 2025c).

Weed control: Weeds in Sorghum fields can reduce yields by causing water and nutrient competition. Weed control methods used in Sorghum must be tailored to the specific weed species. The most common weeds detected in Sorghum fields are *Digitaria sanguinalis*. *Cynodon dactylon*, *Amaranthus* spp., *Cyperus rotundus*, *Euphorbia*, *Partheniumhysterophorus*, *Echinocloa*, and *Chenopodium* spp. (Deshmukh et al., 2017). Weed control is achieved by hand hoeing, mechanical methods or herbicides (Amare et al., 2025; Suresh and Karuppasamy, 2025).

Disease and pest management: Diseases can cause significant crop losses, depending on crop stage, cultivar susceptibility, and environmental factors (Anitha et al., 2020). There are various diseases (e.g., bunt, leaf spot) and pests (e.g., Sorghum fly, stem borer) that can affect Sorghum (Ngugi et al., 2002; Ahn et al., 2023). Sorghum diseases, including fungal, bacterial, and viral, can significantly reduce output and quality of grains and feed (Ngugi et

al., 2002; Anitha et al., 2020; Ahn et al., 2023). Fungal diseases such as anthracnose, leaf blight, and charcoal rot have caused epidemics in Sorghum-growing regions worldwide (Anitha et al., 2020). Pathogens can swiftly mutate, leading to the fast emergence of new pathotypes and races (Anitha et al., 2020). Adjusting N fertilization, using resistant Sorghum cultivars, and applying in-furrow and foliar insecticides can also synergistically suppress aphid infestations and boost grain yield in Sorghum production (Uyi et al., 2025). As a result, the most effective disease and pest management strategies are to use resistant cultivars, cultural interventions (e.g., rotation), and, if necessary, chemical or biological control approaches (Das, 2019).

Harvest: Sorghum is generally harvested when the grains mature and the moisture content decreases (Ali et al., 2015; Oyier et al., 2017; Kubiku et al., 2022a; Kugedera et al., 2022). Harvest time may vary depending on the variety and intended use of the plants. It can be harvested manually or mechanically (Tiryaki, 2005; Almodares et al., 2010; Ali et al., 2015; Kubiku et al., 2022b).

Post-harvest processes: Understanding the physical qualities of Sorghum grains can improve post-harvest operations, including washing, sorting, transport, ventilation, drying, and storage (Gely and Pagano, 2017; Anitha et al., 2019; Mohammed et al., 2022; Singh et al., 2024). The relationship between grain physical properties and moisture content is important for handling and processing operations, as well as predicting transport properties and drying rates using simulation models (Abalone et al., 2004; Anitha et al., 2019).



Figure 8. Sorghum farming (Anonymous, 2025c-f)

2. Cultivation Purposes and Nutritional Value of Sorghum

Plant seeds are utilized as a fundamental food in many cultures around the world, and seed flour is used to make a variety of meals (de Morais Cardoso et al., 2017). It is observed that the white forms of the plant are mostly used as food, and in general, the outer shells containing tannin and other secondary components are separated and used for food purposes (de Morais Cardoso et al., 2017; Gely and Pagano, 2017; Koleva et al., 2025).Sorghum seeds, which are widely utilized as a staple meal in many parts of the world, particularly in Central America, Africa, and Asia, have recently gained importance in the nutrition of celiac patients due to their gluten-free nature (Hossain et al., 2022). Although tannin-free forms of the plant, which has been farmed for nearly 3000 years, have recently been created, tannin-containing variants are expected to be employed in food supplements for obesity control and healthy living in the near future (Baah et al., 2025).

Food: Despite its excellent agronomic properties, Sorghum's usage in food production remains limited globally (Girard and Awika, 2018; Xiong et al., 2019; Hossain et al., 2022). The used part of the plant is the ripened seeds, flour obtained from the seeds and fixed oil (Hossain et al., 2022). Malt is obtained from the germinated seeds in the production of local beverages (beer and liqueur) (Girard and Awika, 2018; Hossain et al., 2022). In addition, syrup is obtained from the green parts of the varieties rich in sugar (Almodares et al., 2010; Martin et al., 2013; Salesse-Smith et al., 2025). Before obtaining seed flour and seed oil, the seed coat containing phenolic substances (tannins) considered to be risky for health is removed from the seed by different methods (Salvati et al., 2024; Amtataw et al., 2025; Khan et al., 2025). Sorghum grain is mostly consumed as a staple in semi-arid regions of Africa and to a lesser extent in India and Central America (Clara W. Mundia et al., 2019; Faye et al., 2021). Sorghum grains are a basic food source for millions of people, especially those living in Africa and Asia (Salvati et al., 2024). It is used in the production of various traditional and modern foods such as bread, porridge, couscous, tortillas and beer by turning it into flour. Sorghum is increasingly being used in various products in the US and Europe because to a growing interest in nutritional diversity, healthy eating, and alternative food ingredients such as "ancient grains"(Xiong et al., 2019). Polyphenols, particularly flavonoids, are the main beneficial bioactive components of Sorghum (D'Almeida C et al., 2025). Sorghum contains high levels of bioactive lipids, including policosanols and phytosterols, which are largely found in waxes on the grain pericarp (Sotak et al., 2014; Stefoska-Needham et al., 2015; D'Almeida C et al., 2025). In addition to bioactive chemicals, Sorghum endosperm digests starch slower than other cereal grains, which can affect postprandial blood glucose response in humans (Sharma et al., 2023; Kim et al., 2025).

In terms of nutritional value, it contains carbohydrates, protein, fiber, vitamins (B group) and minerals (iron, phosphorus, potassium, magnesium, zinc) (de Morais Cardoso et al., 2017; Girard and Awika, 2018). Some Sorghum varieties are also rich in phenolic compounds with antioxidant properties and are a suitable alternative for celiac patients since they do not contain gluten (Sharma et al., 2023; Kim et al., 2025). The pericarp, endosperm, and germ account for roughly 7%, 84%, and 9% of grain weight,

respectively (Salvati et al., 2024). Sorghum grain's nutritional makeup is controlled by climate, environment, and genetics. Grain typically comprises 55-77% starch, 7%-19% protein, 1%-5% fat, 8.5-24% fiber, 1%-2.8% ash, and 9-11% moisture (Xiong et al., 2019; Salvati et al., 2024; Zhang et al., 2025b). The nutritional quality of Sorghum proteins is diminished because they are more resistant to digestion (Hossain et al., 2022; de la Osa et al., 2025) and have low levels of essential amino acids such as lysine, tryptophan, and threonine (Stefoska-Needham et al., 2015). Sorghum grain contains phenolic chemicals that can help prevent and manage chronic diseases, making it a valuable addition to diets (Baah et al., 2025; D'Almeida C et al., 2025; Thomaz Dos Santos D'Almeida et al., 2025). This connection is connected to its abundance in dietary fiber, lipids, phenolic compounds, tannins, and flavonoids, such as anthocyanins, flavones, and flavanones (Wang et al., 2025a). Whole Sorghum flour can provide bioactive qualities in dietary products, including antioxidant, cytotoxicity, and anti-inflammatory activities (Salvati et al., 2024; D'Almeida C et al., 2025; Manivel et al., 2025).

Animal feed: In countries such as the United States, Mexico, and China, Sorghum grain is mostly used as a feed crop (Mathur et al., 2017; Utama et al., 2023; Wang et al., 2025b). Sorghum is an excellent source of green fodder due to its rapid growth, high yield, and high-quality biomass (Hou et al., 2025; Wang et al., 2025d). Sorghum stalks, leaves and grains are an important feed source for cattle, sheep, poultry and pigs (Utama et al., 2023; Ao et al., 2025; Podversich et al., 2025). It can also be used in silage production (Doğrusöz et al., 2024; Hou et al., 2025; Wang et al., 2025d). Sorghum silage is a cost-effective and high-yielding alternative to maize for cow production, particularly in low-moisture environments (Getachew et al., 2016).Choosing the right cultivar and production technology will entirely avoid hydrogen cyanide/ prussic acid (HCN) concerns in fresh sweet Sorghum or sudangrass used for feed (Rao-P et al., 2015). Since sudangrass grows faster after cutting or grazing and accumulates less of the poisonous compound HCN than forage Sorghums, it is utilized for grazing, repeated hay cuts, and silage (Getachew et al., 2016; Paudel et al., 2025; Tutar et al., 2025). Sudangrass has finer stems, more abundant tillers, and is leafier than hybrid forage Sorghums (Getachew et al., 2016). Sorghum-sudangrass hybrids are ideal for hay and grazing. Forage Sorghum hybrids, specifically brown midrib

(bmr) and non-bmr, are commonly used for silage production (Getachew et al., 2016). Forage Sorghum, unlike corn, is better suited for cultivation under mediocre agronomic circumstances (Getachew et al., 2016). Sorghum forage cultivation requires 30% less water and nitrogen fertilizer than corn (Getachew et al., 2016; Kardeş et al., 2023). Unless physically treated, Sorghum's small seed size makes it difficult for ruminants to digest (Getachew et al., 2016). Rooney and Pflugfelder (1986) reported that employing on-board kernel processors during Sorghum silage harvesting increases starch consumption, because Sorghum is the cereal grain with the lowest starch digestibility (Zhang et al., 2025b). It has a crucial role in animal nutrition because of its high energy content and digestibility (Irena et al., 2015; Xiong et al., 2019; Khan et al., 2024). Lower lignin level in bmr plants improves fiber component and overall plant digestibility (Getachew et al., 2016). Therefore, the link between digestibility and forage yield significantly affects agronomic techniques and the creation of new Sorghum cultivars (Getachew et al., 2016).

Biofuel: Some Sorghum varieties, especially sweet Sorghum varieties, contain high levels of fermentable sugar in their stalks (Arumugam et al., 2021). This sugar can be used for ethanol production (Hamadou et al., 2023; Jung et al., 2023). In addition, Sorghum biomass (stalks and leaves) is a potential source for biomass energy production (pellets, briquettes, biogas) (Massey et al., 2014; Mathur et al., 2017; Kaniganti et al., 2025).

Industrial use: Sorghum starch can be used in the adhesive, textile finishing material and paper industries (Chakraborty et al., 2025; Haziman et al., 2025; Zahid et al., 2025). Waxes, tannins and dyes obtained from Sorghum also have various industrial applications (Jenks et al., 2000; Xiao et al., 2020; Cardona et al., 2022; Wang et al., 2025a). In recent years, Sorghum stalks and hulls have also begun to be used in the production of sustainable products such as bio-based packaging materials and composite panels (Ao et al., 2025; Vicente et al., 2025; Zahid et al., 2025).

3. Contribution of Sorghum to Sustainable Agriculture and Food Supply Security

Sorghum is a versatile, climate-resilient cereal crop that plays a significant role in promoting sustainable agriculture and enhancing food supply security, particularly in arid and semi-arid regions (Hossain et al., 2022). Below is a comprehensive breakdown of its contributions.

Drought tolerance: Sorghum has a deep root system and waxy leaf coating, allowing it to thrive in low rainfall areas (300–600 mm annually). Its ability to maintain productivity under water stress makes it ideal for regions affected by climate change.

Efficient water use: Requires 30% less water than maize, making it suitable for dryland farming. Minimizes pressure on limited water resources, promoting sustainable water management.

Soil health and preservation: Sorghum contributes to soil health through, deep roots that reduce erosion and residue that adds organic matter and protects the soil surface.

Low input requirement: Grows well with minimal use of chemical fertilizers and pesticides. Reduces the carbon footprint of agricultural production.

Nutritional value: Rich in carbohydrates, protein, iron, zinc, and B vitamins. Gluten-free and ideal for people with celiac disease or gluten sensitivity. Some varieties have high levels of antioxidants and dietary fiber.

Adaptability to diverse climates: Can be grown in tropical, subtropical, and temperate regions. Provides a stable food source in unpredictable climate conditions.

Staple for millions: Primary food source for over 500 million people, especially in Africa and Asia. Used in traditional foods, porridge, flatbreads, and beverages.

Post-harvest stability: Sorghum grains are less susceptible to spoilage due to their hard outer layer. Can be stored for long periods, aiding food preservation and reducing post-harvest losses.

Income generation: Grown by smallholder farmers, providing them with a reliable source of income. Its by-products (stover, bran, etc.) are used for fodder, fuel, and building material, increasing economic value.

Diversification of farming systems: Intercropped with legumes or other crops to improve farm biodiversity and risk mitigation. Reduces dependence on a single crop, which is crucial for food security.

Biofuel production: High sugar varieties of sorghum (sweet sorghum) are used to produce ethanol, offering a renewable energy source. Helps reduce dependence on fossil fuels.

Food processing and industrial uses: Used in the production of flour, beer, animal feed, and syrups, and promotes agro-industrial development in rural areas.

4. Factors Limiting the Cultivation and Use of Sorghum

Climate and soil conditions may be the most critical factors restricting Sorghum production and utilization, as they are for all other cultivated crops (Chaturvedi et al., 2023). However, the commodity's local and worldwide application, direct or processed product portfolio, sustainability, and diversity of applications are key concerns for the sustainability of Sorghum production (Wang et al., 2015; Cardona et al., 2023; Mamo et al., 2023). Furthermore, the availability of other cultivated crops that may be substituted for Sorghum and are grown and produced all over the world could be viewed as a substantial barrier to Sorghum production increase (Eid et al., 2023; Fu et al., 2025). Indeed, the most significant constraint on Sorghum production is that it competes with corn and is grown only when corn-friendly soil and climate conditions are unavailable (Getachew et al., 2016; Hou et al., 2025; Wang et al., 2025d). Sorghum, being a secondary grain, is vulnerable to fluctuations in demand and availability (Assefa et al., 2014a; Reddy and Reddy, 2021).

The abundance of maize, a preferred feed and ethanol product in global commercial competition, severely restricts or limits Sorghum production (Assefa et al., 2014a). However, the development of new nutritious varieties for human and animal health paves the way for Sorghum to become a more widely used low-cost alternative crop in today's world. While biodiversity is less significant in improved Sorghum varieties, Sorghum diversity and species may impede the ability to standardize Sorghum products for global consumption (Assefa et al., 2014b). This could be one of the reasons it is primarily used to suit local demand rather than for global marketing. However, Sorghum market prices are also influenced by policy changes

among large exporters, making it more susceptible to substitution with maize (Assefa et al., 2014a). While the global impact of the conflict is minor, it is concerning in some developing countries and could have disastrous consequences in Sorghum-producing regions (Clara W. Mundia et al., 2019).

5. Conclusion and Recommendations

In recent years, growing droughts around the world have had a significant influence on agricultural production. Water scarcity and climate change are making it increasingly difficult to feed animals and provide food availability. As a result, transitioning to crops that use less water and are drought tolerant has become essential. Sorghum (*Sorghum bicolor*) can be a useful solution in this area. Sorghum, like maize (corn), can be used to make silage and grain, although it requires much less water. It is extremely heat tolerant and may produce significant yields even under difficult growth conditions. Because of these characteristics, Sorghum stands out as a viable alternative to maize in Türkiye.

Recommendations:

- Support agricultural research to generate Sorghum types suitable for Turkish settings.
- Increase farmer awareness: Educate farmers on the benefits of growing Sorghum over maize.
- Government support: Include Sorghum in agricultural initiatives, particularly in drought-affected regions.
- Expand market potential for Sorghum in feed and food businesses and help farmers market their products.
- In conclusion, Sorghum is an important alternative for animal feed and food security in Türkiye. Increasing productivity can assist farmers adjust to drought circumstances and add to the country's agricultural resilience.

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Chapter 19

SOYBEAN (*Glycine max* L. Merril)

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DOI: https://dx.doi.org/10.5281/zenodo.17463192

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1. General Characteristics of Soybeans

1.1. Origin and distribution

The origin of soybean is considered to be East Asian countries. It is thought to have originated from a wild species, *Glycine soja* (Baydar and Erbaş, 2014). It was first cultivated in China between 2383-2838 BC and used as a foodstuff, and was cultivated in the northern China region in the 11th century BC. The cultivated soybean species were taken to Japan between 200 BC and the 3rd century AD (anno Domini) and production began (Arıoğlu, 2014).

Soybean was taken from China to the European continent in the 17th century and from there to the USA in 1804, and was researched by the USDA in this country in 1898 (Baydar and Erbaş, 2014). Initially, soybeans were grown in the USA in a mixture with black-eyed peas, sorghum, and *Panicum* and used as animal feed. In later years, with the development of the industry, the areas of use of soybean increased rapidly (Arıoğlu, 2014).

Soybean came to Türkiye during the World War I. It was first grown in the Central Black Sea region in the 1940s. Later, in 1973-74, it was grown as an alternative to cotton when whiteflies damaged cotton, the main product in the Çukurova region, and significantly reduced yields. In 1980, projects were initiated to increase soybean production throughout Türkiye. Positive results were obtained from the studies and soybean planting areas increased rapidly. Soybean, which was first produced in Adana-Hatay and İçel, later spread to Antalya, Muğla, Manisa, İzmir, Kahramanmaraş, Gaziantep, Şanlıurfa, and Diyarbakır (Arıoğlu, 2014).

1.2. Plant Properties

Root: It is stated that the roots of soybean which has a taproot system, can go down to a depth of 2-2.5 m, but generally concentrated at 60-70 cm. Following flowering, nodosities are formed on the hairy roots and taproot that increase during the development period by the *Rhizobium japonicum* bacteria, thus fixing the free nitrogen of the air to the soil.Both itself and the plants that come after it can benefit from the nitrogen accumulated in the nodosities.

Stem and Leaves: The soybean stem, covered with dense hairs, has a hard structure that grows upright and tends to branch less in dense plantings and more in sparse plantings. The stem, which can grow up to an average of

60-120 cm, consists of nodes and internodes. Early varieties are generally shorter, while late varieties are taller. Soybean shows three growth habits: determinate, semi-determinate and indeterminate. Leaves consisting of 3 leaflets and a long petiole develop from each node of the soybean (Figure 1). The leaves are usually covered with dense hairs, and the hairiness may vary depending on the variety. With maturation, the leaves first turn brown and then usually fall off.



Figure 1. Soybean plant (İ. Acar)

Flower and Pod: Soybean has a typical legume flower structure. There are 3-10 flowers together in the leaf axils on the plant. The petals can be white or purple. Soybean is a self-pollinating plant, and the cross pollination can be up to 2-3% depending on the conditions. There are usually 3 seeds in the pods, and 2 or 4-seeded pods are also seen in rare cases (Figure 2). Each plant formed about 40-50 pods. In sparse plantings, the number of pods increases due to branching, and this number can rarely be hundreds. In terms of suitability for mechanization, it is desired for the first pod height to be high. Especially in water stress, since the first pod height will decrease, the timely irrigation is of great importance.

Grain: Soybean seeds develop in pods, as in beans. Testa color can vary from light yellow to brown and even black depending on the variety. Seed size varies depending on the variety and growing conditions, and 1000 seeds weight is between 70 and 250 gr. The oil content in the seed is between 18-22%, and the protein content is between 30-45%. Soybean oil contains

omega 9 (oleic acid), omega 6 (linoleic acid) and omega 3 (linolenic acid) fatty acids. Therefore, it is considered a balanced energy source in terms of nutrition.



Figure 2. Soybean pods at different maturity (H.M. Aykutlu)

1.3. Adaptation of soybean

Climate Requirements: Soybean, a short-day plant that requires an optimum temperature of 25-30 °C for both germination and development and can be grown in summer. The total temperature requirement during the vegetation period is 2500-3000 °C, depending on the variety. The vegetation period can be 80-90 days for early varieties and 150-160 days for late varieties. Soybeans have 13 different maturation groups and varieties in the I-V maturity group should be preferred for main crop cultivation in Türkiye, while varieties in the I-II maturity group should be preferred for second-crop cultivation. Water requirement of soybean varies between 450-700 mm according to the maturation groups. Since this amount of water requirement cannot be met by rainfall in other regions of Türkiye, except for the Black Sea Region, and especially in second-crop cultivation, irrigation is absolutely necessary. If soybean suffers from water deficiency at the begining of flowering and seed filling period, both defloration occurs and yield can decimate.

Soil Requirements: Soybean is not very selective in terms of soil requirements as a cultivated plant that can adapt to very different ecological conditions in the world. As soybean can adapt to many different ecological

conditions around the world, it is not very selective in terms of soil requirements. It shows its best development in sandy-clay soils. Because it does not tolerate drought and does not like waterlogging. In terms of cultivation, soybean soils must contain *Rhizobium japonicum* bacteria. Otherwise, this situation must be eliminated by inoculation of bacteria. In fact, during the season, plants should be uprooted from different points in the soybean field, nodosity formation and the activity status of the formed nodosity should be checked, and nitrogen needs should be met with fertilization. Neutral or slightly acidic soil is ideal. Soybean bacteria development is weak in very acidic soils or when acidic fertilizers are used in fertilization.

2. Cultivation Purposes and Nutritional Value of Rye

As is known, the increase in the world population brings with it nutritional problems and causes the rapid depletion or destruction of natural resources. Oilseed crops have an important role in human and animal nutrition due to the oil, protein, carbohydrates, minerals and vitamins they contain. At the same time, they constitute an important source of raw materials for the industrial sector.

Soybean is a unique source of nutrition for both humans and animals in terms of the protein (35-45%), carbohydrate (30%) and fat (18-24%) (Dede and Acar, 2024). Since the production of animal-based oils is expensive and insufficient, a large part of the oils absolutely required for human nutrition are met from vegetable-based oils.

Although there are many plants on earth that contain oil in their seeds, the most important plants that are processed in the industry today to obtain oil from their seeds are; Soybean, Sunflower, Cottonseed, Rapeseed, Peanut, Sesame, Safflower, Castor Oil, Poppy, Flax, Hemp, Jojoba, Corn (from Corn Germ), Olive, Date and Coconut (Atakişi, 1985; Arıoğlu, 2014).



Figure 3. Soybean plant at R6 growth stage (İ. Acar)

Soybean is second only to palm trees in terms of its contribution to world vegetable oil production (Başalma et al., 2025). Soybean has versatile uses and is an important industrial plant that provides raw materials for hundreds of manufactured products in developed industries. Its high-quality oil is used in liquid form in salads, fried foods and mayonnaise (Arıoğlu and Güllüoğlu, 2008). Soybean oil is also used in the production of soap, paint, polish, glue, insecticides, disinfectants and medical drugs, as well as in the production of printing inks. Its pulp is a very valuable animal feed. Its protein is rich in amino acids and has a high nutritional value. Therefore, soybean protein is also used in human nutrition. In addition to its high-quality protein content, it has an important place in the nutrition of people with diabetes, arteriosclerosis and coronary heart disease, as it contains very valuable fatty acids (Omega 3 and the like) that regulate fat metabolism in the human body (Ergin et al., 2023; Başalma et al., 2025).

In addition, soybean is a plant that is also valued as a vegetable in the world. In Japanese cuisine, a meal called "edamame" is made from soy. In this meal, green soybean pods harvested at R6 stage are used (Figure 3).

Since soybean is a legume, it contains more protein in both its seeds and vegetative parts compared to grasses. At the same time, the high biological value of seed protein and the low crude fiber content compared to other oilseed plants (Ergin and Kızıl Aydemir, 2018) make soybean seeds an important concentrated feed. Soybean seeds can be used directly as

concentrated feed, or after the oil is removed, it is used as meal or after some processes (roasting, squeezing) are applied to the seeds, the whole seed is used in the form of soybean flakes after being broken down. Soybean seeds and other products are used in the nutrition of ruminants and poultry, as well as in the nutrition of other animals, including pets and fish (Özçınar, 2021). The fact that soybean seeds can be evaluated as meal after the oil is removed provides much cheaper concentrated feed compared to cereals or plants such as vetch and peas when cultivated for concentrated feed purposes. This has a very important effect on the spread of plant cultivation.

This versatile use of soybean seeds has led to the development of varieties with high seed yield in the plant. Although soybean has large vegetative parts, due to the inverse proportion between seed yield and vegetative development, a decrease in the habitus of these varieties has occurred. For this reason, varieties suitable for roughage production have recently been developed in soybeans. At the same time, it is possible to evaluate oil varieties for roughage purposes. Thompson et al. (2023) investigated the hay yield and quality of soybean varieties developed for oil and feed purposes in their studies. As a result of the study, it was stated that the hay yield of forage varieties (except for one variety) was higher than oil varieties. Another situation in which oil varieties are evaluated as roughage is when the plants are evaluated as roughage when sufficient seed production is not achieved (Acikgöz et al., 2007). There are many soybean varieties registered in Türkiye. However, unfortunately, there is no information in the variety list about whether the varieties were improved for oil or forage purposes (Anonymous, 2025c).

One of the reasons why soybean is important as a roughage is that it has a warm climate and is an annual plant. Due to these characteristics, it is one of the few species that can be preferred in the Mediterranean climate zone (Acikgöz et al., 2007) when it is desired to produce roughage for a short period in the summer (when perennial forage crops are not desired to be grown in the field or when the production of perennial species such as alfalfa is limited). If soybean is used as roughage feed, it is harvested for hay or silage (Öztürk et al., 2020). Also the remaining parts of the plants after the pods harvested at R6 or R8 growth stage, are used as roughage.

Soybean can be grown alone for hay and silage production (Açıkgöz et al., 2013; Kaymak Bayram, 2024) or mixed with corn, sorghum or sorghum x sudan grass hybrids (Alaca, 2017; Gülümser et al., 2021; Basaran et al., 2017; Kızıl Aydemir and Kızılşimşek, 2019). While the forage yield of intercropped soybean with corn or sorghum is higher than sole soybean (Başaran et al., 2017; Mut et al., 2017), the silage properties of the roughage are also improved (Gülümser et al., 2017). When soybean is desired to be silaged, soybean, corn or sorghum can be grown alone in a separate fields, and silage can be made by mixing them after harvest. A researcher mixed corn and soybean in different proportions after growing in separate fields and processed them into silage (İçin, 2022), determined that the silages of 80% corn + 20% soybean and 60% corn + 40% soybean mixtures were both richer in protein and had higher silage quality. When it is desired to make silage from soybean grown alone, additives must be added and processed into silage (Kaymak Bayram, 2024).

After soybean is evaluated as a vegetable, the remaining above-ground part to be used as roughage or green manure remains (Zhang et al., 2017). In a study conducted in India, it was determined that the NDF ratio of the above-ground part remaining after the pod harvest in soybean lines evaluated as vegetables varied between 24.1-41.7% depending on the genotypes (Nair et al., 2015).

In periods when roughage is scarce, the remaining straw after seed harvest can be used in animal feeding. The straw can be used directly (Wang et al., 2014) or can be evaluated as pellet feed (Güleçyüz, 2016) with additional additives. The crude protein ratio of soybean straw varied between 3.2-5.5% (Wang et al., 2014).

3. Contribution of Soybean to Sustainable Agriculture and Food Supply Security

Since soybean is a legume, its most important role in sustainable agriculture is to fix nitrogen in the soil through biological nitrogen fixation. In a study, it was determined that soybean fixes 6-14 kg/da biological N (Korobko et al., 2024). While it uses some of this nitrogen itself, 2.5-4.5 kg/da of nitrogen can also be added to the soil. At the same time, soybean plant makes good use of the nitrogen present in the soil. Another feature of legumes

is that they change the uptake of other nutrient elements in the soil. In fact, in a study, it was determined that the phosphorus, potassium and micronutrient content of corn increased in soybean-corn crop rotation compared to monoculture corn farming (Önal Aşcı and Acar, 2023). Thanks to these features, much less fertilizer can be used and an efficient production can be contributed.

The fact that soybeans are suitable for use as green manure is also very important for sustainable agriculture. Thus, abundant and rapidly degradable organic matter can be added to the soil.

The fact that there is a large amount of protein with high biological value left after the oil is extracted from seeds, and that oil can remain in the pulp in varying amounts depending on the oil extraction method, provides both an important source of protein and a high-energy concentrated feed. In this respect, soybean seeds are an important source of vegetable oil for humans, while at the same time contributing to the production of a significant amount of animal protein.

Another importance of soybeans in terms of food security for Türkiye is that its fresh pods are consumed as vegetables, as in other countries. The increase in temperature experienced in the summer can sometimes limit the cultivation of green beans in Türkiye. While black-eyed peas are seen as one of the alternative plants instead of beans, the fact that soybeans are easily cultivated in many regions of Türkiye increases the potential for soybeans to be used as vegetables in the future.

In addition, as previously stated, soybean seeds were used in the Black Sea region in the past by adding them to corn flour to make cornbread. With changing climate conditions, this use may become current and widespread again. The existence of varieties with different maturity groups in soybeans allows its cultivation as a main and second crop according to the regions in Türkiye. Thus, with correct crop rotation planning, it will have significant effects on sustainable agriculture and food supply by increasing plant production and improving and protecting the soil.

4. Factors Limiting the Cultivation and Use of Soybean

There have been significant changes in the cultivation area and production amounts of soybeans around the world and in Türkiye in the last 50 years. During this period, technological developments have caused continuous increases in the cultivation area, production and yield of soybeans. Indeed, global soybean cultivation area increased from 29 525 000 ha in 1970 to 136 903 000 ha in 2023, production increased from 43 696 000 tons to 371 173 000 tons and yield increased from 1 480 kg/ha to 2 711 kg/ha (Table 1). Although soybean cultivation has spread to many parts of the world, the highest production is done in the USA, Brazil, Argentina and China (Anonymous, 2025a).

It is thought that soybean was introduced to Türkiye in the 1920s. Adaptation trials were first carried out in the Central Black Sea region in the 1930s, and with positive results from these trials, production began in the same region in 1945, and a soybean oil factory was established in Ordu in 1957 (Baydar and Ertaş, 2014). In the region, soybean is also called Çorum or sugar beans. Soybean was grown with corn in 3-5 decares in Ordu.Unfortunately, there has been no significant increase in soybean production in the city for 40 years. The reason for this is that in areas where soybeans are adapted and produce high yields, they are faced with more profitable plants such as beans, corn, tobacco and hazelnuts. Since 1975, the Ministry of Agriculture and Rural Affairs has encouraged soybean sowing as the second crop after cereals in the same year in the Çukurova, Aegean and Southeastern Anatolia regions, supported our farmers by the state with credit and base prices, and took the first place among the plants included in the ongoing second crop project, resulting in a significant increase in planting and production amounts (Kolsarıcı, 2018). Soybean planting area, production and yield values in Türkiye have started to be included in statistics since 1990. While the soybean sowing area in Türkiye was 74 000 ha, production was 162 000 tons and yield was 2 187 kg/ha in 1990, the sowing area increased to 326 000 ha, production to 1 370 000 tons and yield to 4 210 kg/ha in 2023 (Table 1).

Table 1. Soybean planting area, production and yield in the World and Türkiye*

Years	World			Türkiye		
	Cultivation Area (1000 Ha)	Produc. (1000 Ton)	Yield (kg/ha)	Cultivation Area (1000 Ha)	Produc. (1000 Ton)	Yield (kg/ha)
1970	29 525	43 696	1 480			
1980	50 646	81 040	1 600			
1990	57 209	108 456	1 895	74	162	2 187
2000	74 307	161 308	2 170	15	44	2 967
2010	102 858	265 088	2 577	234	86	3 690
2020	127 624	355 871	2 788	351	1 550	4 420
2021	130 646	372 706	2 852	438	1 820	4 150
2022	134 203	353 696	2 635	380	1 550	4 080
2023	136 903	371 173	2 711	326	1 370	4 210
2024				437	1 800	4 120

*(FAO, 2025; TÜİK, 2025, Access Date: 06.05.2025, Agricultural Structure and Production, 1986-2005)

As can be seen from Table 1, although there has been a certain increase in soybean production in Türkiye with second crop agriculture, the total production amount can meet only a small part of Türkiye's soybean needs. In the 2022/2023 period, Türkiye's self-sufficiency rate in soybeans was 5.2% (Anonymous, 2025b).

Since Türkiye's soybean production is insufficient, a large portion of the soybeans needed are imported. In recent years, Türkiye's soybean imports have ranged between 2.4 million tons and 3.1 million tons (Başalma et al., 2025).

In Türkiye, which has a great potential in terms of oilseed production, importing vegetable crude oil and its derivatives is a great loss for the

country's economy. The only problem that arises from the inadequate production of oilseeds in Türkiye is not limited to the foreign currency we pay abroad through imports. In order to prevent the idle capacity of oil factories in our country and to protect crude oil and refined oil facilities; it is appropriate to meet the oil deficit by producing oilseeds rather than importing crude oil (Arıoğlu 2016). Although the ecological conditions are suitable for the production of soybean, an important oil plant in Türkiye; soybean production remains limited because it cannot compete economically with other plant (corn) grown under the same locations. In addition, since producers experience marketing problems in years when world soybean prices are lower than domestic prices, they prefer to grow other plants that they can market more easily. Reasons such as soybean purchase prices being announced long after harvest, costs being much higher than global competitors, and imported products entering the market during harvest prevent soybean farming in Türkiye from reaching the desired level. Although soybean can be used in crop rotation in sugar beet production regions, it is not yet evaluated in these regions (Başalma et al., 2025).

To increase soybean production;

Soybean purchase prices should be determined according to free market conditions. The difference between world soybean prices and the target price (product cost + producer profit) should be paid to producers as a premium.

Supports to be given to soybean production should be announced early and paid at the latest by the end of the relevant calendar year. Support premiums should be kept high in a way that will bring soybean to the forefront in the income competition with other plants.

Companies that will import soybean should be obliged to purchase a certain amount of domestic soybean depending on the amount of soybean they import, or the Turkish Grain Board should ensure stability in soybean purchase prices through support purchases.

Industrial establishments that process soybean should contribute to the development of soybean cultivation in Türkiye by expanding the contracted farming model in domestic soybean purchases.

In order to ensure a profitable price formation in the domestic market, soybean imports should be made according to a certain calendar. Excessive

imports, especially during harvest periods, should be prevented and manipulations on soybean purchase prices should be prevented.

The areas quarantined due to potato wart disease in Central Anatolia and the high plateaus in Central and Eastern Anatolia are drawing attention as new potential soybean production regions. Studies should be carried out on the preparation of soybean adaptation maps for these regions and the development of soybean varieties suitable for these regions.

In the Mediterranean region, corn stands out as an alternative to soybean. Worldwide soybean pricing is 2.5 times that of corn. If it is taken into consideration when determining purchase prices in Türkiye, soybean sowing areas will increase. In addition, *Rhizobiu*m bacteria inoculation should be encouraged.

The fact that soybeans produced in Türkiye are GMO-free should be expressed nationally and internationally, the GMO-free soybean image should be emphasized, and the marketing opportunities of soybeans grown in Türkiye and the products obtained from them should be developed.

Soybean consumption should be expanded in Türkiye, the importance of soybean as human food should be emphasized, and industrial organizations that will process soybeans into high value-added products (lecithin, etc.) and foods should be encouraged.

Relevant sector representatives should be in close cooperation regarding research, breeding, and production activities on soybean in Türkiye. For this purpose, the establishment of a National Soybean Council should be on the agenda. In addition, soybean workshops, where all issues related to soybean are discussed, should be made traditional in Türkiye (Başalma et al., 2025).

5. Conclusion and Recommendations

Oilseed crops have an important act in human and animal nutrition both in the world and in Türkiye. However, there is a significant vegetable oil deficit in Türkiye. The main problem of the vegetable oil industry is the dependence on foreign sources for raw materials. The goal in the vegetable oil sector is to reduce foreign dependency in the coming years. For this purpose; Within the scope of agricultural support, the premium support for oilseeds

should be increased and their continuity should be ensured, and target-oriented support should be provided to oilseed crops with a supply deficit.

On the other hand, by evaluating the existing potential in Türkiye in terms of oilseed production, we have to produce the required oilseeds. Otherwise, we may face great difficulties as a country in the future. Studies have shown that almost all oilseed plants can be grown in Türkiye. One of these plants is soybean. Although the necessary ecological conditions for soybean production exist in Türkiye, it is not in demand by producers at the desired level because it cannot compete economically with other alternative plants (especially corn) grown under the same conditions. Considering its importance as a forage plant in the animal husbandry, and in eliminating the vegetable oil deficit, as well as the use of both its seeds and fresh pods as food, and its potential as an alternative to green due to changing climatic conditions, soybean cultivation should be expanded in suitable ecologies throughout Türkiye.

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Chapter 20

TOBACCO (*Nicotiana tabacum* L)

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DOI: https://dx.doi.org/10.5281/zenodo.17463212

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1. General Characteristics of Tobacco (*Nicotiana tabacum* L.)

Order: *Personatae*

Family*: Solanaceae*

Genus*: Nicotiana*

Species*: Nicotiana tabacum L.*

Tobacco (*Nicotiana tabacum* L.) is a broad-leaved, herbaceous plant belonging to the Solanaceae (nightshade) family, and it is generally cultivated as an annual crop. The native origin of tobacco is considered to be South America. The rapid spread of tobacco was largely influenced by fire- and sun-worshipping communities, who continuously burned fires for their gods and preferred tobacco because of its fragrant smoke. Tobacco was introduced to newly discovered islands by the Spanish and Portuguese, and its first cultivation took place in Mexico (Gately, 2001).

Tobacco was brought to Istanbul for the first time in 1601 by English and Venetian sailors. In Turkey, the first opposition to tobacco came from religious scholars, who argued that smoking was contrary to Islam, based on the belief that anything harmful to human health is forbidden. Initially consumed in the form of pipes and snuff, tobacco later became widely used as cigars and cigarettes (İnalcık, 2000).

1.1 Morphological characteristics of tobacco

Tobacco has a taproot system. The stem is generally round, erect, and covered with fine hairs (trichomes). Large-leaved types such as FCV and Burley can grow up to 250 cm in height, whereas Turkish-type tobaccos have shorter stems, ranging from 80 to 150 cm..

Tobacco is an important cultivated plant grown primarily for its leaves. The leaves vary in form, number, and size depending on their position on the plant. Basal leaves are broader and more rounded than the upper leaves, while both the basal and apical leaves are generally smaller than the middle leaves. Depending on the variety, the leaves may be broad or narrow, shouldered or unshouldered, and have rounded or pointed tips. These morphological traits are important criteria in varietal identification and classification. The leaf margins of tobacco are entire, which is one of the main morphological characteristics used in the differentiation of tobacco varieties. The leaves may be tongue-shaped, elliptical, oval, or cordate (heart-shaped). Leaf tips can be

rounded, pointed, or intermediate in form. The leaf surface may be smooth, blistered, or wavy, and glandular hairs are present on the lower surface. Leaf size (length and width) varies depending on both growing conditions and varietal characteristics. The leaves of Burley and flue-cured Virginia tobaccos are generally large and are therefore referred to as "large-leaf tobaccos." In contrast, Turkish-type tobaccos have smaller leaves and are classified as "small-leaf tobaccos."



Figure 1. Tobacco Plant (A) and flower (B).
Resource: Boksana, (2025), Accessed: 01.08.2025.
https://www.dreamstime.com/basic-cmyk-image163662662

The tobacco plant belongs to the Solanaceae (nightshade) family, and its flowers exhibit the typical morphological characteristics of this family. When the plant reaches the generative growth stage, an inflorescence of the raceme type is formed at the terminal part of the stem. The flowers are generally hermaphroditic, containing both male and female reproductive organs within the same flower. This characteristic allows the plant to reproduce primarily through self-pollination, although a small degree of cross-pollination may also occur. The flowers are tubular in shape with five lobed tips and are arranged in clusters forming a raceme. Flower color varies from white to red. Each flower consists of five sepals, five petals, five stamens, and a single pistil (İncik, 2010).

After pollination and fertilization, the ovary develops into the tobacco fruit, known as a capsule. The shape and size of the capsule vary depending

on genetic and ecological conditions. Tobacco capsules may be spherical, cylindrical, or depressed-spherical in form, and their tips are usually pointed.Tobacco seeds are formed on the placenta inside the capsules. Each capsule contains approximately 2,500 to 8,000 seeds. The seeds are kidney-shaped and extremely small, exhibiting a color range from brown to black. Tobacco seeds contain about 35–40% oil, and their thousand-seed weight ranges from 0.07 to 0.09 g (Kırıcı, 2017).

1.3. Tobacco cultivation and adaptation

Tobacco is originally a subtropical climate plant. Its vegetation period varies between 60 and 150 days depending on climatic conditions such as light, temperature, and precipitation. Although the total heat requirement differs among varieties, it generally ranges from 1800 to 3200 °C.The minimum temperature required for seed germination is 12–14 °C, while the optimum germination temperature is 27–28 °C. For continued plant growth, the minimum temperature requirement is around 10 °C, and the optimum range is between 25 and 30 °C. The maximum temperature at which the plant can grow effectively is 35–40 °C. Although tobacco plants die at temperatures below 0 °C, they can occasionally tolerate short-term exposure down to –3 °C.

During the germination and seedling stages, the water requirement of the tobacco plant is high, and plants are unable to tolerate drought at this phase. As seedlings grow, their resistance to water deficiency gradually increases. The second period when tobacco is sensitive to water stress occurs after transplanting, when the seedlings are establishing new roots in the field. The third critical period corresponds to the flowering stage, which plays a significant role in determining leaf quality.Tobacco plants exhibit rapid growth under moderately distributed rainfall conditions throughout the growing season. However, excessive rainfall delays maturity and causes the leaching of resins and nicotine from the leaves. In addition, high rainfall and humidity favor the development of various diseases.

Tobacco seedlings can be grown in cold, warm, or hot seedbeds, as well as in a float system. Seeds are sown by mixing them with 30–40 times their volume of ash and fine sand and spreading them evenly. The sown seeds are then covered with a maximum of 0.5 cm of sieved sheep and goat manure and

gently pressed with a wooden board. Afterward, they are lightly watered using a fine-mesh sieve and covered.

The average temperature in covered seedbeds is 20–30 °C. Therefore, the temperature in the seedling nursery should not rise above 38 °C or fall below 5 °C. In this regard, during cold days, it is necessary to additionally cover the seedbed with mats. The following operations are performed for the care of the seedlings:

- Irrigaiton: For watering the seedlings, preferably warm well water is used; if unavailable, clean river water can be used. Initially, when the weather is still cold, watering is done in the mornings, and once the weather warms up, in the evenings. Until the seeds germinate, the seedbed should be watered frequently but lightly. As the seedlings begin to grow, watering should be abundant but less frequent to obtain strong, healthy seedlings and to prevent disease outbreaks. One week to ten days before transplanting, watering is reduced significantly.

- **Weed removal:** After irrigation, the weeds growing in the seedling are removed and mortar is sprinkled as a filler in the empty spaces.

- **Thinning:** If the planting is done too densely, either thinning is done or the seedling is raked.

- **Fertilization:** Seedlings cannot develop well due to reasons such as late sowing, poor soil conditions, etc. If the seedlings become weak and yellow, the seedling fertilizer should be diluted or a syrup made with chemical fertilizers should be used.

- **Aeration:** Abundant sunlight regulates seedling growth and eliminates excess moisture. Lack of light causes seedlings to grow poorly. Winds scorch young seedlings, while rain accelerates growth. Frost, rime, and hail damage seedlings.

- **Removal of seedlings:** To determine the maturity of seedlings, pull a few when they are 10-20 cm tall and have 4-6 leaves and wrap them around your finger. If they break, they are juicier and not yet ripe. If they don't break, they are ripe and ready to plant.



Figure 2. Tobacco seedling (A), seedling irrigation (B), seedling uprooting (C) and tobacco seedling (D).
Güleşçi, M. (2025), Accessed: 01.08.2025. https://www.turkishtobacco.net/tutun fideliği

Depending on the regional climate, seedlings are transplanted to the field as follows: in the Aegean region between March 15 and March 20; in the Black Sea region from late May to early June; in the Marmara region between March 25 and May 15; and in the eastern regions, in warm areas at the beginning of June and in cold or high-altitude areas after June 15.

Tobacco fields should have a low groundwater table and soils with medium weight, clay-sandy or loamy texture, low organic matter and nitrogen content, but rich in other elements, especially potassium. The best-quality tobacco is produced on steppe, plateau, and riverside

Planting Time and Spacing: To ensure normal growth and high-quality production, tobacco seedlings should be transplanted as early as possible. Seedlings in the nursery are transplanted to the field once climate and soil conditions become suitable. For Turkish-type tobacco, the planting spacing is 40 × 15 cm, resulting in 15,000–20,000 seedlings per hectare. For

cigar and foreign-origin leaf tobaccos, the spacing is 100 × 60 cm, allowing 1,500–2,200 seedlings per hectare. Transplanting can be done either manually or by machine.



Figure 3. Mechanical planting of tobacco and tobacco field**.**
Güleşçi, M. (2025), Accessed: 02.08.2025. https://www.turkishtobacco.net/tutun-fotograflari

For good seedling planting, the following should be done: Seedlings should not be damaged during planting. Seedlings should be placed in the soil in an upright position, without bending their roots. Tobacco seedlings should have a straight, non-leaning trunk and be no smaller than 12 cm tall. Planting should be done in the early hours of the day when the heat is not high. Seedlings should not be planted too deep or at the surface. Two to three days after planting, the field should be visited and any seedlings that do not take root should be replanted

Maintenance and watering,

For tobacco, a shallow hoeing is performed 10–15 days after transplanting, followed by a deeper second hoeing and hilling around the stems 25 days later. Hoeing serves both to eliminate weeds and to aerate the soil after rainfall or irrigation, thereby accelerating plant growth. In general, Oriental-type tobaccos are not irrigated; however, in dry years, 1–2 irrigations may be applied. Studies have shown that tobacco is more sensitive to water during the budding stage close to flowering, making soil moisture management critical during this period. Malatya, Bitlis, Taşova, Tömbeki, Muş, and Silvan tobacco varieties are irrigated 3–4 times during their growth period, with soil crusts broken after each irrigation. Burley and FC Virginia tobaccos are irrigated 4–5 times.

Harvesting

Tobacco is harvested either by breaking the mature leaves or by cutting them from the stem along with their stalks. Tobacco varieties from the Aegean, Marmara, Black Sea regions, some Eastern varieties, and Virginia tobaccos are harvested by hand. Burley tobacco, on the other hand, is cut from the base along with the stems. Leaves that mature at the same time are called a "hand." Maturation occurs from the lower leaves upwards and varies depending on the variety.



Figure 4. Türk Tobacco (A) ve FC Virginia (B) harvest.
Resource: Karagöz, K., (2025), Accessed: 03.08.2025).
https://www.aa.com.tr/tr/pg/foto-galeri/adiyaman-ciftcisinin-tutun-telasi-

Proper leaf breaking at full maturity is crucial for achieving high quality. Maturity can be determined in the early morning when the leaf tips start yellowing towards the edges, yellow blisters called "frog spots" appear on the leaf surface, and in hairy-leaf varieties, the fine hairs begin to fall off. A cracking sound during leaf breaking and the absence of fibers on the stalk are also indicators of technical maturity. The best time for harvesting is early in the morning. Tobacco exposed to dew or rain should not be harvested until the moisture has evaporated. During each harvest, only 3–4 mature leaves should be picked, and immature leaves should be left on the plant.

Tobacco stringing

The harvested tobacco leaves are stacked on trays or baskets, called sele or küfe, in layers with the veins aligned on top of each other. The leaves arranged on the trays or baskets are threaded onto tobacco sticks, approximately 30–40 cm long, by piercing the midrib of the leaf about 1–2 cm

below the base. The length of the tobacco strings varies depending on the region and drying method.

During stringing, leaves of similar size should be grouped together. Otherwise, smaller leaves may wrap around larger ones, leading to poor drying and lower quality. Diseased, immature, or damaged leaves are discarded before stringing. To maintain quality, "tapa stringing" should be avoided. In tapa stringing, the green chlorophyll remains, causing undesirable darkening during drying. Leaves arranged individually and evenly dry properly, and the curing and handling process becomes easier.In the Aegean region, strings of tobacco leaves are tied to sticks 1.5–2 m long. In the Marmara region, the leaves threaded onto strings are hung on frames 2.5–3 m long, with 8–10 rows arranged opposite each other. Silvan, Muş, and Tömbeki tobaccos are not strung; instead, they are secured together using raffia to form strings 2–2.5 m long. Recently, tobacco stringing machines or drying nets filled without stringing have also been developed.



Figure 5. Tobacco Stringing
Anonymous, (2025), Accessed: 05.08.2025. https://www.trthaber.com/foto-galeri/hatayda-tutun-hasadi/66357/sayfa-1.html

Wilting (Pre-Drying)

In some areas of the Aegean and Marmara regions, as well as certain parts of Southeastern Anatolia, where air temperatures are high during drying, tobacco leaves are first wilted in the shade for 1–4 days before being exposed to the sun. The main purpose of wilting is to partially reduce the leaf turgor by removing some water from the leaves in a shaded and cooler environment, thereby facilitating the subsequent drying process. The duration of wilting depends on the maturity of the leaves, the specific "hands," and the weather conditions. In regions with high relative humidity, wilting is not applied to the

lower leaves, whereas in areas with low relative humidity, the upper leaves are left to wilt for up to 48 hours. During wilting, tobacco strings are hung on nails or hooks attached to walls or ceilings with good air circulation.

Curing (Drying)

he curing method applied to tobacco is closely related to the tobacco type, and the quality of curing has a direct impact on both yield and product quality. In the Aegean region, the **rack curing** method is used. Wires are stretched between stakes placed 40–60 cm above the ground, and the bamboo sticks holding the tobacco strings are arranged on these wires. Depending on air temperature and leaf maturity, tobacco remains on the racks for 4–10 days. Afterwards, the strings are laid on sand or gravel surfaces, with one side exposed to sunlight for 1–3 days and then the other side for another 1–3 days, ensuring the midrib is completely dried.When the main vein turns brown and the leaves take on a yellowish color, curing is complete. The dried tobaccos are then removed from the racks and stacked. Around 100–200 strings are initially stacked in partial storage, and after 10–15 days, they are removed from the strings and placed into permanent storage.In regions such as the Black Sea and parts of the Marmara, where rainfall and dew are common during curing, the wagon curing method is preferred. The frames on which the tobacco strings hang can be easily moved into curing sheds along wooden rails during rain and moved back outside when sunny. The frames are positioned at an angle facing the sun. Simpler methods, such as shed, arbor, or mirror curing, are also used in these regions. After color formation, 15–20 tobacco strings are folded four times and hung on wooden poles called *sandals*. Once thoroughly dried, three strings are tied together to form bundles called *hevenk*. The tobaccos are kept in these bundles for 3–4 days until the midribs are fully dry, then hung in the house attics until baling.In Eastern and Southeastern Anatolia, curing methods vary by variety. In these regions, high temperatures and low relative humidity prevent proper sun-curing of leaves. Therefore, curing is carried out in semi-shaded places known as *eyvan* roofed structures with one open sidw or in *gam*, which are open-sided shelters with roofs made of branches. The *eyvan* method is also common in Eastern Anatolia.



Figure 6. Tobacco drying.
Kaynak: Güleşçi, M. (2025), Accessed: 02.08.2025.
https://www.turkishtobacco.net/tutun-fotograflari

Annealing

Before processing, tobacco must be properly conditioned to achieve the desired moisture content. Oriental-type small-leaf tobaccos are more difficult to condition compared to large-leaf types because of their lower moisture absorption capacity. In the Aegean region, conditioning is achieved by directly spraying water onto the tobacco strings or by covering them with wet sacks. In the Black Sea and Marmara regions, the tobacco strings are left either outdoors during autumn and winter or in soil pits about 2 meters deep for one or two days until they reach the proper level of conditioning.

Baling (Packing for transport and sale)

Before transport and sale, tobacco is subjected to a baling process. First, non-marketable, defective, and diseased leaves are removed from the tobacco strings. The remaining leaves are then classified according to “hand,” color, and size, and each hand is baled separately.The baling systems vary by region:Samsun, Taşova, Düzce, Hendek, and Basma tobaccos are baled as *string bales* weighing 10–20 kg.Aegean tobaccos are packed as *tonga* or *block bales* weighing around 55 kg.Other Marmara Region tobaccos (excluding Düzce and Hendek) are baled using the *row-pastal* or *Rumeli-type* system, weighing 15–25 kg.Artvin, Trabzon, and Southeastern Anatolia tobaccos are baled using the *Samsun-type*, *Alexandria-type*, or *beaten bale* systems.In recent years, traditional baling methods have gradually been replaced by stacking tobaccos into cardboard boxes for easier handling and transportation.



Figure 7. Tobacco bailing.

2. Cultivation Purposes of Tobacco

Tobacco (*Nicotiana tabacum* L.) is a globally significant plant with both economic and social importance, and it has a wide range of uses. The most common application of tobacco is the production of various tobacco products, including cigarettes, cigars, hookah (shisha) tobacco, snuff, and chewing tobacco. These products constitute a major industrial sector, particularly in developed and developing countries, providing employment for millions of people. In addition, nicotine extracted from tobacco is utilized in the pharmaceutical industry as an active ingredient in nicotine replacement therapies, such as patches, gums, and other medications designed to assist smoking cessation. Tobacco also serves as a model plant in biotechnology, playing a key role in genetic research, recombinant protein production, and plant-based vaccine development. Nicotine derivatives are employed as natural insecticides, offering alternative pest control methods in organic farming.

In Turkey, tobacco holds significant historical and economic value. It is extensively cultivated in the Aegean and Southeastern Anatolia regions and is considered a valuable crop for both domestic consumption and export. Turkey is especially prominent in the production of world-renowned Oriental (sharq-type) tobaccos, which are favored by manufacturers for blended cigarette production due to their aromatic and fine-leaf characteristics. The use of hand-rolled tobacco is common in rural areas, making tobacco farming an important source of income for many small-scale farming families. Additionally, tobacco cultivation is one of the few agricultural sectors where women actively participate in the workforce. In recent years, research has explored the industrial potential of tobacco seed oil for applications in soap, biodiesel,

and other oil-based industrial products. Overall, tobacco exhibits a versatile profile, serving both traditional and modern sectors with multiple economic and industrial applications.

2.1. Chemical properties of tobacco

The chemical composition and other properties of tobacco varieties vary according to their genetics and cultivation conditions (Örsel, 2010). Tobacco leaves contain ash, coarse fibers (cellulose and lignin), pentosans, pectins, ether-soluble compounds, polyphenols, phenolic acids and their derivatives, ether-soluble organic acids (such as oxalic, citric, and malic acids), proteins, water-soluble nitrogenous compounds (including amino acids, amides, ammonia, and nitrate compounds, as well as alkaloids), and dynamic carbohydrates (sugars, starch, and dextrins) (Ru et al., 2012). Over 60 phenolic compounds, which constitute the structural components of cells, are present in tobacco, and their side reactions can form more harmful free phenols. However, the toxic effects of tobacco are primarily associated with its alkaloid content (Çok and Öztürk, 2000).Approximately 95% of the alkaloids in tobacco leaves consist of nicotine. Other alkaloids include nornicotine, nicoteine, nicotelline, nicotoin, isonicotine, nicotemin, nicotyrine, nicotine N-oxide, cotinine, anabasine, and myosmine (Kesim, 2004). Factors affecting the alkaloid content include the harvesting method, curing process, topping, and suckering operations. Nicotine levels in tobacco also fluctuate throughout the day, increasing from morning to evening and decreasing at night. Furthermore, processing tobacco can lead to the formation of highly carcinogenic nitrosamines, such as N-nitrosonornicotine, from the leaf alkaloids (Kesim, 2004). Most of the nitrogenous compounds that negatively affect the quality of green tobacco leaves are in the protein-nitrogen form, and they are responsible for the characteristic odor of cigarette smoke.

Tobacco contains substantial amounts of minerals, including potassium, calcium, magnesium, sodium, iron, phosphorus, sulfur, silicon, and chlorine (Odabaşoğlu, 1994). Most of the organic acids present are in the form of malic, oxalic, and citric acids, with smaller amounts of glycolic, succinic, malonic, furoic, and pyruvic acids. The leaf trichomes secrete ether-soluble substances such as volatile oils, resins, waxes, paraffins, and fatty acids. Additionally, the leaves contain various pigments responsible for coloration

and sterols that can transform into harmful compounds upon combustion. Green leaves primarily contain chlorophyll, while yellowing leaves are richer in carotenoid and xanthophyll pigments. The presence of these pigments influences whether the tobacco has a mild or strong flavor profile. Typically, lighter-colored tobaccos are milder in taste, whereas darker-colored tobaccos have a stronger, harsher flavor. Cigarettes are generally produced from lighter-colored tobaccos, while darker varieties are preferred for pipe tobacco, cigars, and snuff.

The sterols present in tobacco leaves include stigmasterol, beta-sitosterol, cholesterol, campesterol, and gamma-sitosterol. Dried tobacco primarily consists of carbohydrates and proteins. In addition, it contains numerous other compounds, including alkaloids, terpenes, polyphenols, aromatic hydrocarbons, aldehydes, ketones, amines, nitriles, nitrogen- and oxygen-containing heterocyclic compounds, and pectic substances (Örsel, 2010). The flavonoids in dried tobacco leaves exhibit stronger antioxidant activity compared to polysaccharides. Another important factor influencing tobacco characteristics is whether the dried tobacco undergoes natural or artificial fermentation. Fermented tobacco experiences chemical, physical, and organoleptic changes that significantly affect its quality (Bush et al., 2001).

The intended recreational use of tobacco is determined by its chemical composition after curing and fermentation. Tobaccos with a high sugar-to-nitrogen ratio are classified as acidic, while those with a low ratio are considered basic. Tobaccos with intermediate ratios are grouped as neutral. Acidic and neutral tobaccos are generally used for cigarette production, whereas basic tobaccos are preferred for cigars. Additionally, cigarette tobaccos are desired to have a low protein content, while cigar tobaccos typically require higher protein levels.

2.2. Technological characteristics of tobacco

The industrial value of the tobacco plant depends on its quality and smoking characteristics. These traits play a critical role throughout the entire production chain, from agricultural cultivation to the final consumer products, and are based on the complex interactions between physical structure,

chemical composition, and processing methodologies (Rodgman and Perfetti, 2013).

Physical Structure and Processability form the foundation of production efficiency. The size, shape, and thickness of *Nicotiana tabacum* leaves are optimized according to the intended product type (cigarettes, cigars, pipes). For example, the thin, broad leaves of FC Virginia tobaccos provide high filling capacity in mechanical rolling machines, whereas the thick leaves of Burley allow controlled nicotine release. Leaf tissue flexibility (tensile strength), particularly due to low lignin and high cellulose content, minimizes breakage during curing, fermentation, and cutting, thereby reducing production losses. Precise control of moisture content (16–18%) is also critical to prevent brittleness.

Chemical composition directly governs the sensory and pharmacological properties of the final product. Nicotine (ranging from 1–10%) is the primary determinant of smoking satisfaction and addiction potential (Benowitz, 2010). The sugar-to-nitrogen (S/N) ratio controls combustion characteristics: high ratios in Virginia tobacco (S/N ≈ 20) produce a sweet, smooth smoke, while low ratios in Burley (S/N < 1) yield a sharp and robust profile. Inorganic ions also play a key role in performance; potassium (K^+) ions increase burning rate and contribute to white ash formation, whereas chloride (Cl^-) ions above 1% enhance moisture retention but may cause poor combustion or "self-extinguishing" effects (Rodgman and Perfetti, 2013).

Curing Technologies stabilize the technological characteristics of tobacco leaves. Flue-curing, conducted at 70–75°C for 5–7 days using heated air, imparts high sugar content, a bright yellow color, and a mild smoking profile to Virginia tobaccos. Air-curing, performed over 4–8 weeks with natural air flow, preserves dark color and high nicotine content in Burley and cigar tobaccos, with modern climate control systems mitigating mold risks. Fire-curing imparts characteristic phenolic aromas to pipe tobaccos. Turkish tobaccos are traditionally sun-cured. In sun-curing, leaves undergo an initial wilting period of 1–4 days, during which the parenchyma dries and water is drawn from the main and secondary veins. Subsequent curing steps vary according to the tobacco variety.

Blending Engineering synergistically combines the technological characteristics of different tobacco types. For example, an American blend

(40% Virginia, 35% Burley, 25% Oriental) balances the sweetness of Virginia, the nicotine strength of Burley, and the aromatic complexity of Oriental tobaccos using mathematical modeling (Leffingwell, 1999). This optimization ensures consistent smoking quality and nicotine levels across commercial brands.

2.3. Nutritional value of tobacco

The nutritional value of the tobacco plant (*Nicotiana tabacum* L.) is not defined by a standard "nutrient profile," as it is not consumed as a traditional food. However, tobacco by-products can be utilized in animal feed. In one study, tobacco stems (TS) and tobacco meal (TM), generated as by-products of tobacco production, were evaluated as alternative feed sources. Analyses showed that TS contained 4.69% crude protein and 1.44% crude fat, while TM had 38.61% crude protein and 10.64% crude fat. TS is high in fiber, with neutral detergent fiber (NDF) at 70% and acid detergent fiber (ADF) at 51%, whereas TM has a lower fiber content (NDF: 43%, ADF: 32%) (Pekpazar and Kılıç, 2020).

In feed quality evaluations, tobacco stems (TS) with a relative feed value (RFV) of 65.88 fall into the "5-red" category, indicating low-quality forage, whereas tobacco meal (TM) is classified as second-grade (good quality) and considered a high-concentration feed. The condensed tannin content of both materials is below 5%, posing no risk to ruminants. Based on these findings, TS can be considered an alternative to low-quality straw and roughages, but it is not suitable for use as a sole feed source. TM, on the other hand, may serve as a high-concentration feed alternative to cottonseed or sunflower meals. Pelletization has been shown to improve digestibility and reduce methane emissions. For safe use in animal nutrition, TS and TM should be ground, pelleted, and, if necessary, enriched with additives. Goats, which exhibit high tannin tolerance, are particularly suitable for utilizing these tobacco by-products (Kılıç et al., 2019).

3. Contribution of Tobacco to Sustainable Agriculture and Food Security

Although tobacco (*Nicotiana tabacum* L.) cultivation occupies a controversial position globally, it provides significant contributions in many

countries, particularly in terms of rural development, income sustainability, and agricultural employment. From a sustainable agriculture perspective, tobacco production offers advantages in several key areas; however, these contributions must be evaluated within regional socio-economic contexts (Geist et al., 2009; Lecours et al., 2012).

In low- and middle-income countries, tobacco farming has become an integral part of rural economies and serves as a primary income source for hundreds of thousands of small family farms. Similarly, in Turkey, tobacco production is carried out through family farming models in the Aegean, Black Sea, Southeastern Anatolia, and Marmara regions, employing a high proportion of women and child labor (Tekdemir et al., 2024). In this context, tobacco plays a pivotal role in ensuring livelihood security and sustaining local economic cycles in rural areas.

Another significant contribution to sustainability is the non-agricultural use and by-product potential of tobacco. Not only the leaves but also the stems, seeds, and residues of the tobacco plant can be utilized across different sectors. For example, the stems and meal generated from tobacco production are suitable for animal feed. Tobacco meal (TM) contains approximately 38.61% crude protein and 10.64% crude fat, making it a viable high-concentration feed alternative to cottonseed or sunflower meals (Kılıç et al., 2019; Pekpazar and Kılıç, 2020). Additionally, these by-products can be processed into pelletized biomass fuel, highlighting their potential contribution to circular economy practices by valorizing agricultural waste.

Tobacco seed oil is being explored for applications in soap and biodiesel production, and its commercial potential in these areas is steadily increasing. With a high oil content of approximately 30–40%, tobacco seed represents an alternative source for energy crops (Grisan et al., 2016). This highlights the multifunctional use of tobacco, particularly in regions where agricultural diversification strategies need to be supported.

The Food and Agriculture Organization (FAO) of the United Nations defines sustainable agriculture not only in terms of environmental factors but also through economic profitability and social inclusivity. In this context, although tobacco remains environmentally controversial, it contributes to sustainability in many countries by alleviating rural poverty, maintaining stable agricultural incomes, and supporting small family farms. Considering

that shifting away from traditional tobacco production regions carries short-term economic risks, the transformative potential and multifunctional uses of tobacco play a critical role in sustainable transition processes (FAO, 2017; Lecours et al., 2012).

Although food security is not directly associated with tobacco cultivation, its indirect effects are significant. The income security of rural households directly influences their access to food. In this context, tobacco serves as a "cash crop" for many small-scale producers, with the income generated being allocated to essential needs such as food, education, and healthcare. Several studies have reported that tobacco production helps stabilize income fluctuations for smallholder farmers and ensures seasonal income continuity (Efroymson et al., 2011; Geist et al., 2009).

However, within the framework of sustainability, the environmental impacts and water use associated with tobacco must also be considered. Tobacco is a crop that typically requires intensive irrigation and chemical inputs, which can reduce soil organic matter and accelerate soil fatigue (WHO, 2017). Consequently, sustainable tobacco cultivation can only provide long-term benefits if it is supported by integrated soil management, reduced chemical inputs, and alternative curing techniques.

Although the tobacco plant is not a direct food product, it contributes indirectly to sustainable agriculture and food security through rural income generation, transformation into industrial products, utilization of by-products, and its potential for biomass and biodiesel production. For these contributions to be meaningful and lasting, production systems must be restructured in accordance with environmental sustainability principles and supported by appropriate agricultural policies.

4. Factors Limiting the Cultivation and Use of Tobacco

While tobacco (Nicotiana tabacum L.) production and uses have historically made significant contributions to agricultural development, numerous environmental, economic, social, religious, and political factors currently constrain this production system. Public health concerns and global anti-tobacco policies, in particular, have led to severe restrictions on both agricultural production and end-use tobacco use (WHO, 2017; Lecours et al., 2012).

A primary limiting factor for tobacco cultivation is the policy and regulatory framework developed in response to its health impacts. The World Health Organization's Framework Convention on Tobacco Control (FCTC) includes numerous measures aimed at reducing tobacco demand, such as tax increases, advertising bans, health warning labels, and restrictions on smoking areas. These regulations directly reduce demand for cigarettes and other tobacco products, thereby negatively affecting production. Furthermore, many countries impose limits on tobacco cultivation areas, provide incentives for alternative crops, and implement educational policies to prevent youth engagement in tobacco production (FAO, 2021; Örsel, 2010).

Another significant factor limiting tobacco cultivation is the increasing environmental awareness and pressures for sustainability. Tobacco is a crop with high water requirements and intensive demands for pesticides and chemical fertilizers. This situation, particularly in areas where tobacco has been cultivated in monoculture over many years, leads to soil fatigue, reduction of organic matter, and loss of biodiversity. Additionally, traditional curing methods, especially for broad-leaf tobacco, require high energy inputs, increasing fuel oil consumption and carbon emissions, thereby exacerbating environmental threats related to deforestation and climate change (Lecours et al., 2012; Geist et al., 2009).,

Climate change has also emerged as a direct limiting factor for tobacco cultivation. Rising temperatures, irregular rainfall patterns, and droughts negatively affect both the growth period and the yield and quality parameters of tobacco. Under conditions of drought and high temperatures, leaf scorching, reduced plant height, premature leaf drying, and imbalances in nicotine content have been observed. Consequently, the development of varieties adapted to climate change and the implementation of effective adaptation strategies have become essential (Ouma and Oino, 2024).

Economic factors are also a significant constraint on tobacco production. Input costs in tobacco cultivation—particularly for fertilizers, labor, seedlings, and irrigation systems—have increased substantially over the years. For small-scale producers, these rising costs make production progressively less profitable. Furthermore, the removal of state monopoly policies (e.g., Tekel) and the privatization of the tobacco sector in Turkey have significantly impacted tobacco farming. With privatization, state

procurement guarantees were eliminated, producer support systems weakened, and small-scale tobacco farmers became vulnerable to market fluctuations. This development has negatively affected the economic stability of families relying on tobacco cultivation in Eastern and Southeastern Anatolia, forcing many producers to abandon the crop. Moreover, the rise of contract farming and the increasing influence of multinational corporations have shifted production decisions toward corporate demands. Consequently, privatization policies have reduced producer independence, weakened traditional production structures, and altered the socio-economic balance within the sector (Tekdemir et al., 2024).

Another factor limiting tobacco utilization is changing consumer habits and societal attitudes toward tobacco products. In recent years, cigarette consumption rates have declined, while e-cigarettes and other non-tobacco nicotine products have gained greater market presence. This trend reduces the production volume of traditional tobacco products and underscores the need for sectoral adaptation. Additionally, customs duties, quota restrictions, and trade limitations on processed tobacco products further constrain the export potential of tobacco (WHO, 2022).

Finally, many countries' "alternative crop" strategies, implemented to reduce tobacco production, directly affect tobacco farming. Under these policies, producers are encouraged to cultivate vegetables, legumes, oilseeds, or industrial crops, with the transition supported by various government incentives. However, for this transition to be successful, both marketing infrastructure and agricultural extension services must be effectively established. Otherwise, the shift poses economic risks to producers and undermines the intended sustainability objectives (FAO, 2021).

5. Conclusion and Recommendations

The tobacco plant has historically maintained its significance as both an economic and cultural agricultural product. Its morphological characteristics, wide adaptability, and high nicotine content enable it to be cultivated under diverse climatic and soil conditions, contributing to its widespread production worldwide. Turkey, with its favorable climate and varietal diversity, ranks among the leading countries in high-quality tobacco production, particularly in the Aegean, Black Sea, and Southeastern Anatolia regions, which produce

leaves with superior aroma and combustion properties. Industrially, tobacco is primarily used in cigarette manufacturing, while it also finds applications in pharmaceuticals, cosmetics, and biopesticide production.

However, tobacco cultivation currently faces significant challenges. Climate change, drought, pest and disease pressures, rising production costs, and global tobacco control policies have all contributed to the contraction of cultivation areas. Moreover, the adverse health impacts of tobacco use influence consumption demand and lead to shifts in sectoral policies. Therefore, it is crucial to develop sustainable, environmentally friendly, and economically viable practices throughout all stages of production and processing.

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Chapter 21

WHEAT (*Triticum* L.)

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DOI: https://dx.doi.org/10.5281/zenodo.17463232

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1. General Characteristics of Wheat

Cereals provide more than 50% of the worldwide crop production and are important renewable resources for food, feed, and industrial materials. Wheat (*Triticum* spp.) is the primary cereal of temperate regions and a major source of dietary protein and energy for the human population, especially living in underdeveloped and developing countries. It is the most widely cultivated crop on global scale, and the most produced cereal after maize and rice (FAOSTAT, 2023a).

Human history is closely interwoven with wheat and its relatives since they belong to the Neolithic founder crops upon which modern agriculture was built. Together with other cereals such as barley and rye, wheat is known as one of the first domesticated crops more than 12.000 BP (before present) in the Fertile Crescent, spanning modern-day Türkiye, Iraq, Israel, Jordan, Lebanon, Palestine, Syria, Kuwait, and Iran (Ulas et al., 2018). The spreading of wheat from its center of origin across the world has been investigated by many researchers in detail. According to the most up-to-date literature, its primary migration route into Europe passed through Anatolia into around 8000 BP, followed by a northward expansion through the Balkans to the Danube region by approximately 7000 BP, and westward into Italy, France, and Spain during the same period. Finally, its cultivation reached to the United Kingdom and Scandinavia around 6000 BP. Simultaneously, it moved eastward through Iran into Central Asia, arriving in China by roughly 3000 BP, and spread to Africa primarily through Egypt. Later, wheat was introduced to Mexico by Spanish explorers in 1529 and to Australia in 1788 (Abbo et al., 2013).

It is known that the basic Triticeae genome is organized into seven chromosomes (x = 7). Accordingly, *Triticum* species are classified into three ploidy levels: diploid forms (2n = 2x = 14), tetraploid forms (2n = 4x = 28), and hexaploid forms (2n = 6x = 42). The earliest wheat species to be domesticated successfully was einkorn (*T. monococcum*), and it played a crucial role in the establishment of agriculture within the Fertile Crescent and the only diploid species (2n = 2x = 14, A^mA^m genome) for which both wild (*T. boeticum*) and domesticated forms are known to exist. Einkorn has a close relationship with *T. urartu* (2n = 2x = 14, AA genome), the A genome donor of both tetraploid durum wheat and hexaploid bread wheat. However, both

wild and domesticated einkorn have a long cultivation history and human-driven selection in diverse environments unlike *T. urartu*. *Aegilops speltoides Tausch* is widely recognized as the donor of the B genome. It is well established that wild emmer (*Triticum dicoccoides*), which originated from the natural hybridization between *T. urartu* (the source of the A genome) and *Ae. speltoides* (the source of the B genome), is the ancestral progenitor of modern tetraploid and hexaploid wheat species (Özkan et al., 2020).

The other important species for wheat domestication is known as emmer (*T. dicoccum*), a tetraploid wheat (2n = 4x = 28, AABB genome), from its wild progenitor *T. dicoccoides* (2n = 4x = 28, AABB genome). During domestication process, the last important step is that the tetraploid wheat species later hybridized with a wild diploid species, *Aegilops tauschii* (2n = 2x = 14, DD genome), leading to the formation of hexaploid wheat.Notably, domesticated hexaploid wheats do not have a corresponding wild hexaploid ancestor in nature; instead, they represent a naturally occurring hybridization event associated with early agricultural practices, which eventually gave rise to one of the most widely cultivated crops worldwide (Özkan et al., 2020).

Harlan and de Wet (1971) introduced the concept of the gene pool by considering the potential of cultivated plants to form fertile hybrids with their wild relatives. According to this theory, wheat and its wild relatives are classified into three interrelated gene pools. The primary gene pool includes cultivated species, which can interbreed and produce fertile offspring. The secondary gene pool comprises approximately 35 wild relatives, which generally produce infertile or partially fertile hybrids when crossed with members of the primary gene pool. The tertiary gene pool includes more distantly related species, such as those belonging to the genera *Agropyron* and *Elymus*. Species from the genera *Triticum*, *Aegilops*, *Amblyopyrum*, and *Dasypyrum* constitute the primary and secondary gene pools. Wild species from genera that are distributed in Türkiye are listed in Table 1.

Table 1. Wild species belonging to the genera *Triticum*, *Aegilops*, *Amblyopyrum*, and *Dasypyrum* that are distributed in Türkiye*

Latin name	Common name in Turkish	Chromosome number	Genome
Ae. biuncialis Vis.	İkikılçık	2n=4x=28	UUMM
Ae. caudata L.	Karaot	2n=2x=14	CC
Ae. columnaris Zhuk.	Kıl buğday	2n=4x=28	UUMM
Ae. comosa Sm. in Sibth. & Sm.	Uzunkılçık	2n=2x=14	MM
Ae. crassa Boiss.	Kalın buğday	2n=4x=28; 2n=6x=42	DDMM; DDDDMM
Ae. cylindrica Host	Kirpikli ot	2n=4x=28	DDCC
Ae. geniculata Roth	Konbaş	2n=4x=28	MMUU
Ae. juvenalis (Thell.) Eig	Kaba buğday	2n=6x=42	DDMMUU
Ae. kotchyi Boiss.	Asi buğday	2n=4x=28	SSUU
Ae. neglecta Req. ex Bertol.	Tüylü buğday	2n=4x=28	UUMM
Ae. peregrina (Hack. in J. Fraser) Maire & Weiller	Kum buğdayı	2n=4x=28	SSUU
Ae. speltoides Tausch	Ak buğdayanası	2n=2x=14	SS
Ae. tauschii Coss.	Tesbih buğdayı	2n=2x=14	DD
Ae. triuncialis L.	Üçkılçık	2n=4x=28	UUCC; CCUU
Ae. umbellulata Zhuk.	Hanım buğdayı	2n=2x=14	UU
Ae. uniaristata Vis.	Tek kılçık	2n=2x=14	NN
Ae. vavilovii (Zhuk.) Chennav.	Zarif buğday	2n=6x=42	DDMMSS
Amblyopyrum muticum (Boiss.) Eig	Narin buğday	2n=2x=14	TT
Dasypyrum villosum (L.) Candargy	Kızılev	2n=2x=14	VV
Triticum boeticum Boiss.	Yabani siyez	2n=2x=14	A^mA^m
T. dicoccoides (Körn. ex Asch. & Graebn) Schweinf.	Yabani gernik	2n=4x=28	AABB
T. timopheevii (Zhuk.) Zhuk. v. *araraticum* (Jakubz.) Yen	Deli Rus buğdayı	2n=4x=28	AAGG
T. urartu Thumanjan ex. Gandilyan	Urartu buğdayı	2n=2x=14	AA

* Özkan et al. (2020)

A key distinguishing trait between wild and domesticated wheat is the presence of a non-shattering rachis in domesticated ones. In wild wheat, once the seeds mature, the rachis—the central axis that holds the spikelets together—breaks apart naturally to enable seed dispersal. While this trait is essential for reproduction in natural ecosystems, it posed a challenge for early farmers, as the seed heads would disintegrate during harvesting, whether by hand or with tools. Consequently, wheat plants harboring mutations at the *Brt* (brittle rachis) locus that prevented rachis shattering were unintentionally favored by such harvesting techniques of early farmers. Over time, this led to the fixation of the non-shattering rachis trait in domesticated wheats. The other major trait among them is whether the grains are hulled or free-threshing (Figure 1). This free-threshing characteristic is controlled by a dominant mutation at the *Q* locus, which interacts with recessive alleles at the *Tg* (tenacious glume) locus to reduce glume adhesion. Early domesticated species such as einkorn, emmer, and spelt are hulled, while modern wheat species are free-threshing (Faris, 2013).



Figure 1. Comparison between hulled and free-threshing wheat grains. The upper grains are enclosed within tough glumes (hulled type), while the lower grains represent free-threshing modern wheats where the kernels easily separate from the glumes during harvest

As mentioned above, since its initial domestication around 12.000 BP, wheat has been central to sustaining human nutrition and civilization (Jaradat, 2011). Since then, in addition to the differences of the morphological traits between wild and domesticated ones described above, adaptive traits suited to target environment played a critical role during domestication and the spread out of domesticated wheat. Synchronization of flowering time with the prevailing climatic conditions of the target regions is considered one of the most influential factors during dispersal (Peng et al., 2011; Royo et al., 2020). This is mainly based on three major genetic systems: vernalization (*Vrn*) genes, photoperiod (*Ppd*) genes, and genes associated with "earliness per se" (*Eps*), which regulate intrinsic flowering time. Vernalization, the process of promoting flowering through exposure to low temperatures, plays a central role in determining the plant's growth habit—classifying varieties as winter types (which require prolonged cold exposure) or spring types (which do not require vernalization).The genetic basis of vernalization in wheat is highly allelically diverse, and previous studies have shown that combinations and frequencies of *Vrn* alleles with adaptive significance vary by geographic region, reflecting local environmental selection pressures. Early domesticated cereals had likely sensitivity to photoperiod and vernalization, similar to their wild progenitors (Motzo and Giunta, 2007) (Figure 2).



Figure 2. Photoperiod sensitivity in wheat genotypes: Left – photoperiod-sensitive einkorn (*T. monococcum*); Right – photoperiod-insensitive emmer (*T. dicoccum*) grown under the same conditions.

The lack of vernalization and photoperiod requirements enables certain spring type varieties to be sown flexibly, including in regions with mild winters and at various times throughout the year. Research on wild emmer wheat (*Triticum dicoccoides*) suggests that the spring growth habit likely evolved from ancestral winter forms in the progenitors of cultivated hexaploid wheat (Kato et al., 1997). In addition to these, early farmers also selected for other yield-related traits such as plant height, waxiness, number of spikes, weight of spikes and grains, contributing to the diversification of botanical forms (Peng et al., 2011).

2. Cultivation Purposes and Nutritional Value of wheat

Today, the most important wheat species are bread (*Triticum aestivum*, 2n = 6x = 42, AABBDD genome) and durum (*Triticum durum*, 2n = 4x = 28, AABB genome) wheat. In addition, the club wheat (*T. compactum*, 2n = 6x = 42, AABBDD genome) has been still cultivated although not as much as other modern species (Figure 3).



Figure 3. Cultivated modern wheat species: durum wheat (left) and bread wheat (right).

Among its cultivated types, common or bread wheat dominates global production while durum wheat accounts for approximately 6% of the total wheat cultivation area. According to the Food and Agriculture Organization of the United Nations (FAO), wheat among cereals ranks third followed by maize and rice for production quantity, and total wheat production of wheat was recorded 800 million tons on the cultivation area of 220 million hectares in the world in 2023 (FAOSTAT, 2023a). In Türkiye, wheat ranks first among all crops for production, and total wheat production of wheat was recorded 20.8 million tons on the cultivation area of approximately 6.9 million hectares in 2024 (TUIK, 2024). In parallel to world wheat production, bread wheat dominates production with a share of about 79% in Türkiye.

Wheat has a prominent position worldwide not only due to its ease of storage, high adaptability, and nutritional qualities, but also because it serves as the primary raw material for a wide range of bakery products—such as bread, cakes, biscuits, cookies, and crackers—as well as flour-based foods including pasta, noodles, and other similar products. Bread wheat and durum wheat are, in fact, named according to the types of products produced from them. In general, both types contain approximately 60–70% starch, 8–15% protein, 2–3% lipids, and 2–3% minerals and dietary fiber on a dry matter basis (Shewry and Hey, 2015). However, differences in protein composition, pigment concentration, and kernel hardness distinguish these two groups. Bread wheat typically contains 10–14% protein, with a higher proportion of glutenin and gliadin proteins that form a strong gluten network. This feature provides good dough viscoelasticity and gas retention capacity, making bread wheat ideal for bread, cakes, biscuits, and other bakery products (Shewry et al., 2002). The starch fraction is mainly composed of amylopectin (~70–75%) and amylose (~25–30%), which contribute to dough texture and bread staling. Bread wheat also contains small amounts of lipids (2–3%) and minerals such as iron, zinc, and magnesium. Durum wheat, by contrast, has 12–16% protein, with a stronger gluten quality but less extensible dough compared to bread wheat. This is due to the higher proportion of glutenin subunits that yield firm and non-sticky dough, suitable for pasta, couscous, and bulgur production (Dexter and Matsuo, 1980; Köksel et al., 2020). Durum kernels are also rich in yellow pigments (carotenoids, particularly lutein), which are responsible for the golden color of semolina and pasta. Furthermore, durum wheat tends

to have higher vitreousness (kernel hardness) and higher ash content than bread wheat, affecting milling and semolina yield (Köksel et al., 2020).

In addition to the information briefly mentioned above, for processing end-use products, wheat quality can be examined under several main categories. Protein content, protein quality and grain hardness or softness account for many of the differences in quality. Consequently, when combined with wheat color (white or red), production season (winter or spring) which varies according to ecology, and often the main designations used by major exporting countries, these factors generally form the basis of the primary wheat classes (Köksel et al., 2020). These categories also form the basis of the global wheat trade and the grading systems used by various countries. Accordingly, Australian Premium Hard (APH), Canadian Western Red Spring (CWRS), Canadian Western Amber Durum (CWAD), U.S. Hard Red Spring (HRS), U.S. Hard Red Winter (HRW), U.S. Soft Red Winter (SRW), and U.S. Soft White (SW), can be sorted as examples.

Wheat quality varies depending on cultivar, soil and climatic conditions, and cultivation practices such as irrigation, nutrition, and crop protection applications. Quality traits are also characterized by these characteristics and may vary depending on the product to be processed and industrial sector. It can be clearly said that wheat quality is shaped by a combination of genetic factors, environmental conditions, and their interactions. Some traits, such as protein quality, grain hardness, milling traits, grain color, and tolerance to pre-harvest sprouting, are mainly controlled by genetic factors while some traits, such as protein content, grain size and uniformity, test weight, and moisture content, are influenced by environmental factors. The interaction between genotype and environment further explains variations in protein content, grain size and uniformity, and test weight. Together, these factors define the technological and nutritional properties of wheat, ultimately determining its suitability for different end-use products.

As mentioned above, many economically important foods are produced from wheat. Türkiye ranks among the leading countries both in wheat production and consumption. With an annual per capita consumption of around 170 kg, it is one of the highest wheat-consuming nations globally (FAOSTAT, 2023b). Moreover, Türkiye holds a prominent position in

international trade, being the largest exporter of flour and the second-largest exporter of pasta (FAOSTAT, 2023c). Türkiye has a strong position not only flour and pasta but also in the export of the other processed wheat products. Bulgur and biscuit exports are remarkable in terms of both economic volume and value. In addition, semolina has emerged in recent years as another product with its expanding share in international trade (FAOSTAT, 2023c). Türkiye also serves as a global hub for the wheat-based food industry. Due to this role, and particularly as a result of rising imports over the past five years, the country has become the world's second-largest wheat importer after China (FAOSTAT, 2023c). With its high production capacity in the flour and pasta industries, Türkiye primarily supplies processed wheat products to many countries.

2.1. Neglected crops: Transitional forms of modern wheat

Several ancient hulled wheat species have an important role in the domestication and diversification of modern wheat species. Among them, einkorn (*T. monococcum*), emmer (*T. dicoccum*), and spelt (*T. spelta*) are recognized as transitional forms of modern wheat, representing evolutionary and agricultural bridges between wild relatives and current high-yielding modern species.Although their cultivation areas have significantly declined with the expansion of high-yielding bread and durum wheats worldwide, these species have continued to be grown in certain regions, both for traditional consumption and for niche markets (Zaharieva and Monneveux, 2014; Tekin et al., 2018).

The domestication and spread of these ancient wheats originated in the Middle East before extending into Europe (Nesbitt and Samuel, 1996). Many studies conducted on einkorn and its wild ancestor, have suggested that Karacadağ Mountains in South-East Türkiye can be origin center of einkorn. The earliest archaeobotanical remains of einkorn discovered at sites near Karacadağ—such as Abu Hureyra (de Moulins, 2000), Cafer Höyük (de Moulins, 1993), Çayönü (van Zeist & de Roller, 1992), and Nevali Çori (Pasternak, 1998)—provide strong evidence supporting the domestication of this species in the region. However, the domestication site of emmer is still unclear. Özkan et al. (2002) claimed that the northern part of Fertile Crescent is domestication site of the species. Mori et al. (2003) also supported this

hypothesis and postulated that Kartal Mountain in North-East of Gaziantep in Türkiye can be domestication site. It can be stated that the Karacadağ Mountain, West of Diyarbakır in South-Eastern Türkiye is considered the primary domestication site of emmer based on the most recent scientific evidence (Ozkan et al. 2005; Luo et al. 2007). On the other hand, although the precise domestication center of spelt remains uncertain, genetic and archaeobotanical evidence generally points to the Fertile Crescent as the primary origin. Spelt is believed to have arisen through hybridization between tetraploid emmer wheat and the wild diploid *Aegilops tauschii* (Wang et al., 2024). Some recent studies have also claimed the polyphyletic hypothesis; whereby Asian and European spelt types emerged independently through separate evolutionary pathways. Archaeobotanical records show traces of spelt in Northern Iraq, Transcaucasia, and the Fertile Crescent, but it became a fully established cultivated crop in Central Europe around 3000–2500 BCE, coinciding with demographic changes and technological innovations such as the adoption of the plow(Lechterbeck and Kerig, 2024).

Today, the cultivation of ancient wheat species such as einkorn, emmer, and spelt is limited compared to modern bread and durum wheat, yet these species retain significant cultural and economic importance in niche agricultural systems. Einkorn is still cultivated in restricted areas of Europe, particularly in Austria, France, Germany, Hungary, and Italy, as well as in Türkiye while emmer persists in marginal and mountainous agricultural lands of Türkiye, Ethiopia, and the Caucasus, while Italy represents a major production hub where “farro” is cultivated under geographical indication in regions such as Garfagnana (Perenzin et al., 2013). Spelt, on the other hand, has maintained a stronger presence in Central and Western Europe, with substantial cultivation in Germany, Switzerland, Belgium, and Northern France, and it is also produced in North America, particularly in Ohio (USA) and Ontario (Canada) (Campbell, 1997; Abdel-Aal and Hucl, 2005).



Figure 4. Spikes of ancient hulled wheat species. On the left is einkorn (*T. monococcum*, "siyez"), and on the right is emmer (*T. dicoccum*, "gernik").

There are no official statistics on the cultivation of ancient wheats worldwide, since they are not recorded separately from cereals such as common wheat, barley, oats, and rye; instead, they are grouped under the category of "other cereals". However, despite the lack of official data, some researchers have provided estimations regarding their cultivation areas. Dhanavath and Prasada Rao (2017) reported that emmer contributes about 1% of total wheat output in India. Perenzin et al. (2013) estimated that the cultivation area of hulled wheats or "farri" is less than 4.000 ha. Among them, einkorn is grown on approximately 300 ha especially in Po plain south of Brescia. Emmer is the most widely grown hulled wheat, cultivated on roughly 3.000 ha while spelt is cultivated in central Italy on about 500 ha (Perenzin et al. 2013). The most widely cultivated hulled wheat worldwide is probably spelt wheat. Campbell (1997) reported that spelt was grown approximately 5% of the wheat cultivation area in Switzerland in the 1990s. Now, it is estimated that there are about 30.000 ha of spelt in Western European countries such as Germany, Belgium, Northern France, and Switzerland (Kulathunga et al., 2020). On the other hand, unlike the rest of the world,

detailed statistics on hulled wheat cultivation are provided by The Turkish Statistical Institute (TUIK) in Türkiye since the country has a rich historical past for these hulled wheat species except for spelt. The TUIK reports *einkorn* and *emmer* wheat within the statistical category of "kaplıca" wheat. In addition to "Kaplıca", these wheat species are also referred to as "Kavlıca" in Eastern Anatolia and "Gacer" in Kayseri (Akar and Eser, 2016). Iza, Mal, and Mahsul are also different local names used for these species (Yaman et al., 2020). In Türkiye, it can be clearly said that the most cultivated hulled wheat species is einkorn.Examples of einkorn and emmer wheat, traditionally known as "siyez" and "gernik" in Türkiye, are shown in Figure 4.

In the 1950s, the production of hulled wheats in Türkiye, which once occupied extensive cultivation areas across various regions, reached approximately 130.000 tons (Akar and Eser, 2016). Over time, however, production declined sharply, largely due to the replacement of hulled wheat with high-yielding modern durum and bread wheat varieties that do not require the labor-intensive dehulling process.Production statistics from the last decade suggests that grain yield has remained stable, whereas fluctuations in total production of Kaplıca primarily reflect changes in harvested area. In 2014, hulled wheats were cultivated on 3.166.2 hectares, but by 2023 this figure had dropped dramatically to 1.171 hectares (Table 2). During the same period, yields ranged between 171–215 kg da^{-1}, while total production ranged between 13.071 tons in 2018 to 2.361 tons in 2023 (TUIK, 2024).

Several factors underline both the fluctuations and the long-term decline in production.First, hulled wheat cultivation is largely associated with subsistence farming, much of which is not reflected in official records.This is because hulled wheats are typically grown on steep, arid, and low-fertility lands, with a considerable share of production used as animal feed (Kaplan et al., 2014; Tekin, 2023). For example, Karabak et al. (2019) reported that in İhsangazi district, where einkorn is most widely cultivated, 68% of the harvest is used for livestock feed, while only 32% is directed to bulgur production; of this, merely 11% is consumed domestically and the remainder sold in markets.Second, traditional agricultural practices continue to dominate in hulled wheat production. According to Karabak et al. (2019), 54% of einkorn farmers use broadcast sowing, and only 31% apply topdressing fertilizers. Similarly, Giuliani et al. (2009) noted that farmers in the mountain villages of

Sinop and Kastamonu typically engage in subsistence agriculture, with an average farm size of about 15 decares. A further limiting factor is the absence of standardized seed.Until recently, Türkiye lacked registered hulled wheat varieties, and in the absence of formal certification systems, farmers relied on self-propagated seeds and informal exchanges within local communities and farmers (Giuliani et al., 2009).

Table 2. Area harvested, production, and yield statistics of hulled wheats in Türkiye*

Year	Area harvested (ha)	Yield	Production (ton)
2014	3.166.2	194	6.152
2015	2.262.0	208	4.700
2016	2.276.7	200	4.549
2017	3.076.0	215	6.610
2018	6.102.1	214	13.071
2019	1.592.3	189	3.006
2020	1.521.7	185	2.820
2021	2.376.2	171	4.069
2022	1.788.2	193	3.447
2023	1.171.2	202	2.361

*TUIK (2024)

Despite these limitations, einkorn and emmer are gaining renewed importance. Beyond their traditional role in feed and bulgur, they are increasingly used for pasta, noodles, tarhana, einkorn paste, and rustic bread. Rising demand for natural and traditional foods in Türkiye has expanded their consumption well beyond primary production zones like Kastamonu (Tekin, 2023). Globally, their high protein, dietary fiber, mineral, and phytochemical content—including phenolic acids, alkylresorcinols, tocols, carotenoids, and B vitamins—has attracted considerable interest (Gebruers et al., 2008; Hejtmánková et al., 2010; Hidalgo & Brandolini, 2008; Lachman et al., 2013;

Zhao et al., 2009). Furthermore, they have been recommended in dietary interventions for conditions such as hypercholesterolemia, allergies, colitis, rheumatoid arthritis, depression, and certain cancers (Piergiovanni et al., 1997).

Thus, although their global cultivation areas remain limited, ancient wheat species such as einkorn, emmer, and spelt continue to offer significant value for human nutrition, cultural identity, and sustainable agriculture, suggesting that they may regain greater importance in future food systems.

3. Contribution of Wheat to Sustainable Agriculture and Food Supply Security

The history of wheat production reflects not only the evolution of agriculture but also humanity's ability to adapt food systems to meet growing demands. Since the Industrial Revolution, rapid population growth and urbanization have exerted increasing pressure on global agriculture. The Green Revolution of the mid-20th century marked a turning point, as advances in breeding, irrigation, mechanization, and chemical inputs significantly boosted wheat yields, enabling underdeveloped and developing countries in particular to overcome severe food shortages and reducing the risk of famine on a global scale. Today, wheat remains one of the cornerstones of global food security, providing about 20% of total dietary calories and proteins consumed worldwide.

To elaborate further, the global wheat harvest area has fluctuated between 204 and 239 million hectares, showing only a slight increase over the past five decades. However, during the same period, total wheat production increased from 222 to 760 million tons, mainly due to increase in yield from 1.1 to 3.7 tons per hectare (FAOSTAT, 2023a). Overall, the increase in wheat production has been driven by using of semi-dwarf cultivars, which are more productive, respond more efficiently to inputs such as fertilizers and water, and include varieties resistant to both biotic and abiotic stresses.

Both over the past century and during the Green Revolution, wild relatives and landraces of wheat have made major contributions to yield improvement and, consequently, to the overall increase in wheat production. A landmark example is the Japanese landrace *Akakomugi* (carrying *Rht8c* and *Ppd-D1*), which Italian breeder Nazareno Strampelli used to develop highly

successful varieties such as *Ardito* and *Mentana*. These cultivars later formed the genetic basis of breeding programs across the Mediterranean, South America, Russia, China, and beyond. Similarly, the introduction of Japanese landrace *Norin-10*, derived from *Shiro Daruma*, into CIMMYT by Norman Borlaug led to the creation of semi-dwarf, high-yielding varieties that revolutionized wheat production during the Green Revolution (Nadeem et al., 2021).

Several landraces have left a lasting impact on wheat improvement. For example, “Turkey Red” introduced by German Mennonites migrated from Crimea to the U.S. in the 19th century contributed traits such as climatic resilience and disease resistance, while “Chinese Spring” became a cornerstone for wheat genetics and genomics, providing resources for both breeding and molecular research. Other important landraces, including *Marquis*, *Red Fife*, *Kunduru*, and *Saragolla*, have shaped regional gene pools in Canada, Türkiye, and Italy, among others (Nadeem et al., 2021).

In addition to landraces, wild progenitors and transitional forms have enriched the modern wheat gene pool with alleles for resistance to major diseases (e.g., rusts, powdery mildew, Septoria), pests (aphids, nematodes), and abiotic stresses. Recent molecular studies confirm the high genetic diversity of landraces across the Fertile Crescent, Mediterranean, and China, highlighting their importance as reservoirs of unique alleles related to yield, adaptation, and resilience.

Ultimately, exploiting genetic diversity of landraces and wild relatives remains a critical goal for breeding programs. Advances in sequencing and genomic tools now enable the precise characterization of this diversity, accelerating the discovery of novel genes and facilitating their use in developing resilient wheat cultivars for sustainable agriculture and global food security.

4. Factors Limiting the Cultivation and Use of Wheat

As highlighted in the previous section, total wheat production has increased more than threefold over the past five decades, largely due to the development and use of semi-dwarf varieties, mechanization, chemical fertilizers, irrigation, and other technological innovations supported to cultivation practices. Nevertheless, despite this remarkable progress, several

factors continue to limit the cultivation and utilization of wheat worldwide. These constraints can be broadly categorized into biotic stresses (such as diseases and pests), abiotic stresses (including drought, heat, salinity, and poor soil fertility), and socio-economic and technological challenges that hinder the efficient production and distribution of wheat.

Drought is widely recognized as the most devastating of all environmental stresses globally, reducing yields far more severely than other stress factors (Farooq et al., 2014; Nyaupane et al., 2024). As is well known, agricultural drought occurs when continuously decreasing rainfall (meteorological drought) coincides with increased evapotranspiration, resulting in insufficient soil moisture for plants to complete their normal growth and development. It is reported that only about 350 million hectares of agricultural land worldwide are irrigated, accounting for merely 20% of the total cultivated area. The remaining vast areas rely on rainfed farming, which is of vital importance for the Mediterranean basin, including Türkiye. In this region, more than 90% of agricultural production in Algeria, Morocco, and Tunisia (Schilling et al., 2020), 77% in Türkiye (Anonymous, 2022), 64% in Italy, and 56% in Portugal (Jacobsen et al., 2012) depends on rainfall. Climate models project that under ongoing global climate change scenarios, both the intensity and frequency of drought will increase. Paudel et al. (2020) reported that average global temperature is rising by 0.06 °C annually, while precipitation is decreasing by 16.09 mm per year. Simulations obtained from general circulation models predict that by the end of the 21st century, precipitation may decline by up to 50% in parts of Northwest Africa, up to 20% along the western coast of the Balkan Peninsula, and up to 25% along the western coast of Türkiye (Tramblay et al., 2020).

Considering both its wide cultivation area and its substantial water requirements, wheat is regarded as the crop most severely affected by drought stress worldwide. More than 50% of global wheat-growing areas are exposed to periodic drought (Rajaram, 2001; Pfeiffer et al., 2001). For instance, in Türkiye—an important global wheat producer and net exporter—wheat farming is predominantly rainfed and therefore highly vulnerable to recurrent drought stress, which causes significant fluctuations in annual production. As an example, due to severe droughts experienced across the country in 2007, 2008, and most recently in 2021, average wheat production fell from around

20 million tons to 17.2, 17.8, and 17.7 million tons, respectively (TUIK, 2024).

In addition to drought, other abiotic stresses significantly restrict wheat production. Heat stress, particularly during the grain-filling stage, can drastically reduce yield and grain quality, and its frequency is expected to rise under global warming scenarios. Soil salinity also represents a growing challenge, especially in irrigated regions where poor water management leads to salt accumulation, impairing plant growth and productivity. Low soil fertility, particularly nitrogen and micronutrient deficiencies, further constrains yield potential in many rainfed and marginal production systems. Together, these abiotic factors pose substantial threats to wheat cultivation, especially in regions already vulnerable to climate change.

Biotic stress likewise remains a persistent limitation. Diseases such as stem rust (*Puccinia graminis f. sp. tritici*), stripe rust (*P. striiformis* f. sp. *tritici*), leaf rust (*P. triticina*), powdery mildew, and septoria leaf blotch continue to cause major yield losses. For instance, the rapid emergence of new pathogen races, including virulent forms like Ug99 and its derivatives in stem rust, underscores the ongoing susceptibility of wheat. In addition, insect pests such as Hessian fly, Russian wheat aphid, and wheat stem sawfly inflict damage across different regions. The reliance on chemical controls is neither environmentally sustainable nor economically viable in the long term, emphasizing the importance of breeding for durable resistance using diverse genetic resources.

5. Conclusion and Recommendations

According to UN-FAO projections, global agricultural production will need to increase by around 50% by 2050 in order to meet the food requirements of the growing world population. Achieving this target on existing croplands will require substantial gains in grain yield, particularly for major cereals such as wheat. Several studies have estimated that wheat yields must rise by approximately 2.4% annually until 2050 to satisfy global demand (Shiferaw et al., 2013). However, the current rate of genetic improvement in wheat yield remains close to 1% per year (Crespo-Herrera et al., 2018; Tadesse et al., 2019; Mondal et al., 2020).

Achieving this goal of expected genetic gain is becoming increasingly complex and challenging due to the increasing severity and frequency of abiotic and biotic stresses. Drought is the most significant stress factor to wheat production, but increasing temperatures, salinity, and declining soil fertility also threaten production stability. Similarly, the emergence of new pathogen races, especially belonging to rust species (*Puccinia* spp.), and pest infestations continue to challenge wheat cultivation across regions. Together, these factors demonstrate that yield targets cannot be achieved through traditional approaches alone, and innovative strategies are required to ensure food security.

One of the most important approaches should be the wider use of genetic resources. Landraces, wild relatives and neglected wheat species such as einkorn, emmer and spelt harbor novel alleles for stress tolerance and disease resistance that are not present in modern varieties. Their integration into breeding programs, supported by pre-breeding initiatives and germplasm conservation efforts, is essential to accelerate genetic gain. Advances in molecular markers, genomics, and genome editing tools offer additional opportunities to utilise this diversity more efficiently and develop climate-resilient wheat varieties. Additionally, the adoption of agroecological and climate-sensitive farming practices such as conservation tillage, crop rotation, precision irrigation, and optimised fertiliser use can help reduce environmental degradation and enhance sustainability. Finally, socio-economic and political support will also be needed to achieve these goals. Strengthening seed systems, improving farmers' access to certified seeds and technologies, and investing in agricultural infrastructure are vital steps. In this way, wheat can continue to play a central role in global food security for both current and future generations.

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ISBN: 978-625-378-362-4