

Sesame renaissance: Iran's emerging influence in the global sesame market

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Abstract – Sesame seeds and their various derivatives, such as sesame oil, can be special in household diets worldwide due to their unique nutritional and health properties. Despite the long history of sesame cultivation in Iran and its suitability to the Iranian climate, Iran remains an importer of sesame. In other words, sesame production in Iran faces numerous constraints and obstacles, limiting its production capacity. This study aims to present sesame production status in Iran over the past 22 yr, elucidating the production trends, quantity and value of imports, obstacles, and solutions for sustainable sesame seed production in the country. To achieve this goal, in addition to reviewing national and international databases, extensive correspondence was conducted with stakeholders in sesame production, ranging from farmers to researchers, promoters, and policymakers, to compile a comprehensive list of leading challenges in sesame production and operational solutions to overcome these challenges. The analysis revealed that the most significant challenges in sesame production in the country could be categorised into seven main sections, including poor agronomic management, soil fertility decline, pest, diseases and weed issues, inadequate breeding programs, lack of sustainable financial support, an uncertain sesame market and fragmented and ineffective research. To address these issues, it is essential to enhance sesame production by updating agricultural management practices, introducing and making high-yielding and stress-tolerant varieties accessible, improving soil management techniques, conducting applied research, and transferring knowledge to farms. Also, establishing sesame producer associations and cooperatives can help eliminate intermediaries in the production-to-sales chain. Timely support from government institutions for small-scale sesame producers and raising consumer awareness of sesame's nutritional and health benefits and its by-products are crucial to overcoming these challenges. All these actions can lead to the promotion and development of sesame production in Iran to meet the high domestic and global demand for this valuable and nutritious seed. This cannot be achieved without increased interaction between farmers, researchers, promoters, and policymakers.

Keywords: Breeding programs / development / performance / agricultural management

Résumé – Renaissance du sésame : l'influence émergente de l'Iran sur le marché mondial du sésame. Les graines de sésame et leurs divers dérivés, comme l'huile de sésame, peuvent occuper une place spéciale dans les régimes alimentaires des familles du monde entier en raison de leurs propriétés nutritionnelles et de santé uniques. Malgré la longue histoire de la culture du sésame en Iran et son adéquation au climat iranien, l'Iran reste un importateur de sésame. En d'autres termes, la production de sésame en Iran est confrontée à plusieurs contraintes et obstacles, limitant sa capacité de production.

Cette étude vise à présenter l'état de la production de sésame en Iran au cours des 22 dernières années, en explicitant les tendances de production, les importations en volume et en valeur, les obstacles et les solutions à une production durable de graines de sésame dans le pays. Pour ce faire, en plus de l'examen des bases de données nationales et internationales, des échanges ont été menés avec les parties prenantes de la production de sésame, des agriculteurs aux chercheurs, promoteurs et décideurs politiques, afin de compiler une liste complète des principaux défis pour la production de sésame et les solutions opérationnelles pour les relever.

L'analyse a révélé 7 principales catégories de freins: (1) la mauvaise gestion agronomique, (2) le déclin de la fertilité des sols, (3) les problèmes de ravageurs, maladies et adventices, (4) les programmes de sélection

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inadéquats, (5) le manque de soutien financier durable, (6) un marché du sésame incertain et (7) une recherche fragmentée et inefficace.

Pour relever ces difficultés, il est essentiel d'améliorer la production de sésame en mettant à jour les pratiques de gestion agricole, en introduisant et en rendant accessibles le semis de variétés à haut rendement et résistantes au stress, en améliorant les techniques de gestion des sols, en menant des recherches appliquées et en transférant les connaissances aux exploitations agricoles. En outre, la création d'associations et de coopératives de producteurs de sésame permet de s'affranchir d'intermédiaires dans la chaîne de production à la vente. Un soutien opportun des institutions gouvernementales aux petits producteurs de sésame et une sensibilisation accrue des consommateurs aux bénéfices nutritionnels et santé du sésame et de ses sous-produits, s'avèrent essentiels pour relever ces défis. Toutes ces actions peuvent conduire à la promotion et au développement de la production du sésame en Iran pour répondre à la forte demande nationale et mondiale. Mais elles supposent une interaction accrue entre les agriculteurs, les chercheurs, les promoteurs et les décideurs politiques.

Mots-clés : Programmes de sélection / développement / performance / gestion agricole

Highlights

This study reviews 22 years of sesame production in Iran, highlighting key challenges such as poor agroeconomic management, pest issues, and market uncertainties. It proposes solutions, including improved practices, better varieties, and increased collaboration between farmers, researchers, and policymakers.

1 Introduction

Sesame (*Sesamum indicum* L.) belongs to the Pedaliaceae family. It is one of the oldest oilseed crops cultivated worldwide, primarily for its diverse culinary applications, including its high-quality edible oil (Bedigian, 2010). Although the origin of sesame remains debated, it is believed to have been domesticated in India initially (Bedigian, 2015). Sesame is a plant adapted to tropical and subtropical climates. It can be cultivated between latitudes 40 degrees north and 40 degrees south, primarily in a narrow belt near the equator, predominantly in its northern regions.

Sesame seeds are highly nutritious, and their inclusion in the diet, whether in the form of seeds or oil, offers numerous health benefits. These seeds can contain up to 63% oil, higher than any other seeds; however, the oil content of seeds varies between 48 to 52% under laboratory conditions and between 44 to 48% in industrial extraction (Wei *et al.*, 2022). Furthermore, sesame oil contains significant amounts of essential unsaturated fatty acids, including 37 to 47% linoleic acid and 35 to 43% oleic acid, as well as low levels of saturated fatty acids, including 8 to 11% palmitic acid and 5 to 10% stearic acid (Ozdemir *et al.*, 2018). Additionally, sesame seeds are rich in proteins (14 to 30%), carbohydrates (4 to 20%), ash (4 to 7%), and fibres (3 to 7%), along with various vitamins and minerals (Wei *et al.*, 2022). A unique feature of sesame seeds is the presence of specific molecules, including antioxidants from the lignan group. Sesamin (0.2% to 1.6%) and sesamol (0.02% to 0.75%) are two significant lignans found in sesame seeds, but other types of lignans have also been identified in small amounts in sesame seeds (Andargie *et al.*, 2021). Due to the presence of these antioxidants and its high oil stability,

sesame is referred to as the "queen of oilseeds". These properties in sesame seeds and oil protect the body against various diseases (Pathak *et al.*, 2014). Consequently, global consumption of sesame is increasing due to changes in consumer lifestyles and awareness of its health benefits. Sesame seed consumption is estimated to reach approximately \$7.245 billion by the end of 2024, with sesame oil accounting for 65% of this amount (The World Bank, 2023).

The cultivation history of sesame in Iran dates back over 4000 yr (Bedigian, 2004). While sesame has traditionally been a product of southern Iran's warm and dry regions, its desirable agricultural characteristics, particularly its low water requirement, have led to its popularity for cultivation in many parts of the country. Currently, sesame ranks second after rapeseed in terms of cultivated area among oilseed crops, with sesame cultivation prevalent in more than 20 out of Iran's 31 provinces (Agricultural Production Statistics, 2023). However, the full potential of sesame production in Iran has not been realised due to several challenges that have impacted its production and trade in the past decades. Therefore, the main objective of this study is to summarise the production trends, quantity, and value of sesame exports and imports over the past 22 yr (from 2000 to 2022) and to provide insights into the obstacles, solutions, and future research directions for sesame in Iran. In this review, data from national and international databases, including the Ministry of Agriculture, the Statistical Centre of Iran, the Customs Administration of Iran, the Food and Agriculture Organization of the United Nations and the World Bank, have been utilised. Additionally, a detailed examination of reputable domestic and foreign scientific sources and extensive correspondence with researchers (25 people), promoters (32 people), and farmers (60 people; the questionnaire used for farmers is provided in the supplementary file) in sesame production in the country has been conducted to document the challenges facing sesame production in Iran, recommendations, opportunities, and research activities needed to increase production in the future.

2 The history of sesame cultivation and production globally and in Iran

In 2022, nearly 74.6 million metric tons of sesame oilseeds were produced worldwide. Seventy-nine percent of global sesame production comes from ten countries, including Sudan,

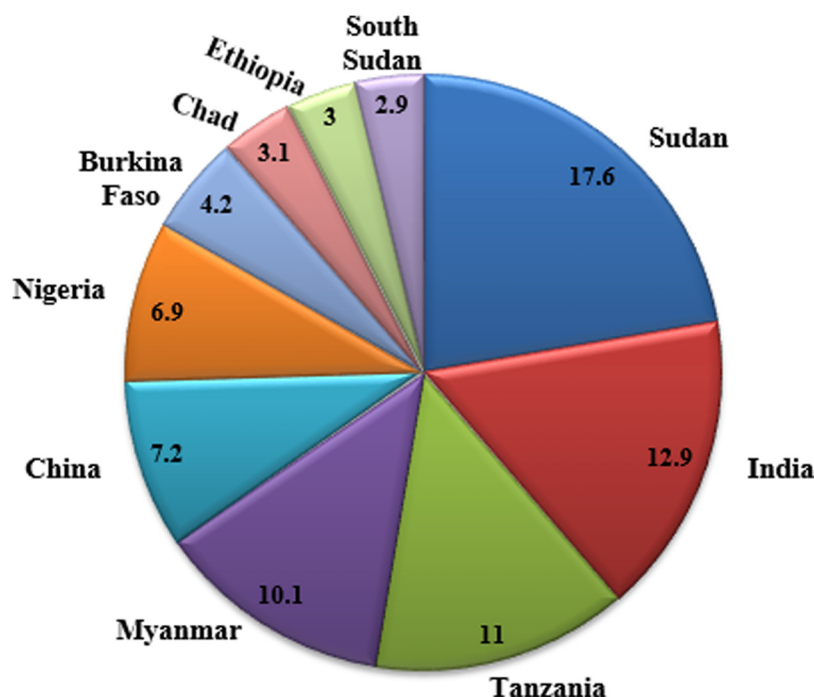


Fig. 1. The share of the world's top ten countries in sesame production (FAO, 2024a).

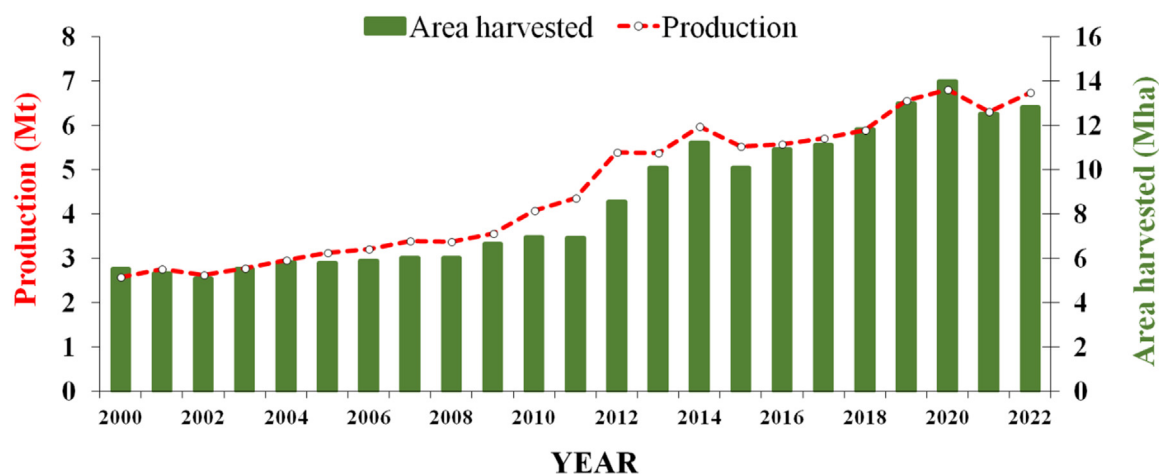


Fig. 2. Changes in area harvested and sesame production trends worldwide during the last 22 yr (FAO, 2024a).

India, Tanzania, Myanmar, China, Nigeria, Burkina Faso, Chad, Ethiopia, and South Sudan (Fig. 1). Iran's share of global sesame production in 2022 was 0.7%. Additionally, in 2022, Sudan reported the largest cultivated area for sesame, with nearly four million hectares, accounting for 30% of the world's cultivated area. Iran accounted for 0.3% of the world's cultivated area for sesame (FAO, 2024a).

In 2022, the highest yields were reported in the Central African Republic, Lebanon, and Uzbekistan, equivalent to 4827, 3517, and 1865 Kg ha⁻¹, respectively (FAO, 2024a). However, many other countries did not achieve 1000 Kg ha⁻¹ yields; in some cases, yields of less than 500 Kg ha⁻¹ were reported (Sadeghi Garmaroodi *et al.*, 2021). Statistics show that global sesame area harvested and production have increased by 133% and 162%, respectively, over the past

22 yr (from 2000 to 2022), while the average global yield has only increased by 12%. (Figs. 2 and 3).

The analysis of changes in the area harvested, production (Fig. 4), and yield of sesame seeds (Fig. 3) over 22 yr in Iran reveals that the area harvested with this crop reached its maximum in 2013, totalling 52300 hectares. Subsequently, there was a declining trend until 2018, when it reached 42000 hectares in 2022. The production of sesame seeds was 30700 metric tons at the beginning of the study period, peaked at 50800 metric tons in 2013, and reached 39000 metric tons in 2022. The yield of sesame seeds fluctuated from a minimum of 578 Kg ha⁻¹ in 2003 to a maximum of 1066 Kg ha⁻¹ in 2009. The latest statistics indicate a yield of 929 Kg ha⁻¹ in 2022 (Agricultural Production Statistics, 2023). Throughout the years under study, the average yield of sesame in Iran has been

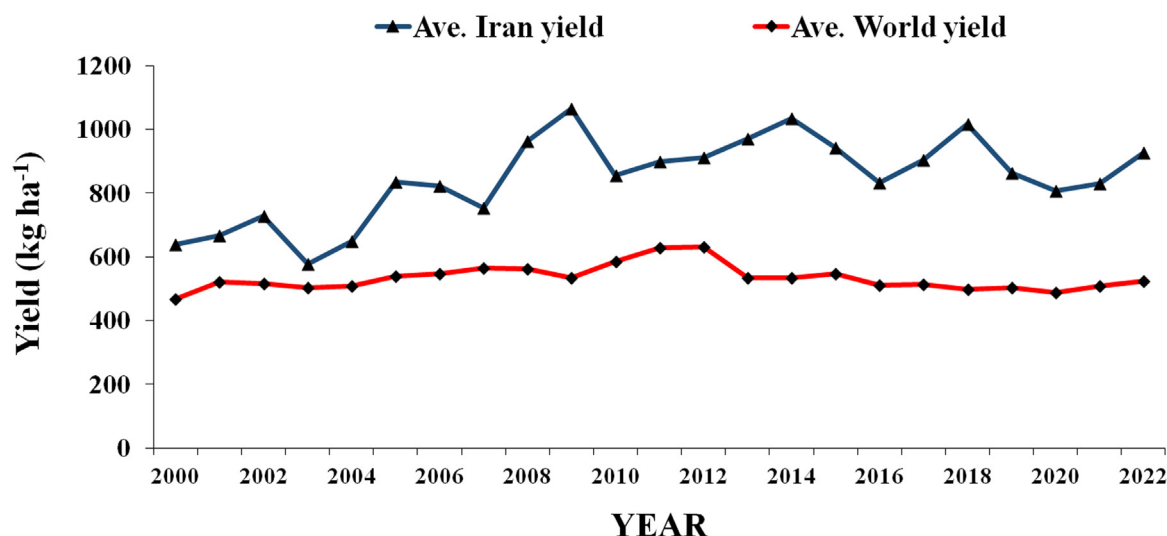


Fig. 3. Changes in the trend of sesame yield in the world and Iran during the last 22 yr (FAO, 2024a; Agricultural Production Statistics, 2023).

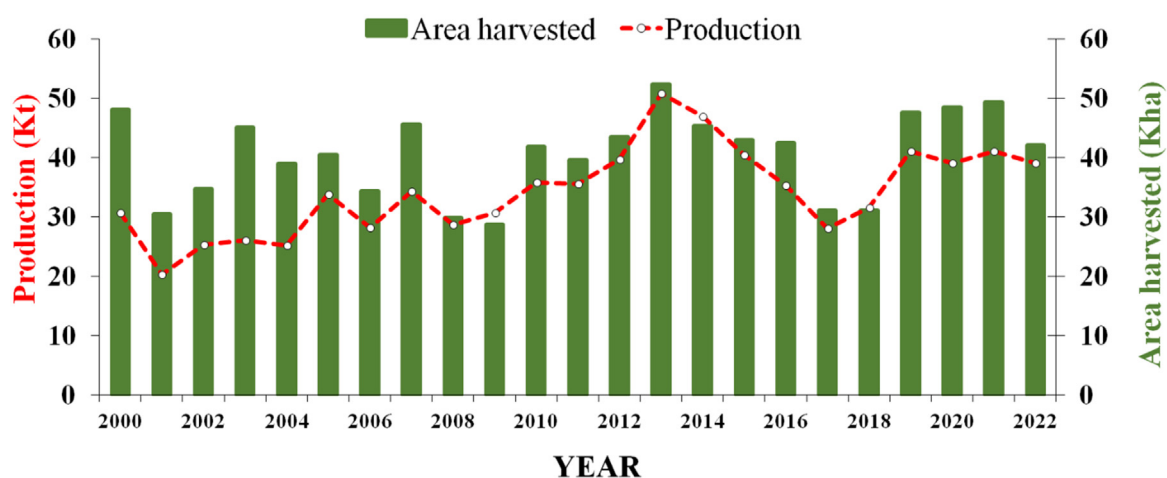


Fig. 4. Changes in the area harvested and sesame production trend in Iran during the last 22 yr (Agricultural Production Statistics, 2023).

higher than the global average yield (Fig. 3). Among oilseed crops, sesame is the only one in which Iran's average yield exceeds the global average to such an extent, although the reasons for this are discussed further below.

In recent years, the commercial sesame seed market has experienced significant growth, with the trade of this product increasing notably. In 2022 alone, approximately 2,459,738 metric tons of sesame seeds, valued at around 35 billion dollars, were traded by various countries. The largest amounts of imports were made by China (1.6 million tons), Turkey (223 thousand tons), Japan (204 thousand tons), India (149 thousand tons), and South Korea (77 thousand tons). Sudan (492 thousand tons), India (276 thousand tons), Nigeria (261 thousand tons), Ethiopia (228 thousand tons), and Tanzania (167 thousand tons) are considered major exporters of this product (OEC, 2023). Iran's share of the global sesame export market is almost negligible despite importing approximately 69 thousand tons of sesame seeds valued at around 121 million dollars in 2022 (Iran Customs Administration, 2023). Iran's major imports in recent years have come from India, the United Arab Emirates, Pakistan, and Afghanistan. Figure 5

illustrates the quantity and value of sesame imports into Iran from 2000 to 2022. Nevertheless, the disregard for the country's high domestic demand for sesame, which exceeds 120 thousand tons annually, and its processed products on the one hand, and the overlooking of the suitable earning potential of this plant on the other, have led to the country's trade balance for this product to be negative in recent years consistently. This is despite the increasing domestic and global demand for sesame seeds and oil due to their desirable nutritional properties, which present a suitable opportunity for Iranian producers and traders to improve production and engage in the appropriate marketing of this product.

3 Challenges towards sesame production in Iran

3.1 Poor agronomic management

Poor agronomic management in all crop plants, including sesame, often leads to a significant gap between achievable and actual yields. Although, according to national statistics

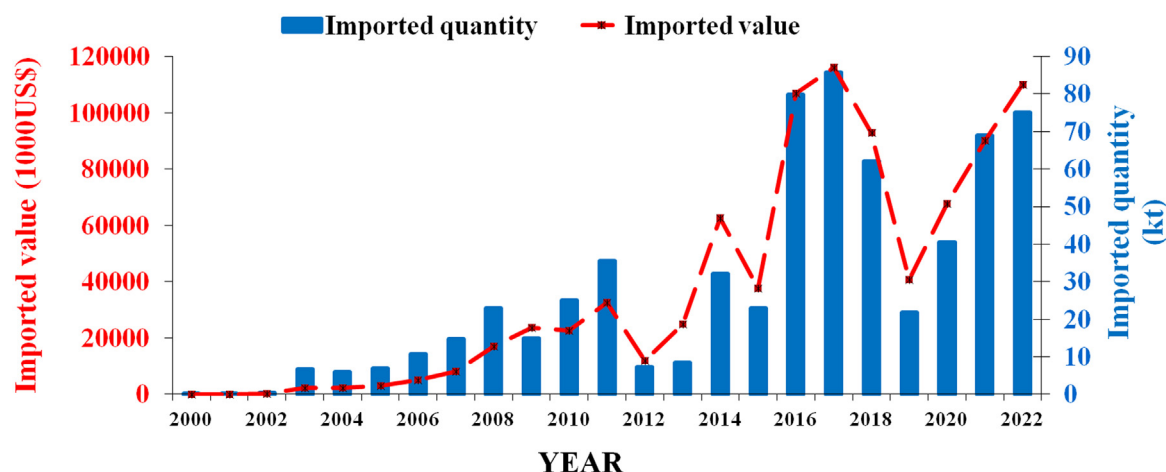


Fig. 5. Changes in the quantity and value of sesame imports to Iran during the last 22 yr (Iran Customs Administration, 2023).

Table 1. Comparison of sesame total water requirement with other oilseed crops.

Crop	Water requirement ($\text{m}^3 \text{ha}^{-1}$)	Reference
Sesame	4500–6000	Gholamhoseini, 2020 Saboury <i>et al.</i> , 2021
Soybean	5500–7500	Allen <i>et al.</i> , 1998
Sunflower	6000–10000	Kranz and Specht, 2012
Safflower	6000–span>12000	FAO, 2024b
Groundnut	5000–7000	Steduto <i>et al.</i> , 2012
Rapeseed	5000–7000	

(Agricultural Products Statistics, 2023), the average sesame yield in Iran in recent years has been up to 59% higher than the global average sesame yield, it should be noted that the potential yield of sesame exceeds these figures. This is evidenced by official statistics of yields exceeding two tons and, in some cases, up to three tons in countries such as the Central African Republic, Lebanon, and Uzbekistan (FAO, 2024a). Furthermore, progressive sesame farmers who have benefited from proper agronomic management have reported yields close to 1500 Kg ha^{-1} in Iran. However, on most sesame farms in Iran, crop management relies on farmers' years of experience and basic agronomic practices, resulting in reduced yields and decreased production.

The primary and likely most significant obstacle to improving sesame production in Iran and other countries with similar climatic conditions, such as Iraq, Pakistan, and Afghanistan, is the reduction of water availability and improper water management in sesame cultivation. Although sesame is known as a drought-tolerant crop, its production significantly decreases under conditions of insufficient water availability (Gholamhoseini, 2020). Sesame is sensitive to water scarcity at the seedling stage due to limited root expansion. In addition, during flowering and seed formation stages, it is sensitive to water stress due to increased leaf surface area and the formation of delicate reproductive organs (Ghasemi Hamedani *et al.*, 2022). Sesame is grown as a summer crop in various regions of Iran, typically sown

between May and July after the harvest of wheat, barley, and canola. In Iran, as with many other sesame-producing countries with similar climates, its water requirement relies solely on irrigation. Although the water requirement of sesame is less compared to other oilseed crops (Tab. 1), the water requirement for cultivation ranges from 4500 to $6000 \text{ m}^3 \text{ha}^{-1}$, depending on irrigation methods, climatic conditions, and farm management (Gholamhoseini, 2020). However, in many sesame farms in the country, water availability is inadequate, resulting in a sharp decline in yield, or outdated irrigation methods, such as flood irrigation, lead to excessive water consumption by the plant, resulting in inefficient water use.

Poor agronomic management, such as manual planting without precise spacing and arrangement, is common in most sesame fields. Research in agronomy has shown that both higher and lower densities than the optimal density in sesame cultivation can reduce seed yield by 30 to 50% (Gholamhoseini *et al.*, 2022a; Habibzadeh and Gholamhoseini, 2022). Additionally, in many regions of Iran, sesame is planted after the harvest of wheat and barley. Due to the late harvesting of the autumn crop resulting from the unavailability of harvesters or the prolonged process of land preparation before sesame cultivation in conventional land preparation methods, sesame planting is delayed, leading to a significant reduction in seed yield. It has been reported that for each day of delay in sesame planting from the desired planting date, seed yield decreases by up to 1.4% (Ogbonna and Umar-Shaba, 2012).

Inproper and incredibly repetitive crop rotations are also inappropriate management factors in sesame fields that lead to decreased seed yield. Repeated sesame cultivation can accumulate fungal spores, causing root rot and severely declining seed yield (Langham, 2008). Harvest time is another factor directly or indirectly affecting the reduced sesame yield in most farms in the country. Since over 99% of sesame farms in Iran, like other parts of the world, use varieties and genotypes sensitive to seed shattering, if the farmer delays harvest until full maturity to achieve maximum yield, over 50% of the seeds will shatter, reducing yield. In early harvesting, which most farmers in Iran and other parts of the world follow, sesame is harvested when only the lower capsules of the plant are mature. In contrast, the upper capsules have not yet fully matured, and the seeds are not

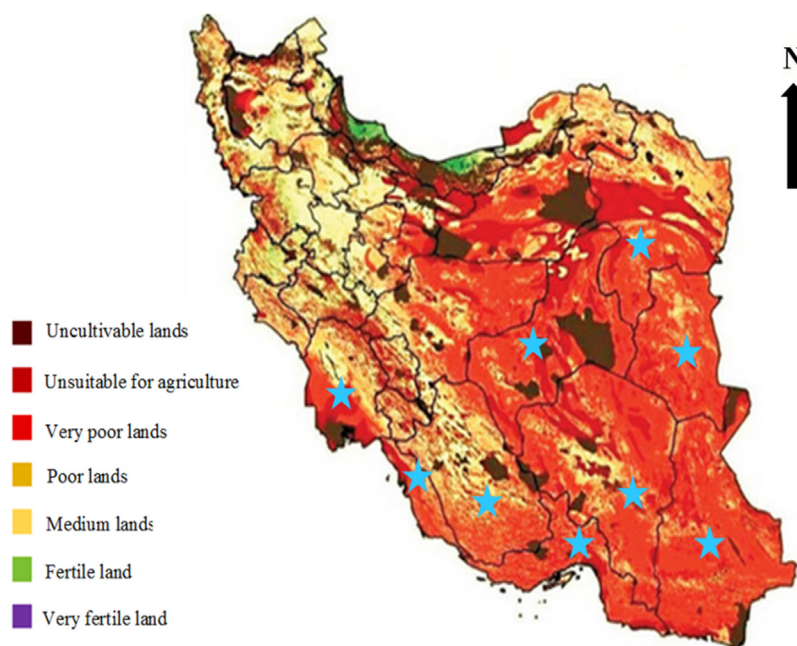


Fig. 6. Fertility map of Iran, highlighting the major sesame cultivation areas marked with a star (Doulabian *et al.*, 2021).

filled. Under these conditions, the weight of a thousand seeds, an essential component of seed yield, is low (Sadeghi Garmaroodi *et al.*, 2022), another factor in sesame fields' reduced yield.

3.2 Declining soil fertility

Despite agricultural production growth in Iran over the past three decades, many Iranian agricultural soils suffer from organic matter depletion, nutrient depletion, and high erosion (Doulabian *et al.*, 2021). This issue is more severe in semi-arid and arid regions of Iran, where most of the sesame cultivation in the country is concentrated. A close examination of Iran's land fertility map, aligned with the country's most crucial sesame cultivation areas (Fig. 6), reveals that sesame cultivation mainly occurs in infertile lands. Furthermore, subsistence farmers with small-scale farms, who own most of the sesame cultivation areas, lack of financial capacity to purchase and use effective organic and chemical fertilisers to enhance soil fertility, leading to further yield decline from these farms. Contrary to the common perception among most farmers that sesame is a very low-demand and almost nutrient-independent plant, sesame, like other crop plants, achieves its highest yield when water and nutrients are optimally available (Saboury *et al.*, 2021). It has been reported that the lack of nitrogen fertiliser or its underutilisation can reduce sesame yield by 20 to 50% (Gholamhoseini *et al.*, 2022b). Conversely, sesame cultivation in proper planting arrangements and densities on land with organic matter content exceeding one percent and the plant's nutrient requirements met has resulted in yields of over 2500 Kg per hectare under experimental conditions (Gholamhoseini, 2021) and up to two tons in commercial farms. Therefore, ensuring the supply of nutrients for sesame and preserving soil fertility poses a significant challenge in managing sesame farms to achieve desirable economic performance.

3.3 Dilemma of pests, diseases and weeds

Sesame is a plant that is susceptible to attacks by many insect pests; however, the relative importance of these insects varies between regions. Common sesame pests, such as grasshoppers, leafhoppers, aphids, and thrips, can cause damage to sesame fields at all growth stages and are prevalent on a large scale. Among these, aphids and leafhoppers feed on the plant, cause damage, and transmit diseases, leading to significant losses (Garzo *et al.*, 2020). The most important pests of sesame in Iran and countries with similar climates include the winter cutworm (*Agrotis segetum*), whitefly (*Bemisia spp.*), sesame capsule borer (*Antigastra catalaunalis*), leafhoppers (*Cicadellidae spp.*), cotton bollworm (*Helicoverpa armigera*), beet armyworm (*Caradrina exigua* (Syn: *Laphigma exigua*)), and Egyptian cotton leafworm (*Spodoptera lituralis* (Syn: *Prodenia litura*)). However, the severity of pest damage in sesame cultivation depends on climatic conditions and planting dates (Mawcha *et al.*, 2021). It has been reported that globally, up to 30% of sesame yield losses can be attributed to pest damage (Lukurugu *et al.*, 2023).

Among plant diseases, fungal wilt diseases are the most important diseases of sesame in Iran and many other parts of the world. Various fungal agents cause this disease, with *Fusarium* species (*Fusarium oxysporum* f.sp. *sesami*), *Macrophomina* (*Macrophomina phaseolina*), and *Phytophthora* (*Phytophthora parasitica*) being among the most common (Sadeghi Garmaroodi *et al.*, 2021). These pathogenic agents are more prevalent when sesame is planted consecutively in a same field. Due to the manual harvesting of sesame in most areas of the world, there are always plant residues accompanying the seeds, which are the main factors in the transmission and establishment of diseases in subsequent years. Various fungi, including *Helminthosporium sesami*, *Alternaria sesami*, *Nigrospora sphaerica*, and bacterial pathogens such as *Pseudomonas syringae* pv *sesami*, cause leaf spot diseases

and extensive damage to sesame fields (Ransingh *et al.*, 2021). Finally, phyllody disease is one of the most important diseases in Iran and many sesame cultivation areas, and it can destroy sesame fields. The causative agent of this disease is a specific type of bacterium called *Phytoplasma*, which is transmitted by a pest called leafhopper (*Circulifer haematiceps*) (Ahmed *et al.*, 2022). Unfortunately, precise estimates of yield loss and reduction in sesame cultivation areas due to pests and diseases are unavailable in Iran. However, pests and diseases are always undeniable problems in sesame fields.

Like other crop plants, sesame growth, development, and production are severely reduced due to competition with weeds. Since this plant has slow early growth (Langham, 2007), it is more susceptible to weed damage. Therefore, severe damage will occur to the crop if weed control cannot be achieved in the early stages of growth or, more precisely, in the critical period. In some cases, production may ultimately fail. A wide range of weeds are found in sesame fields, with the most important ones including heliotrope (*Heliotropium spp.*), common mallow (*Malva neglecta* Wallr), pigweed (*Amaranthus spp.*), black nightshade (*Solanum nigrum* L), bindii (*Tribulus terrestris* L), common purslane (*Portulaca oleracea* L), white goosefoot (*Chenopodium album* L), cocklebur (*Xanthium strumarium* L), spider flower (*Cleome viscosa* L), dyer's croton (*Chrozophora tinctoria* (L.) Juss), prostrate knotweed (*Polygonum aviculare* L), wild foxtail (*Setaria spp.*), barnyard grass (*Echinochloa spp.*), nutgrass (*Cyperus spp.*), bindweed (*Convolvulus spp.*), camelthorn (*Alhagi spp.*), ground cherry (*Physalis alkekensi* L.), caper (*Capparis spinosa* L), mesquite (*Prosopis stephaniana* Will), johnsongrass (*Sorghum halepense* L. (Pers)), and Bermuda grass (*Cynodon dactylon* (L.) Pers). One of the most significant obstacles to increasing yield and cultivation area of sesame, both in Iran and elsewhere, is the lack of introduction of specific herbicides for this crop. Large pesticide companies do not produce dedicated herbicides for sesame because sesame is not a major crop in leading agricultural countries, and a crop cannot become significant if specific herbicides are unavailable. In previous years, many human resources were available for farmwork, including hand weed control. These resources are unavailable for sesame fields now, or their costs are too high. Therefore, weed control remains one of the most pressing challenges in sesame cultivation.

3.4 Inadequate breeding programs

One of the most effective methods for increasing production per unit area and enhancing productivity in crop production is the use of improved varieties with high quantitative and qualitative performance. Despite significant efforts in breeding activities in recent decades in Iran, a considerable volume of sesame is still produced in Iran, like many other parts of the world, from local populations of this plant (Dossa *et al.*, 2016). In Iran, like many other sesame-producing countries, numerous indigenous populations are adapted to the climatic and soil conditions of the production region. However, due to various reasons such as the long growth period, inadequate fertilisation, high sensitivity to biotic and abiotic stresses, lack of uniformity in management due to the mixture of local populations, and poor seed retention in capsules, these indigenous populations have low yields

which have a direct impact on the low production of sesame in the main producing countries.

3.5 Lack of economic financing

It should be noted that in agriculture, there is a time gap between the provision of production inputs and the achievement of the product, especially for smallholder farmers who own a significant portion of sesame farms and do not have significant economic resources. Inputs must be provided through formal or informal means. Although this problem has long existed in the production of all agricultural products, and farmers complain every year about the lack of timely allocation of funds, one of the factors contributing to the low production and performance of sesame in Iran is the lack of access of smallholder farmers to economically viable official financing for agricultural activities. In sesame farming, this financing category is essential for purchasing seeds and other inputs, land preparation, labouring for various tasks (mainly weeding), and harvesting. This affects the timely execution of agricultural operations. For example, a shortage of equipment financing for land preparation leads to late planting and, consequently, reduced yields.

Another effect of the lack of credits is the change in agricultural land use. It should be noted that converting agricultural lands to residential and industrial lands is irreversible and leads to economic, social, and environmental issues. As mentioned in the previous sections, the agricultural lands where sesame is cultivated are mostly infertile, water-deficient, and small-sized (less than three hectares). Therefore, they do not offer desirable economic returns for farmers, which can accelerate their conversion. Moreover, sesame cultivation is traditionally practised in many parts of the world and has been inherited within families. However, in recent years, the inheritance of land from one generation to another has led to the permanent fragmentation of agricultural lands, posing a severe threat to land integrity. The fragmentation of agricultural lands means the uneconomical use of land for cultivation, leading to its withdrawal from the agricultural production cycle.

3.6 Uncertain sesame market

Despite the negative trade balance for sesame seeds in Iran in recent years, with the majority of domestic demand, over 120,000 tons annually, being met through imports (Iran Customs Administration, 2023), this significant demand in the domestic market and the potential market in global sesame trade, ranked 995 out of 4641 reputable global markets (OECD, 2023), has not led to the development of sesame cultivation as expected. International sanctions, the monopoly and rent-seeking behaviour of import companies, and the imposition of numerous tariff and non-tariff regulations are among the influential factors in creating a non-competitive and unattractive market for sesame production in Iran. Additionally, price suppression of purchased sesame from farmers in the domestic market is another reason for farmers' lack of competition in expanding sesame cultivation. Furthermore, the production costs of sesame increase for farmers every year. In this regard, the assessment of the Producer Price Index, which indicates producer costs in the production process compared to a similar

period in the past, shows that over the past decade, this index has been increasing annually for sesame production, reaching 26 units in 2011 and 514 units in 2022 ([Statistical Centre of Iran, 2023](#)). This significant upward trend in the Producer Price Index alongside sesame imports indicates that intermediaries and brokers are the main beneficiaries in the domestic sesame market, negatively impacting farmers' profitability of sesame production. The weak financial capacity of sesame producers in Iran, who cannot often store and market their products, and the absence of cooperatives and associations aimed at preserving the value of the produced crop force small-scale farmers to sell their products with minimal profit, resulting in reduced profitability of sesame production and ultimately reduced production.

3.7 Fragmented and ineffective research

Not only in Iran but also globally, agricultural research related to sesame, despite all its benefits, is negligible compared to other crops. A keyword search for sesame on reputable scientific platforms such as Science Direct yields 7919 results in the agriculture and life sciences subcategory. This is while a search for sunflower and soybean produces 32680 and 111019 results, respectively, and for a non-oilseed crop like maize, it produces 132925 results. Within Iran, keyword searches for sesame, sunflower, soybean, and maize in the Scientific Information Database (SID.ir) yield 230, 397, 680, and 1688 scientific articles, respectively. Moreover, breeding programs for sesame are also minimal and slow. The main reason is that sesame is considered a staple crop in underdeveloped countries like Sudan or a secondary crop in developing countries like Iran. Research budgets are very limited in many sesame cultivation areas, and other crops have higher priority and receive more resources. Therefore, fewer researchers are attracted to sesame. Additionally, the lack of implementation of long-term projects, restrictions on genetic material exchange, and the lack of motivation for knowledge-based companies to engage in research and development are other influential factors in sesame research.

4 Solutions to overcome sesame production obstacles

4.1 Improvement in agronomic management

Sesame production is influenced by various agronomic management practices, with the most important being land preparation, planting date, planting arrangement and plant density, irrigation and crop rotation. This section aims to propose appropriate agronomic management for successful sesame cultivation.

The most crucial stage in sesame cultivation is land preparation for planting. Since sesame seeds are tiny and their seedlings are weak with slow initial growth ([Langham, 2008](#)), the seedbed must be free of weeds, warm, levelled, moist, and have a compact surface. It should be noted that continuous implementation of conventional land preparation methods such as ploughing, disking, rolling, and harrowing, especially in sesame fields with poor soils in dry and semi-arid climates, leads to undesirable outcomes such as a reduction in soil organic matter ([Rousta et al., 2020](#)) and soil moisture retention

capacity ([Afzali-Nia et al., 2018](#)). Therefore, conservation agriculture methods that preserve at least 30% of the previous crop's residues and no-tillage have been emphasised in sesame cultivation. It has been reported that in Fars, one of Iran's most important sesame cultivation areas, conventional tillage has the lowest yield, and conservation tillage has the highest yield ([Afzali-Nia et al., 2020](#)). Additionally, due to the reduced time required for land preparation, sesame planting is less delayed under the conservation agriculture system.

In determining the planting date for sesame, three essential points must be considered: first, suitable temperature for germination; second, temperature stability to ensure that there is no temperature drop after germination; and third, flowering time (35 to 50 days after planting) should not coincide with excessive heat. Generally, sesame should not be planted before the soil temperature at planting depth (two to three centimetres) reaches 21°C (air temperature less than 22 to 23 °C) ([Sadeghi Garmaroodi et al., 2022](#)). Early and very early planting dates, especially in cooler regions, can lead to reduced yields due to slow seedling growth. Late planting dates may also lead to reduced yield due to a shortened growth period and consequently reduced use of resources, as well as the possibility of harvest coinciding with autumn rains, causing delays in sesame harvesting and subsequent planting. Depending on the delay, postponement of sesame planting dates can reduce sesame yield by 20 to 50 percent ([Ogbonna et al., 2012](#)).

Another crucial agronomic management for sesame is optimal planting arrangement and plant density. Like other crops, planting arrangement and plant density in sesame should be adjusted in a way to minimise competition between plants and allow them to effectively utilise existing growth factors ([Postma et al., 2021](#)). Moreover, adequate spacing for proper canopy development is essential. Under these conditions, maximum plant yield and increased efficiency of input utilisation are achievable. Increasing plant density beyond the desirable level, as seen in many small-scale sesame farms across Iran due to non-mechanised cultivation and hand planting, reduces photosynthetic efficiency and results in a decrease in the transfer of photosynthetic products to seeds, thus reducing yield ([Gholamhoseini et al., 2020](#)). [Figure 7](#) shows the appropriate density range to achieve maximum seed yield in single-branched and multi-branched sesame cultivars.

On the other hand, densities below the desirable level, resulting from poor seedbed preparation or inappropriate irrigation methods (especially flood irrigation), can significantly reduce yield per unit area. Farmers who practice mechanised sesame planting usually consider row spacing according to available resources to avoid adjusting equipment. However, if possible, planting in narrow rows, 45 cm instead of the conventional 75 cm row spacing, is preferable in sesame cultivation due to better plant establishment, rapid ground cover, more effective weed competition, and reduced soil evaporation ([Gholamhoseini et al., 2023](#); [Karimi et al., 2018](#)). Additionally, plant spacing varies from 7 (in single-branched varieties) to 10 cm (in multi-branched varieties) ([Habibzadeh and Gholamhoseini, 2022](#)). Therefore, the suitable density range for sesame varies between 19 to 22 plants per m² in multi-branched genotypes and 29 to 32 plants per m² in single-branched genotypes ([Gholamhoseini et al., 2020](#); [Gholamhoseini, 2021](#)).

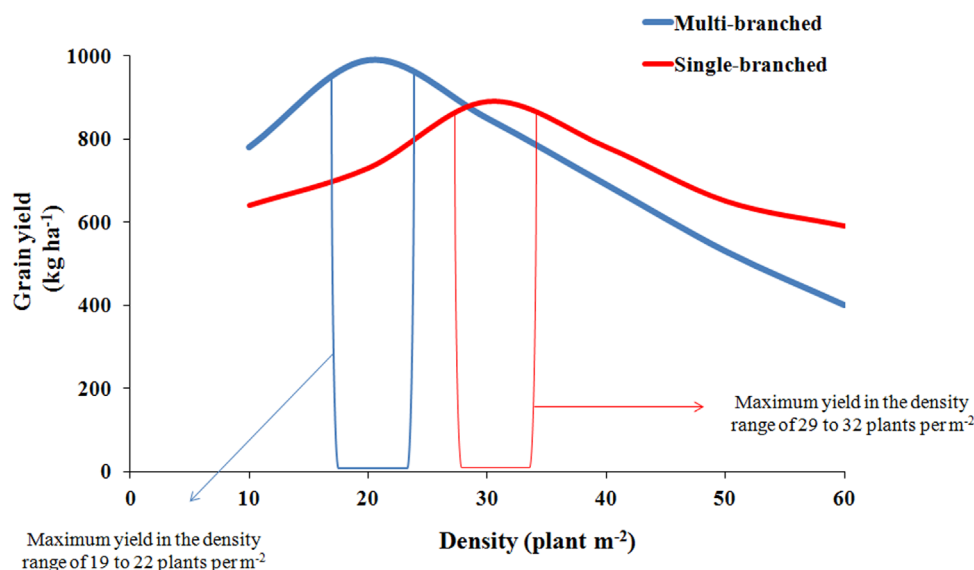


Fig. 7. Optimum plant density in sesame (Gholamhoseini *et al.*, 2020; Gholamhoseini, 2021).

Another crucial aspect of agronomy in successful sesame production is attention to irrigation and soil moisture control. In sesame cultivation, yield is more influenced by water distribution throughout the growing season than by the amount of water the plant receives (Gholamhoseini *et al.*, 2021; Gholamhoseini *et al.*, 2022c). Compared to other crops, irrigation for sesame during the growing season should be light and staged. Heavy and voluminous irrigation is unsuitable for sesame as it could accelerate the spread of fungal diseases. The fact that sesame can tolerate the depletion of 50 to 60 percent of soil available moisture in the root zone without significant adverse effects on seed yield (Gholamhoseini, 2020; Gholamhoseini, 2022) can be used for irrigation planning in fields facing water constraints.

Additionally, the timing of irrigation cessation in sesame cultivation is essential. In soils with medium to heavy texture and furrow irrigation methods, irrigation for sesame should be stopped when flowering is completed. In soils with a light texture and drip irrigation method, one to two more irrigation rounds during the flowering period have effectively increased yield (Gloaguen *et al.*, 2021; Langham, 2007).

Choosing appropriate crop rotations is also one of the management practices that can have a direct impact on sesame yield. Sesame, as a summer crop, can replace most summer crops in crop rotations. Many producers have incorporated sesame into their wheat or barely rotation because it increases yield, extends limited water so that producers can concentrate water for the next crop and provides a second cash crop (Langham, 2008).

Another effective aspect in increasing agricultural production, including sesame, is effective extension services and timely dissemination of agronomic findings to farmers. As mentioned earlier, most sesame-producing farms in Iran are managed by farmers who still rely on traditional production methods and are less familiar with effective research findings to increase production. Effective extension services can significantly increase production by facilitating technology transfer, developing farmers' knowledge, and familiarising

them with modern agronomy management methods. The use of incentives such as free distribution of sesame seeds or other effective inputs in sesame farming extension programs, participation of experienced promoters, determining the appropriate timing for extension programs and accurate information dissemination, implementation of farm day programs, dissemination of research findings in the form of easy-to-use educational packages for farmers such as pamphlets and instructional videos, and alongside all these measures, attention to Indigenous knowledge of farmers and efforts to upgrade rather than eliminate them are among the factors that can enhance the effectiveness of extension programs and ultimately increase sesame production.

4.2 Soil fertility improvement

Soil fertility can be defined as the soil's ability to provide the necessary nutrients for crop growth (Nord *et al.*, 2022). Therefore, for sustainable production, sesame field soil management must ensure adequate amounts of all essential nutrients are available to the plant at the right time. The root system of sesame allows it to absorb nutrients from depth within the soil (Ghasemi Hamedani *et al.*, 2020). Numerous reports are available regarding increased sesame yield with optimal nutrient availability (Wacal *et al.*, 2019; Hassaan and Bughdady, 2018). However, one of the most significant factors contributing to low sesame yields in farmers' fields is the lack of an adequate supply of necessary plant nutrients. The first step in improving soil fertility in sesame fields is awareness of soil conditions. Soil testing is one of the best management methods and precise tools for assessing soil fertility (Mallarino, 2005). Although this method imposes costs on the farmer, its results can form the basis for fertiliser recommendations and prevent unnecessary use of some fertilisers.

The next step is improving the status of organic matter in the soil. Since dry and semi-dry areas are the most important

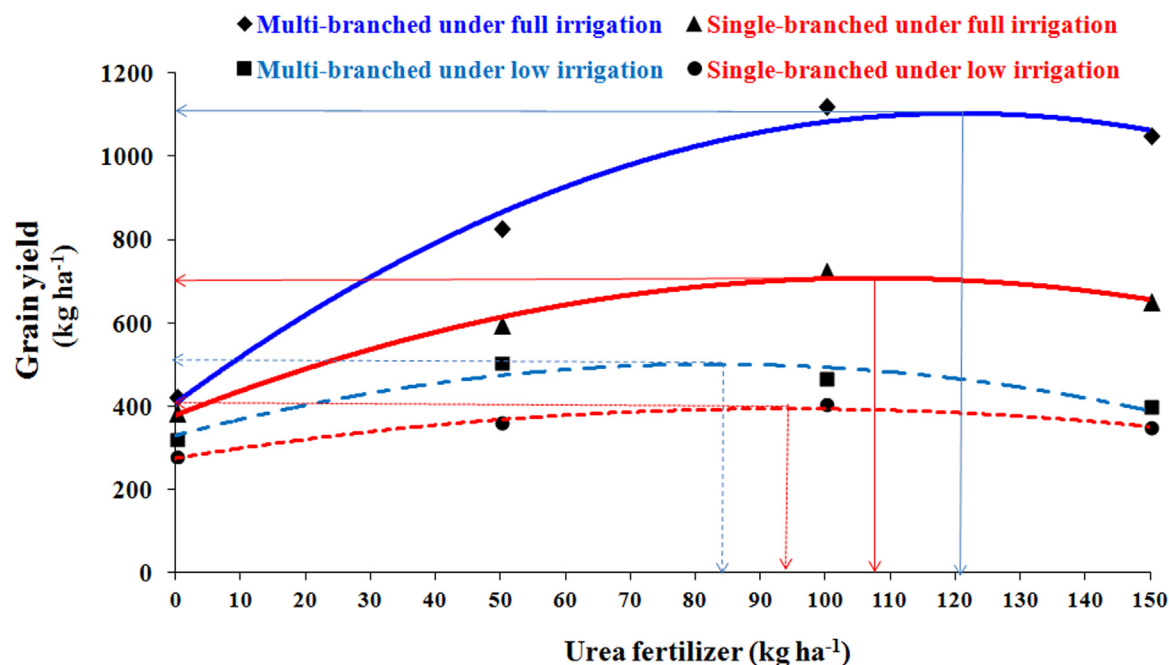


Fig. 8. Nitrogen fertiliser required in sesame cultivation according to water availability and variety. The vertical arrows show the maximum amount of nitrogen required, and the horizontal arrows show the maximum yield (Gholamhoseini *et al.*, 2021; Gholamhoseini, 2022; Gholamhoseini *et al.*, 2022b).

regions for sesame cultivation and soil organic matter in these areas is generally negligible (Rezaei *et al.*, 2022), it is necessary to strengthen soil organic matter using low-cost but effective methods. The most important factors contributing to reducing soil organic matter in sesame fields include improper crop rotation, burning or complete removal of residues from the field, conventional tillage operations, especially mouldboard ploughing, and unbalanced use of chemical fertilisers, especially urea. On the other hand, there are management methods that can enhance soil organic matter, such as using legumes in rotation, adhering to conservation agriculture principles (maintaining at least 30 percent residue cover in the soil, minimum tillage, and permanent vegetation cover in the field), restricting grazing, and using organic fertilisers such as manure.

The third step in improving soil fertility in sesame fields is the proper and balanced use of chemical fertilisers, especially nitrogen, according to water availability. On average, sesame requires 100 to 120 Kg of urea per hectare under full irrigation conditions (providing 6000 to 7000 m³ of water with proper distribution) and 85 to 95 Kg of urea per hectare under water scarcity conditions (providing 4000 m³ of water) (Gholamhoseini *et al.*, 2021; Gholamhoseini, 2022; Gholamhoseini *et al.*, 2022b) (Fig. 8). Farmers need to apply urea fertiliser in split doses to prevent its leaching, with half applied at the three to four-leaf stage of sesame and the rest side-dressed along the planting rows at a depth of three to five centimetres at the onset of flowering.

Phosphorus is sesame's second most important nutrient, directly contributing to its increased yield. The phosphorus application rate in sesame cultivation should be determined

based on the availability of this nutrient in the soil. If soil test results show that the available phosphorus content is more than 15 ppm, there is no need to use phosphate fertilisers in sesame cultivation. On the contrary, if the available phosphorus content in the soil is less than 5, between 5 to 10, and between 10 to 15 ppm, the application of 150, 100, and 50 Kg per hectare of triple superphosphate fertiliser is recommended, respectively. Moreover, the potassium fertiliser application rate for sesame cultivation depends on soil characteristics, especially the amount of potassium available in the soil and the percentage of clay content (Fig. 9). Farmers can mix phosphate and potassium fertilisers with the soil before planting. However, placing the fertiliser in a band below and alongside the seed is more effective than surface broadcasting.

Sulphur is another highly effective nutrient that increases sesame yield but has received less attention. Research has shown that increasing sesame yield by providing the necessary sulphur can range from 8 to 18% (Raza *et al.*, 2018). It should be noted that sulphur uptake is closely related to nitrogen uptake, and the nitrogen-to-sulphur ratio should be in the range of 10 to 15 in most crops, but for oilseeds such as sesame, this ratio should be less than 10 to achieve increased yield and improved quality. In other words, using high nitrogen levels without sulphur can decrease crop productivity. The application of sulphur-containing fertilisers in sesame cultivation should be based on soil testing. As a general recommendation, applying 75 to 100 Kg ha⁻¹ of sulphur powder before planting or the same amount of ammonium sulphate fertiliser along with irrigation water, considering soil pH and lime and bicarbonate content of irrigation water is advisable.

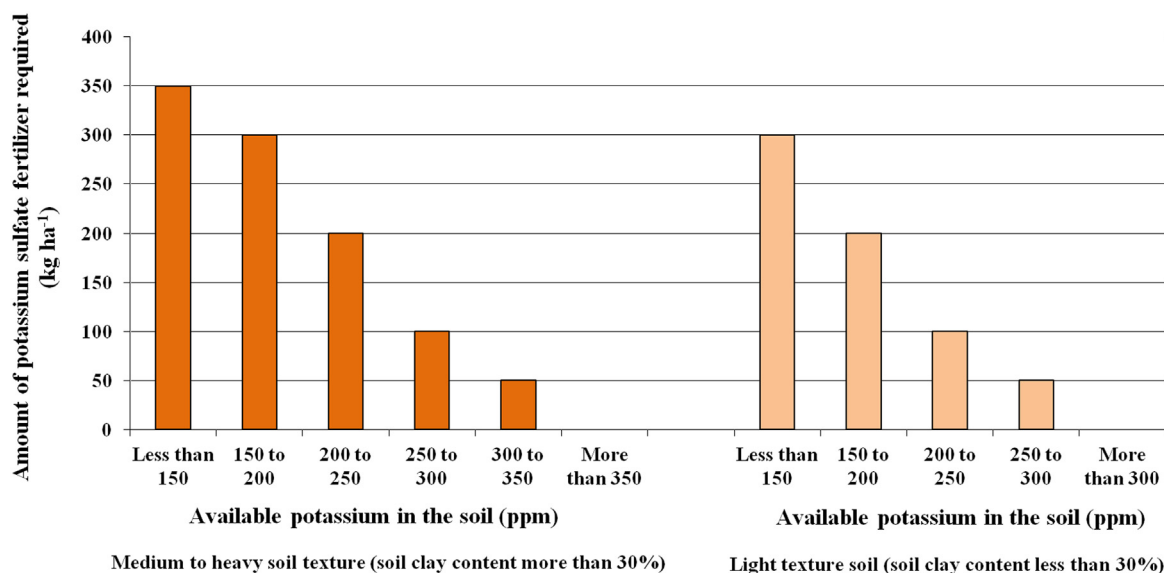


Fig. 9. The amount of potassium fertiliser required in sesame cultivation according to the soil test (Sadeghi Garmaroodi *et al.*, 2022).

Table 2. Integrated weed management in the sesame fields.

Preventing the establishment of weeds	Crop rotation, mixed cultivation, use of clean sesame seeds, use of pre-emergence herbicides such as pendimethalin (4 L ha ⁻¹) or trifluralin (2 L ha ⁻¹), use of mulch, edge of field weed control
Reducing the adverse effects of emerging weeds	Choosing the suitable variety, Highly vigorous seeds, accurate planting date and depth, proper planting arrangement and density, water and nutrients management, application of post-emergence herbicides before weed bolting such as haloxyfop-r-methyl (0.75 L ha ⁻¹), sethoxydim (3 L ha ⁻¹), clethodim (1 L ha ⁻¹), fluazifop-p-butyl (1.5 L ha ⁻¹) and cycloxydim (3 L ha ⁻¹), weeding (twice 15 and 30 days after planting) or cultivator (30 days after planting)
Reducing weed seed bank	Residue management, weed seed-free machinery, use of decomposed organic fertilisers, prevention of weed seed production

4.3 Integrated pests, diseases and weeds management

As previously mentioned, pests, diseases, and weeds are among the factors reducing sesame yield globally. Currently, Iran's main reliance on pest control is the use of chemical pesticides. For example, pesticides such as cypermethrin and diazinon for controlling sesame seed borer, oxydemeton-methyl and deltamethrin for grasshoppers, monochlorophos for green stink bugs, sumicidin for *Agrotis*, thiamethoxam for whitefly, and a wide range of chemical pesticides recommended and used by farmers for other pests. However, with proper integrated management, economic damage from pests can be reduced, and the indiscriminate use of these pesticides can also be prevented. Employing appropriate crop rotation, adhering to optimal planting dates, using mixed cropping methods, weed management, irrigation management, using tolerant and resistant varieties, and improving conditions for the activity of natural enemies are all integrated practices effective in controlling sesame pests (Egonyu *et al.*, 2005). Regarding fungal and viral diseases of sesame, which are transmitted mainly by seeds (Langham and Cochran, 2021),

seed disinfection with fungicides such as Vitavax-Thiram, obtaining seeds from reputable sources and using tolerant varieties are the most suitable methods for disease control.

In relation to weeds, a comprehensive management plan in sesame fields should affect the population dynamics of weeds in several stages of their life cycle, including 1) preventing the establishment of weeds by seeds, rhizomes, or bulbs, 2) reducing the adverse effects of emerged weeds on sesame growth and development, and 3) reducing weed seed bank in the soil (Tab. 2). The overall roadmap for weed management in sesame fields should be based on the principle that a combination of several agronomic, physical, biological, and chemical methods is necessary to minimise the presence of weeds in the field and maximise the impact on reducing weed growth and increasing sesame's competitive ability with them.

4.4 Improvement of breeding programs

One of the most important ways to achieve increased production per unit area and improved efficiency in sesame production is the use of improved sesame varieties with higher

quantitative and qualitative performance and compatibility with adverse production conditions such as water scarcity, heat, cold, salinity, low soil fertility, pests, and plant diseases. As mentioned earlier in the production constraints section, many farmers worldwide still rely on local sesame varieties for production. Despite some desirable traits of these genotypes, such as resistance to specific regional diseases or climate adaptation, undesirable agronomic traits of these genotypes, including slow initial growth, sensitivity to biotic and abiotic stresses, poor nutrient uptake, indeterminate growth habit, low harvest index, and uneven ripening, affect sesame production. Alongside these characteristics, severe sensitivity to seed shattering is common among local populations and domestic varieties in Iran and many other sesame-producing countries (Langham, 2011).

The performances of seed-shattering genotypes do not show the potential performance but the preserved seeds inside the capsules. Therefore, farmers are forced to harvest sesame plants prematurely to prevent up to a 50% loss in seed yield due to shattering (Neme *et al.*, 2020; Usman *et al.*, 2022), another factor contributing to yield reduction. Furthermore, this issue is a major barrier to mechanisation in sesame cultivation. Hence, improved sesame varieties with desirable agronomic traits, tolerance, or resistance to biotic and abiotic stresses, and, most importantly, resistance to seed shattering can improve performance and return on investment, enabling the expansion of sesame cultivation. In this regard, the role of gene banks and facilitating international exchanges of genetic materials is crucial in increasing genetic diversity in this crop. Unfortunately, wild sesame species in Iran and many other countries have not been thoroughly studied, and there is a need for international cooperation for germplasm exchange and related research. Introducing new varieties using the genetic diversity available in global collections is much better than inducing mutations in commercial varieties or selecting from existing local populations.

Moreover, improving and updating breeding methods is a practical step in introducing varieties in a shorter time frame. Introducing a new sesame variety in classical breeding programs takes over 10 to 12 yr. However, significant time and cost savings can be achieved by using modern breeding methods (Ahmar *et al.*, 2020). Additionally, the participation of other scientific institutions in developing and introducing new sesame varieties is essential. Besides governmental institutions, private companies in many leading countries also participate in the introduction of new cultivars.

A prominent example is Sesaco Corporation in the United States, which introduces sesame varieties resistant to seed shattering. Therefore, in Iran and other sesame-producing countries, in addition to governmental institutions, private companies should have a more substantial presence in introducing sesame varieties. Hence, the accurate identification of native populations and, if necessary, increasing genetic diversity using international genetic resources, followed by the introduction of improved sesame varieties with high yield potential, and ultimately the availability of seeds of introduced varieties to farmers are factors that, with improved performance and sustainability, can effectively contribute to the development of sesame cultivation.

4.5 Allocation of more economic financing

The agricultural sector in Iran and many other sesame-producing countries are predominantly engaged in traditional farming methods or transitioning from traditional to modern practices, and in most cases, the actors in this sector do not have significant income levels. Therefore, it is essential to allocate affordable and accessible government and non-governmental credits and facilities with sufficient repayment periods to encourage them to engage in productive activities and increase production efficiency. The allocation and distribution of low-cost credits for sesame producers in Iran, in addition to improving production through updating necessary equipment and tools, lead to increased income for farmers and improved living standards, preventing agricultural producers from migrating to cities and preventing the employment of active agricultural workforce in false urban jobs.

4.6 Maintaining and developing the market

Developing the market and production potential in key regions for oilseed production, including sesame in Iran, requires investment to address the shortage of necessary resources and facilities, which exceeds the capabilities of official institutions alone. Therefore, forming and engaging with NGOs (non-governmental organisations) established by producers is essential. Familiarising these organisations with planning, management, and marketing practices will enhance productivity and increase production. These NGOs can significantly contribute to facilitating communication between the market and farmers, implementing appropriate policies and government programs, participating in decision-making, ensuring farmers' access to resources and facilities, fostering a production culture, creating and managing small businesses, etc.

Another point is that in the sesame value chain, numerous commercial intermediaries (dealers) significantly reduce the profit margin of sesame-producing farmers. To overcome this market problem, sesame producers NGOs could facilitate the sale of products to wholesalers or even directly to end consumers at attractive prices. Additionally, these producer associations can sign contracts with certain domestic and foreign companies to access more profitable international markets. Furthermore, with financial support from private partners, sesame cooperatives can process sesame seeds from raw form into more profitable products, such as oil. This undoubtedly creates added value for sesame production for domestic and international markets, improves farmers' income, and generates employment. It is essential to note that associations and cooperatives have greater capacity and potential for production than individual farmers. On the other hand, the connection and trade with large purchasing units by sesame-consuming businesses are more accessible and practical with associations and cooperatives.

Another important factor in expanding the sesame market is increasing consumer awareness. Although there is consensus among scientific forums and researchers regarding the

desirable nutritional properties of sesame seeds and products, and in many cases, sesame is referred to as a medicinal plant, the public needs to become more informed about sesame's nutritional and therapeutic benefits. Sesame seeds and sesame oil have significant medicinal and therapeutic benefits for the entire body, especially the liver, kidneys, spleen, and digestive organs (Wei *et al.*, 2022). The high oil content of sesame seeds not only lubricates the intestines but also nourishes internal organs (Miraj and Kiani, 2016). Several studies have reported that natural lignans present in sesame seeds, such as sesamin and sesamol, have various medicinal effects, including anti-inflammatory, antioxidant, anti-cancer, blood pressure-regulating, blood sugar-regulating, auditory protective, and cholesterol-lowering properties (Wu *et al.*, 2019; Majdalawieh and Mansour, 2019). Increased awareness among the public about these diverse medicinal and therapeutic properties of sesame and increased consumption will lead to greater investment in pharmaceutical, food, and health industries, market growth, and ultimately increased sesame production.

4.7 More coherent and applicable research

As mentioned earlier, research on sesame faces challenges such as insufficient budget, researchers' lack of interest in studying this plant, and lack of collaboration between international research organisations. In recent years in Iran, agricultural research on sesame and its breeding improvements using government budgets has had some success, resulting in the introduction of several improved varieties such as Fakhra, Sardar, Shevin, and Mina, along with the provision of farm management guidelines. However, these introduced varieties usually experience yield reduction when they enter the field due to differences in agricultural management between research stations and farmers. Therefore, in the future, it may be appropriate for breeders to address this performance gap by selecting varieties from farmers' fields and providing methods to improve farm management. Another aspect is that the small size of the sesame genome, diploid and low number of continuous genes (Wang *et al.*, 2022) makes this plant suitable for studying disease resistance and oil biosynthesis, and research in this area could also be beneficial for other oilseeds.

Furthermore, genes related to non-shattering capsules and determinate growth are essential traits of mechanised sesame farming and should be prioritised in research agendas (Miao *et al.*, 2021). Despite a few studies, such as that of Ghasemi Hamedani *et al.* (2022), the root system architecture of sesame has not been evaluated. However, the unique feature of sesame for tolerating adverse environmental conditions lies in its root characteristics. Therefore, it is necessary to investigate the root structure of sesame to determine the desirable root type for each climatic condition. Additionally, evaluations should be conducted under field conditions and long-term to better understand genotype tolerance to stresses and their overlapping mechanisms.

Over time, the marginalisation of sesame cultivation has led to the erosion of genetic diversity in sesame populations in Iran. Therefore, it is necessary to increase genetic diversity in sesame using classical breeding and genetic engineering methods. Some studies on miRNA in sesame have been

conducted (Zhang *et al.*, 2021), and the scope of its application needs to be expanded. Breeding programs should also include improving the quality of sesame seeds in terms of producing valuable compounds such as sesamin, sesamol, and tocopherol. Thus, understanding the production cycles of these compounds in plant cells is essential. Ultimately, research programs on sesame in Iran and other producing countries should lead to technology development that introduces sesame as a sustainable, income-generating, and high-yielding crop.

5 Conclusion

Although sesame production in Iran has increased over the past two decades, according to statistics, Iran lacks a significant position in the global market. It relies on imports to meet nearly two-thirds of its domestic demand. Despite sesame cultivation being prevalent in the country since ancient times, Iran can be considered one of the homelands of the sesame plant. Various agricultural, economic, and social factors have hindered the increase in sesame production in Iran, as highlighted in this study. Among the most important issues are poor agronomic management, soil fertility decline, pest, disease and weed problems, limited breeding programs, lack of financial support, uncertain sesame markets and insufficient effective research.

Despite these challenges, sesame cultivation in Iran continues. By adopting innovative agronomic management methods, effectively disseminating research findings to farms, implementing proper production cycles, introducing and supplying superior varieties to farmers, increasing financial support from governmental and non-governmental sectors, and conducting practical research, the future of this valuable crop can be more promising than ever. In other words, more significant interaction among stakeholders in sesame production in the country, including farmers as production pioneers, researchers and promoters as production arms, policymakers as supporters, and even consumers, can lead to further blossoming of sesame production in Iran. It is important to note that based on every agricultural, economic, and environmental criterion, sesame has advantages and potentials that can transform it into a significant crop in the agricultural pattern of Iran and countries with similar conditions.

Conflicts of interest

The authors declare that they have no conflicts of interest in this article.

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