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# Moroccan sesame: Current situation, challenges, and recommended actions for its development☆

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**Abstract –** Sesame (*Sesamum indicum* L.) is one of the most recommended oil crops due to its nutritional and medicinal properties. It is a tropical and subtropical plant; however, it is also cultivated in arid and semi-arid regions, including Morocco. Nevertheless, the sesame crop in this country faces many constraints and challenges that restrict its production potential. The objective of this study is to present the situation of sesame production in Morocco during the last twenty years by describing and discussing the seed production, the harvested area, the value of imports, and the most important challenges. Also, some relevant strategies and measures to counteract these constraints and, thus, improve sesame production have been proposed and discussed. To make a fair diagnosis, a survey was carried out among 33 sesame producers in the Tadla area, in addition to the national and international databases that were consulted. The results showed that sesame area and production dropped markedly between 2000 and 2020. As a result, the import quantities and values have been significantly and gradually increased during the same period. The observed decline in both the area and the production may be due to several constraints including recurrent drought, restricted supply in irrigation water, poor cultural practices, low-yielding cultivars, and pests and diseases. Therefore, there is an urgent need for scientific research in terms of breeding to develop and release high-performing and adapted varieties and crop management to find and adopt the best cultural practices. Besides, sesame producers should organize themselves in associations or cooperatives to ensure an added value of their production and improve their profit margin and income. All these actions and measures would be able to promote and develop the sesame sector in Morocco to meet and satisfy the high domestic and global demand for this precious and valuable seed.

**Keywords:** moroccan sesame / challenges / sesame marketing / poor crop management / low-yielding varieties / sesame importation

**Résumé – Sésame marocain : situation actuelle, défis et actions préconisées pour son développement.** Le sésame (*Sesamum indicum* L.) est l'une des cultures oléagineuses les plus recommandées en raison de ses propriétés nutritionnelles et médicinales. C'est une plante tropicale et subtropicale, mais elle est également cultivée dans les régions arides et semi-arides dont le Maroc. Néanmoins, la culture du sésame dans ce pays fait face à de nombreuses contraintes et défis qui limitent son potentiel de production. L'objectif de cette étude est de présenter la situation de la production du sésame au Maroc au cours des vingt dernières années en décrivant et en discutant la production des graines, la superficie récoltée, la valeur des importations et les défis les plus marquants. En outre, certaines stratégies et mesures pertinentes pour surmonter ces contraintes et donc améliorer la production du sésame ont été

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proposées et discutées. Pour établir un diagnostic juste, une enquête a été réalisée auprès de 33 producteurs de sésame de la zone du Tadla, en plus des bases de données nationales et internationales consultées. Les résultats ont montré que la superficie et la production du sésame ont nettement chuté entre 2000 et 2020. Par conséquent, les quantités et les valeurs des importations ont augmenté de manière significative et progressive au cours de la même période. La baisse observée à la fois de la superficie et de la production peut être due à plusieurs contraintes, notamment la sécheresse récurrente, l'approvisionnement limité en eau d'irrigation, les mauvaises pratiques culturales, les cultivars à faible rendement et les ravageurs et maladies. Il y a donc un besoin urgent de recherche scientifique en matière de sélection pour développer et diffuser des variétés performantes et adaptées, et de conduite culturale pour trouver et adopter les pratiques appropriées. Par ailleurs, les producteurs de sésame devraient s'organiser en associations ou coopératives pour assurer une valeur ajoutée de leur production et améliorer leur marge bénéficiaire et leur revenu. Toutes ces actions et mesures seraient à même de promouvoir et de développer la filière sésame au Maroc pour répondre et satisfaire la forte demande nationale et mondiale pour cette bonne et précieuse graine.

**Mots clés :** sésame marocain / défis / commercialisation du sésame / mauvaise conduite culturale / variétés à faible rendement / importation de sésame

## 1 Introduction

Sesame (*Sesamum indicum* L.) belongs to the Pedaliaceae family and is known under various names such as til, gingelly, sim-sim, gergelim, etc. Sesame is one of the oldest aromatic, medicinal, and oilseed crops in the world and is native to tropical and subtropical regions (Kavak and Boydak, 2006). Due to its increasing export value, its production area has expanded to arid and semi-arid regions in Africa, Asia and South America (Anilakumar *et al.*, 2010; Weldemichael *et al.*, 2021).

Among the most nutritious oilseeds, sesame occupies a prominent place (Ashri, 1998). Sesame seeds are rich in oil (50–62%), with high content of unsaturated essential fatty acids and low content of saturated fatty acids, protein (18–25%), carbohydrates (13.4–25.0%) and digestible fiber (9.8%; Wei *et al.*, 2015; Couch *et al.*, 2017). Sesame seeds are also rich in vitamins, namely vitamin E, vitamin C, vitamin A, thiamine (B1), riboflavin (B2), niacin (B3), pyridoxine (B6) and folate (B9), minerals (calcium, potassium, pantothenic acid, phosphorus, iron, magnesium, zinc), lignans (sesamolin and sesamin) and tocopherols (Ünal and Yalçın, 2008; Hassan, 2012; Couch *et al.*, 2017; Gharby *et al.*, 2017). These functional components confer numerous applications for nutritional, pharmacological and industrial purposes (Anilakumar *et al.*, 2010; Tripathy *et al.*, 2019). Sesame seeds have preventive effects against several diseases such as osteoporosis (Onsaard, 2012), liver diseases (Anilakumar *et al.*, 2010; Azab, 2014), intestinal diseases (Ogunsola and Fasola, 2014), cardiovascular diseases (Khosravi-Boroujeni *et al.*, 2017; Aslam *et al.*, 2018; Nakamura *et al.*, 2020) and also activities against cancer of the lung (Fang *et al.*, 2019), breast (Zeweil *et al.*, 2019), prostate (Alfuraydi *et al.*, 2019), colon (Shasmitha, 2015), liver (Azab, 2014), cervical (Siao *et al.*, 2015), blood and skin cancer (Wu *et al.*, 2019). Sesame seed oil also has valuable applications in industries. It is used in the manufacture of cosmetic products (Barel *et al.*, 2014; Weldemichael and Juhar, 2018), soaps (Warra *et al.*, 2016; Sharma *et al.*, 2017; Hassan and Wawata, 2019), biodiesels (Mujtaba *et al.*, 2020; Nematian *et al.*, 2021; Lee *et al.*, 2022), biopesticides (Vasanthi and Rajavel, 2021), and varnishes (Adebisi and Ajala, 2011). Additionally, sesame seeds have a very rich flavor profile with over 200 volatile compounds that can be used as food additives (Jia *et al.*, 2019; Yin *et al.*, 2019).

Besides, phytochemical composition of sesame seeds is correlated with the seed coat color which varies from white to black through intermediate colors (Hang *et al.*, 2013). In general, white sesame seeds are intended for food, oil production and to improve the nutritional quality of foodstuffs, however, black seeds are preferred for medicine practices (Hang *et al.*, 2013; Hussain *et al.*, 2018; Karshenas *et al.*, 2018). On the other hand, a correlation between seed coat color with seed germination and seed weight in sesame was reported. Black seeds have high germination percentage and seedling vigor, while white seeds have high seed weight (de Paula Queiroga *et al.*, 2011).

As a result, the global demand and trade of sesame seeds have increased rapidly over the past two decades (Dossa *et al.*, 2017). Although the global sesame cultivation area is expanding, especially in Africa, productivity and yield are still very low, resulting in a huge gap between seed supply and demand (Sarkar *et al.*, 2016). Sesame is grown in harsh environments and its growth and development are greatly affected by adverse conditions (Witcombe *et al.*, 2008). Drought, waterlogging, heat, and salt are the main abiotic factors that affect sesame yield and productivity (Dossa *et al.*, 2019). Therefore, improving its seed yield and quality is one of the main objectives of sesame breeding (Zhang *et al.*, 2013; Couch *et al.*, 2017).

Sesame is a minor oilseed crop in Morocco, mainly cultivated in the Tadla area (Beni Mellal-Khenifra region) as a medicinal and aromatic plant. This area accounts for more than 90% of the national sesame production. The overall area has never exceeded 2000 ha; however, in 2020, it was limited to 849 ha providing a production of about 700 t (ORMVA-Tadla, 2021). Despite its low productivity, sesame generates a turnover of 28 million dirhams (about three million dollar, US$) and provides 70 000 workdays, which contributes greatly to the socio-economic development of the local population (AgriMaroc.ma, 2019). To meet its needs in sesame seeds, Morocco was obliged to import more than 89 587 t between 2000 and 2020 (Office des Changes, 2022). In 2020, the quantity imported cost the Moroccan State a budget that exceeds 23 000 000 US$ (Office des Changes, 2022).

In this context, the Green Morocco Plan strategy 2008–2020 (GMP2008-2020) aimed to overcome these problems by improving the socio-economic development of small farmers (Badraoui, 2014). The GMP had pointed, for 2020, a 200% increase in sesame cultivation area along with a 400% increase in seed production. Nevertheless, during the 2009–2020 period, sesame seed production decreased by 55%, from 1500 t to 663 t, and the harvested area dropped by 43%, from 1500 ha to 849 ha (FAOSTAT, 2022).

Sesame has been considered as a priority cash crop in the Tadla area by the GMP-Regional Agricultural Plan. However, its potential production has not been achieved due to several challenges that have affected its production and trade over the past decade. Therefore, the main objective of this review is to summarize trends in sesame production, quantity, and import value between 2000 and 2020 and provide an overview of challenges, opportunities, and ways of sesame development in Morocco. This work is intended to be an effective contribution to the diagnosis of the current situation of this sector and the prospective strategy to overcome the different challenges and improve production and other components of the sesame value chain in Morocco.

## 2 Methodology

To highlight the situation of sesame cultivation, a survey was conducted among 33 farmers in the area of Tadla, the most producing zone in Morocco, covering questions related to productivity and its components, technical management, and marketing. Thus, the variables studied were the harvested area, the sowing date, the sowing density, the origin of the seeds used, the fertilization, the control of weeds, diseases, and pests, the type and number of irrigations, the irrigation cost, the harvesting period, the drying, the post-harvest treatments, the seed yield and the selling price.

Other data such as quantities and values of sesame imports, productivity, harvested area, and soil conditions were obtained from national and international statistical databases, namely the Food and Agriculture Organization of the United Nations (FAOSTAT), the Office des Changes of Morocco (Office des Changes), the Office de Mise en Valeur Agricole du Tadla (ORMVAT) and the fertility map of cultivated soils in Morocco (Fertimap). We also performed a detailed literature review from credible sources to document scientific research on sesame in Morocco.

## 3 Sesame in Morocco: An overview

### 3.1 Presentation of the sesame production area

In Morocco, the sesame crop for seed production has been known for a long time and is one of the specific crops of the Beni Mellal-Khénifra region, found particularly in the Tadla area. This crop is grown as a catch crop with a relatively short cycle and represents an important source of income for local farmers. The Tadla plain is located at an average altitude of 400 m and covers around 259 600 ha of the useful agricultural area of which 49% is irrigated (ORMVA-Tadla, 2021; Fig. 1). The climate is arid to semi-arid with a dry season from April to October and a wet season from November to March. Annual rainfall is 300 mm and the average temperature is 18 °C, with a maximum in August (38 °C) and a minimum in January (3.5 °C; ORMVA-Tadla, 2021).

### 3.2 Morphological and biochemical characteristics of Moroccan sesame seeds

In recent years, attempts to characterize Moroccan sesame seeds have been made by some researchers. Rizki *et al.* (2015) reported that Moroccan sesame seeds are characterized by a spherical, flat, oval, or narrow oval shape. The seed coat color also varies from yellow to brown. The size of the seed is highly variable and the length, width, and thickness vary from 2.3, 1.3, and 0.71 mm to 3.2, 2, and 0.87 mm, respectively (Rizki *et al.*, 2015). According to the same authors, the Moroccan sesame is characterized by a relatively low 1000-seed weight, ranging from 2.72 g to 3.27 g. From a nutritional point of view, the Moroccan sesame seeds contain 45% to 55% oil, 22% to 28% protein, 3.5% crude fiber and 4.5% ash (Rizki *et al.*, 2015; El Harfi *et al.*, 2015; Gharby *et al.*, 2017). The oil is of good quality presenting physical and chemical properties suggested by the Codex Alimentarius Commission (Gharby *et al.*, 2017; Nabloussi *et al.*, 2017). Overall, Moroccan sesame oil may be potentially used for both human nutrition and industrial applications. Indeed, it is rich in unsaturated fatty acids such as linoleic acid (46.9%) and oleic acid (37.4%), while palmitic acid is the main saturated fatty acid (9.1%). δ-tocopherol is the main component presenting 90.5% of total tocopherols, followed by d-tocopherol (7.3%) and α-tocopherol (2.2%) (Gharby *et al.*, 2017). Among the different phytosterols found in the Moroccan sesame seed oil, β-sitosterol was the most abundant (60%) followed by campesterol (17.8%), D5-avenasterol (7.5%), stigmasterol (6.4%), D7-stigmasterol (0.3%), cholesterol (0.2%), and D7-avenasterol (0.1%; Gharby *et al.*, 2017). Chlorophyll and carotenoids are important quality parameters as they are correlated with color, which is a basic attribute to assess oil quality. The Moroccan sesame oil has also a notable amount in carotenoids (0.59–3.34 mg/kg oil), chlorophylls (0.53–7.57 mg/kg oil), and total phenolic content (61.30–72.63 mg GAE/kg oil; El Harfi *et al.*, 2015). Finally, due to their remarkable nutritional quality, Moroccan sesame seeds can be a subject of further biochemical analysis such as amino acids profile, allergic peptides and lignans profile.

### 3.3 Sesame productivity and harvested area in Morocco between 2000 and 2020

Over the world, sesame is grown on a global area of about 12.82 million hectares (ha) and Sudan, India, and Myanmar lead in terms of the harvested area, with 5 173 521, 1 520 000 and 1 500 000 ha, respectively (FAOSTAT, 2022; Tab. 1). Currently, Morocco has only 849 ha mainly found in the Tadla area accounting for over 90% of the national production, while the rest (10%) is ensured by Meknes and Safi, as shown in Figure 1 (ORMVAT, 2021). According to FAOSTAT (2022), more than 6.5 million tons (t) of sesame seeds were produced globally in 2020. The most producing countries are Sudan (1 525 104 t), Myanmar (740 000 t), the United Republic of Tanzania (710 000 t), and India (658 000 t; Tab. 1). Morocco ranks among the last producers in the world with 663 t in 2020, which makes it the 22nd largest producer of sesame seeds in Africa. However, in terms of seed yield, it ranks third after China (1.62 t/ha) and Nigeria (0.79 t/ha), with a mean value of 0.78 t/ha that is higher than the overall average yield recorded in the top 10 producers (0.65 t/ha).

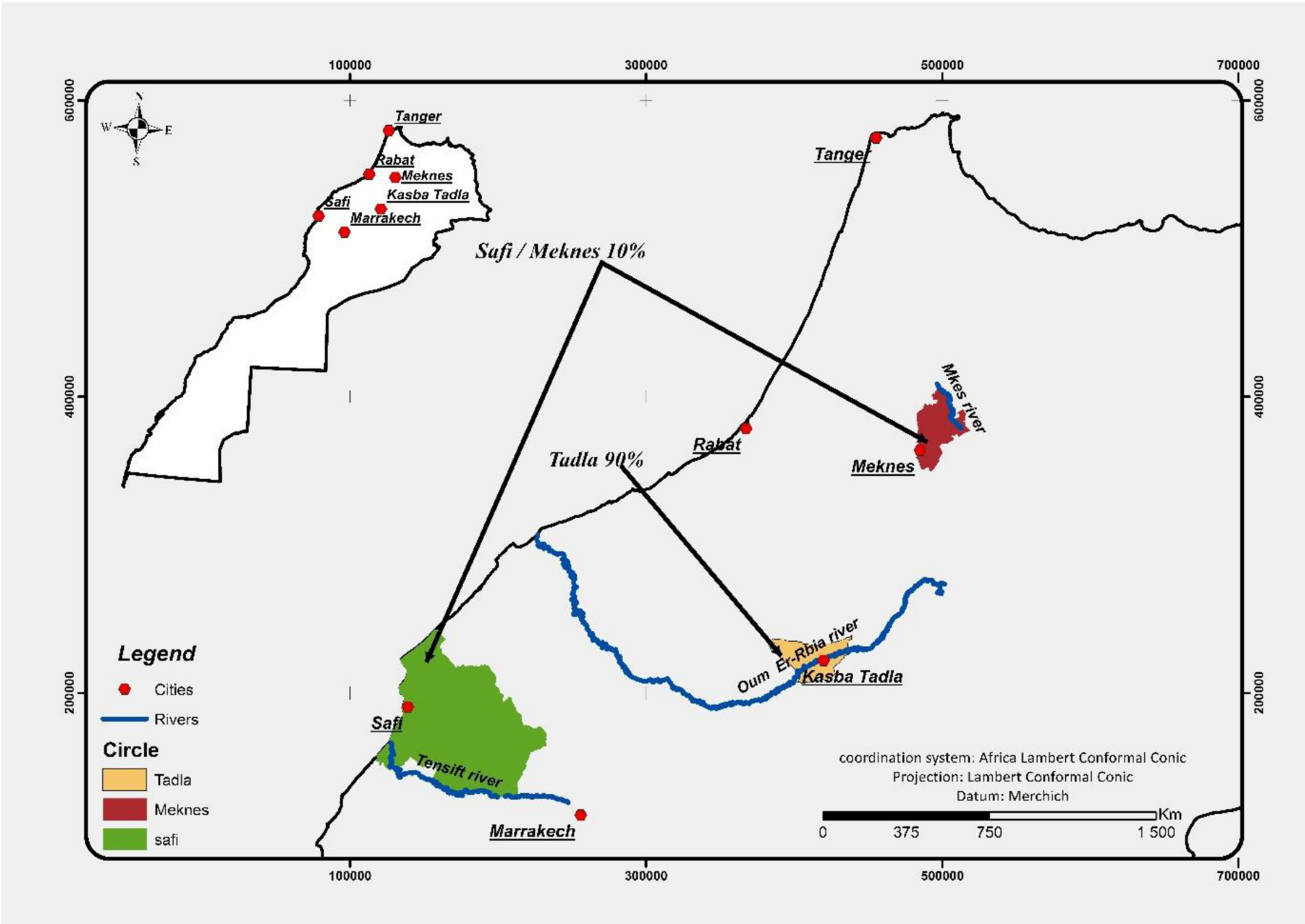


**Fig. 1.** Map of sesame production areas in Morocco. Tadla alone provides 90%, while Safi and Meknes together provide 10% of national production.

**Table 1.** Production, harvested area, and seed yield in the top 10 sesame producing countries along with Morocco (FAOSTAT, 2022).

| Country | Production (t) | Area (ha) | Harvested yield (t/ha) |
|---|---|---|---|
| **Sudan** | 1 525 104 | 5 173 521 | 0.29 |
| **Myanmar** | 740 000 | 1 500 000 | 0.49 |
| **United Republic of Tanzania** | 710 000 | 960 000 | 0.74 |
| **India** | 658 000 | 1 520 000 | 0.43 |
| **Nigeria** | 490 000 | 621 413 | 0.79 |
| **China, mainland** | 447 178 | 276 313 | 1.62 |
| **Burkina Faso** | 270 000 | 450 000 | 0.60 |
| **Ethiopia** | 260 258 | 369 897 | 0.70 |
| **Chad** | 202 074 | 392 241 | 0.52 |
| **South Sudan** | 189 721 | 608 159 | 0.31 |
| **Morocco** | 663 | 849 | 0.78 |

Overall, between 2000 and 2020, the production and harvested area of Moroccan sesame decreased from 1300 t to 663 t and from 2200 ha to 849 ha, respectively (FAOSTAT, 2022). The peak seed production was 2110 t in 2007, followed by 1610 t in 2012 (Fig. 2). This peak was linked to an important harvested area of 2512 ha (2007) and 1350 ha (2012) during these two rainy years with a good watering in 2007 (410 mm) and 212 (248 mm). On the other hand, there was a drastic drop during 2013 in terms of production (375 t) and harvested area (625 ha) that could be explained by the drought that affected Morocco in the 2013–2014 period. Overall, there have been ups and downs, with a concordance between the production and the harvested area. It is in this context that the GMP2008-2020 was launched by the Ministry of Agriculture

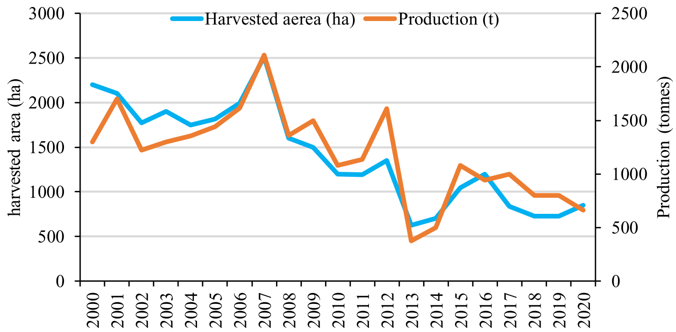


**Fig. 2.** Sesame harvested area (ha) and seed production (t) in Morocco during the 2000–2020 period (FAOSTAT, 2022).

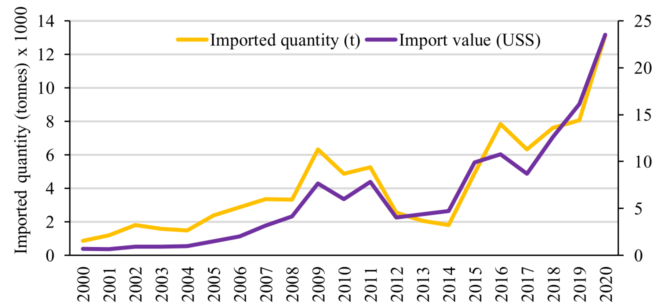


**Fig. 3.** Quantity (t) and value (US$) of sesame seed imports into Morocco between 2000 and 2020 (Office des Changes, 2022).

and Maritime Fisheries to increase the cultivated area and the production of sesame seeds from 1500 ha to 4000 ha and 1500 t to 6400 t, respectively. However, according to FAOSTAT data (2022), during the period 2009–2020, Morocco recorded a decrease in seed production by more than 50%, from 1500 t to 663 t, due to a 52% reduction in the harvested area, from 1500 ha to 849 ha. Thus, sesame cultivation in Morocco has failed to meet the GMP2008-2020 objectives and expectations, which requires a proper analysis to identify constraints and challenges and to design approaches and strategies to develop this sector.

### 3.4 Quantities and values of sesame seed imports during 2000–2020

Due to its nutritional, medicinal and industrial value, the demand for sesame seeds is increasing rapidly in the world and also in Morocco. Indeed, Moroccans consumed more than 14 000 t of sesame seeds in 2020, of which more than 90% are imported (Office des Changes, 2022). The production remains too low compared to the other oil crops. To meet its needs for sesame seeds, Morocco resorts to imports from Egypt (80%) and India (19%). The average quantity of sesame seeds imported in 2020 was over 13 138 t (Office des Changes, 2022). The quantity imported increased drastically between 2000 and 2020, from 864 t to 13 138 t (Fig. 3). Although the overall trend shows an increase in imports during the 2000–2020 period, one could observe a decrease in some years due either to better national production in those years or to competition on the global sesame market (Wacal *et al.*, 2021).

According to Exchange Office (2022), Morocco exceeded a budget of 218 279 839 MAD (Moroccan Dirham), equivalent to 23 519 000 US$, in 2020 for sesame seeds import. A huge increase (> 300%) in the value of sesame imports occurred between 2000 and 2020, from 6 301 663 to 218 279 839 MAD (679 000 to 23 519 000 US$; Fig. 3). Between 2000 and 2008, the imports value was much lower and did not exceed 38 346 199 MAD (4 132 000 US$). During the period 2012–2014, the value of imports was around 43 547 754.9 MAD (4 693 000 US$), which represents a decrease of 43% compared to 2009 (71 038 400 MAD / 7 655 000 US$). However, during the period 2014–2020, an enormous increase was recorded in the imports value, going from 43 547 754 to 218 279 839 MAD (4 693 000 to 23 519 000 US$), as a result of the massive imported quantity. Imports of sesame seeds are too expensive for the Moroccan treasury. Nevertheless, the strong national demand for sesame seeds is an opportunity for producers and traders to improve sesame production and marketing in Morocco.

## 4 Sesame challenges in Morocco

### 4.1 Climate change and drought

Sesame is a tropical and subtropical crop, but it is also grown in arid and semi-arid climatic conditions (Arslan *et al.*, 2018). Unlike other oilseed crops, sesame appears to be more drought tolerant (Islam *et al.*, 2016). However, in arid and semi-arid areas, drought often occurs in conjunction with heat or high temperatures, which significantly impairs sesame productivity (Hassanzadeh *et al.*, 2009). Adverse effects on seed yield and quality have been noticed when water stress occurs especially at germination and flowering stages (Hassanzadeh *et al.*, 2009; Boureima *et al.*, 2011; Komivi *et al.*, 2016; Dossa *et al.*, 2017; Kouighat *et al.*, 2021). In Morocco, drought has always been present as a structural element of the climate, with increasing frequency in recent decades, due to climate change (Zraibi *et al.*, 2011). Sesame is mainly grown in the Tadla region as a catch crop, planted between June and October. Therefore, this crop is fully irrigated to overcome the drought and high evaporation demand occurring during the entire life cycle of the plant. The results of our survey showed that 5 to 11 irrigations are applied throughout the crop cycle, with an average of 7 irrigations. These irrigations are provided by the water from the dam, the Seguias (channels made of reinforced concrete designed for irrigation) and the local water table. The gravity-type irrigation is the most used for sesame cultivation (97.2% of farmers). To reach out the irrigation water in the Tadla perimeter, farms pay on average 2.04 MAD/m$^3$ (0.3 US$/m$^3$) for groundwater, 1.36 MAD/m$^3$ (0.15 US$/m$^3$) for water from the dam and pumping and 1.09 MAD/m$^3$ (0.12 US$/m$^3$) for water from the dam only. Overall, sesame ranks fifth in terms of irrigation cost (1.31 MAD/m$^3$ = 0.20 US$/m$^3$), with low profitability for the farmer (4.24 MAD/ha = 0.5 US$/ha; El Harfi, 2016). However, the performance of the irrigation system remains very low to average due to high water losses, lack of irrigation uniformity, and high cost of the same, which results in low sesame yields. Furthermore, no study has been carried out to quantify the water requirements of sesame under Moroccan conditions. Therefore, further researches on the water requirements of the crop and the potential for drought tolerance in Moroccan sesame are needed.

### 4.2 Poor cultural practices

Poor cultural practices such as improper soil preparation, late sowing, and lack of control of pests and diseases could impair sesame production. In Morocco, sesame is a minor crop and is mainly grown in the Tadla region as a catch crop, planted just after the cereal harvest. This practice directly influences the sowing date because the cereal harvest cannot be done before May or June. Most farmers of the Tadla area (90%) are used to planting sesame from the end of Mai to the end of June. Indeed, sesame yield decreased with late planting (Mahdi *et al.*, 2007; Olowe, 2007), while early planting reduces borer infestation and increases sesame seed yield (Gebregergis *et al.*, 2018).

Low seed yields may also be due to less fertile soil. Sesame yield has been reported to decrease with depletion of soil nutrients by excessive cultivation (Wacal *et al.*, 2019). In the surveyed area, 42% of farmers apply phosphate-based underground fertilization in the form of DAP (diammonium phosphate, 18-46-0) at planting time. During the coverage, 86% of farmers apply 1–3 q/ha of nitrogen fertilizer in the form of ammonitrate or urea. In contrast, 11% of farmers did not apply any fertilizer during the entire crop cycle. This is due to the inability of small farmers to purchase fertilizer. According to the questionnaire, to fertilize one hectare, farmers need on average 400 to 600 MAD (45 to 67 US$). Because soils are of average to low fertility (Fertimap, 2021) and farmers do not add fertilizer every growing season, soil nutrients in Tadla are increasingly depleted. As a result, the soils are getting poorer and the seed yields are getting lower.

At the vegetative stage, Moroccan sesame undergoes minimal maintenance techniques. Weeding is rare and is done manually or by grazing for the majority of farmers ($>$ 67%). Worse yet, 20% of the farmers questioned do not carry out any intervention. To control pests, most farmers (83%) use one to five insecticide treatments during the crop cycle. However, the phytosanitary treatment is done after the appearance of attacks and infestation of the crop, which makes the control of pests more difficult and inefficient.

Sesame harvesting in Morocco is mostly done at the end of September (60%) or during October (40%). Harvesting and post-harvest treatments are done manually, which requires a lot of labor and therefore a high production cost. The average labor time needed is about 58 days/ha of which harvesting alone requires more than 68% of the total costs. The average labor cost per hectare is about 3700 MAD (417 US$). After harvesting, the majority of farmers (98%) in the investigated area sell their production in local markets (souks) directly without any prior storage due to the lack of financial means. This negatively affects the sale price ranging from 15 to 20 MAD/kg (1.7–2.25 US$) only.

### 4.3 Pests management

Like other species, sesame is susceptible to pests that are responsible for significant yield losses. Among the various factors reducing sesame productivity, pests generally cause very serious damage to the crop. Their physical damage may be limited on the foliage, but the impact on final yield is markedly high. Only pest attacks account for more than 50% of the sesame production loss, with a decline of about 25% of the average potential yield (Egonyu *et al.*, 2005; Karuppaiah, 2014; Mehalingam, 2015; Gebregergis *et al.*, 2016; Geremedhin and Azerefegne, 2020). The incidence of sesame pests depends on the sowing date and climatic conditions (Ahirwar *et al.*, 2010; Karuppaiah and Nadarajan, 2013; Gebregergis *et al.*, 2018). More than 65 species of insects and mites infest sesame including sesame worms (*Antigastra catalaunalis*), sesame seed bug (*Elasmolomus sordidus*), midge (*Asphondilia sesami*), green vegetable bug (*Nezara viridula*), African bollworm (*Helicoverpa armigera*), grasshoppers (*Locusta migratoria*), aphids (*Myzus persicae*), and whitefly (*Bemisia tabaci* Genn) which are the most damaging pests (Ahuja and Bakhetia, 1995; Biswas *et al.*, 2001; Egonyu *et al.*, 2005; Berhe *et al.*, 2008; Suliman *et al.*, 2013; Ogah and Nwilene, 2014; Ayana, 2015; Gebregergis *et al.*, 2018; Geremedhin and Azerefegne, 2020). Sesame is also infected by several fungal, bacterial and viral diseases. Among the most important pathogens are angular leaf spot (*Cercospora sesamicola*), white leaf spot (*Cercospora sesami*), wilt (*Fusarium* spp.) and Alternaria leaf spot (*Alternaria sesami*; Kolte, 1985; Cho and Choi, 1987; Jonsyn, 1988; Javed *et al.*, 1995; Ojiambo *et al.*, 1999). Sesame diseases cause a reduction in the growth, development, yield and quality of sesame seeds (El-Bramawy and Wahid, 2006; Wei *et al.*, 2018).

A preliminary work was carried out during 2010 in the Tadla area and showed that the Moroccan sesame cultivars are very sensitive to pest attacks, which can lead to a loss in seed yield of about 43% (INRA, 2010). In particular, *Rhizoctonia* spp. and *Macrophomina phaseoli* are the most important fungi in this Moroccan area (INRA, 2010). Unfortunately, there is a serious lack of studies on diseases and their damage to sesame in Morocco, which makes the task of crop improvement more difficult.

On the other hand, weeds can be more detrimental than crop pests as yield reducers (Gharde *et al.*, 2018). Sesame is susceptible to weed competition during early emergence due to its low initial growth (Mane *et al.*, 2017; Lins *et al.*, 2019). Too high yield losses (up to 75%) due to weed infestation have been reported in sesame (Bhadauria *et al.*, 2012; Terefe *et al.*, 2012; Mehdipour *et al.*, 2017; Zarghani *et al.*, 2017). In the irrigated perimeter of Tadla, about 25 spring and summer weed species were reported (INRA, 2010). Perennial monocotyledonous grassy weeds are represented mainly by *Sorghum halepense* (L.) Pers and *Cynodon dactylon* (L.) Pers. While, among the annual dicotyledonous, *Portulaca oleracea* (L.) and *Amaranthus retroflexus* (L.) are the most representative. To minimize damage and ensure better productivity, manual weeding and a wide range of herbicides are applied to the Moroccan sesame crop. However, there has been no thorough study on these crop enemies as well as the level of their damage under Moroccan conditions. This suggests the importance and relevance of launching appropriate studies to find out alternatives to chemical treatments like as development of resistant/tolerant varieties and improvement of technical management.

### 4.4 Low yielding cultivars

Low-yielding sesame cultivars could be one of the reasons behind the low production of this crop in Morocco. El Harfi *et al.* (2021) reported that traditional Moroccan sesame populations are characterized by wild traits such as long cycle, low seed retention and lack of resistance/tolerance to abiotic and biotic stress. In addition, these populations are genetically very close, characterized by a low genetic diversity (El Harfi *et al.*, 2021). Therefore, increasing sesame productivity can be achieved by, first, increasing the existing genetic variability and, then, developing high-yielding, drought-tolerant, pest and disease-resistant varieties adapted to Moroccan conditions.

### 4.6 Limited land allocated to sesame in subsistence farming

With the current climate change phenomena, arable land is expected to become more limited due to drought and desertification in the future. The problem is much more pronounced for oil crops in which a reduction of 10% in 2030 and 30% in 2050 in terms of the planted area has been predicted by Gomes *et al.* (2009). This situation is detrimental to small farmers and the sustainability of agricultural products. Sesame in Morocco is a subsistence crop that aims, at small-scale production, to directly satisfy family food. According to our survey findings, the majority of farmers (81%) reserve an area of no more than 3 ha for sesame cultivation. The analysis of survey data also showed that, for the entire sample, the mode of land ownership is direct and the legal status of the land is what is locally called "Melk". This gives rise to areas and plots fragmentation which continues to increase from one generation to another by inheritance. In addition, this causes social conflicts between heirs who end up abandoning or under-exploiting the land. This also explains how sesame production in Morocco is negatively affected.

### 4.7 Poorly established sesame market

Sesame seeds are known as a widely used food in Africa (Oktay and Sadıkoğlu, 2018). However, in Morocco, sesame consumption is still low and seasonal. This low consumption is due to the lack of population awareness of the sesame benefits, which weakens the sesame market at the national level. Besides, there are several intermediaries involved in the marketing operation, which reduces the profit margin for the small sesame producers. On the Moroccan market, the price of a kilogram of sesame seeds varied between 40 and 50 MAD (4.5 and 5.63 US$), while farmers sell it at a much lower price (< 2.2 US$/kg). The producer price index (PPI) measures the average change over time in sale products obtained by domestic producers, excluding any taxes, transportation, and marketing margins that the buyer may have to pay (Wen *et al.*, 2019). As a result, it is often considered a leading indicator of price trends for a product in the economy as a whole. According to FAOSTAT (2022), the PPI of sesame on the Moroccan market between 2009 and 2013 remained relatively high (114–117); however, beyond 2013, the PPI has undergone a drastic fall from 115 in 2009 to 91 in 2015 with a reduction around 21%. Between 2016 and 2019, the PPI increases and stabilizes by 100. This indicates that commercial intermediaries have proven to be the biggest winners in the sesame market in Morocco, which negatively affects the productivity and profitability of this crop for domestic producers. Overall, the average cost of sesame production in the Tadla zone is 6175 MAD/ha (696 US$/ha). Harvest and post-harvest operations represent 45% of the total cost, followed by irrigation (15%), tillage and fertilization (8% each). Considering the average cost of production and the average selling price, the overall rate of profitability is about 44.90%. On the other hand, almost all the farmers in the region surveyed (98%) do not store sesame seeds. This may be due to the lack of financial liquidity to create storage units and marketing centers. Furthermore, the absence of cooperatives and farmers' societies aimed at adding value to sesame products pushes small farmers to sell their harvested sesame seeds at very low prices.

### 4.8 Limited research

Globally, sesame cultivation is considered orphaned with less support from science, industry, and policy (Dossa *et al.*, 2017). Despite its importance, sesame has been the subject of very little research in Morocco. Indeed, most of the studies that have been carried out so far on Moroccan sesame have targeted agromorphological, biochemical and genetic characterization (Rizki *et al.*, 2014, 2015, 2019; El Harfi *et al.*, 2015, 2016, 2018, 2021; Souguir *et al.*, 2016; Terouzi *et al.*, 2016; Gharby *et al.*, 2017; Nabloussi *et al.*, 2017). More recently, new research works on sesame germplasm enhancement and breeding have been launched.

The major obstacle to genetic improvement is the lack of pre-existing genetic diversity in the germplasm to be improved. Although the sesame was cultivated in Morocco for a very long time, the local populations are characterized by a limited genetic diversity (El Harfi *et al.*, 2018, 2021) making genetic improvement of this crop more difficult. Therefore, to expand the existing genetic variability, new genetic materials should be introduced from different geographical origins or developed through biotechnology techniques. Recently, novel genetic variability has been induced *via* chemical mutagenesis (ethyl methanesulfonate, EMS) in the Moroccan germplasm (Kouighat *et al.*, 2020). This could open up new opportunities for scientific research on sesame in Morocco.

## 5 Strategies for overcoming challenges

### 5.1 Improvement of the farmers' knowledge and technical management

Sesame cultivation is exposed to many constraints including the most important related to inappropriate cultivation techniques, namely soil fertilization, irrigation, sowing date, planting density and crop pests (Caliskan *et al.*, 2004; Ojikpong *et al.*, 2007; Sharaby and Butovchenko, 2019). The objective of this section is to propose appropriate crop management for successful sesame cultivation. Unfortunately, according to the national literature, there are a few studies on the effects of agronomic practices on the productivity in Moroccan sesame. A study carried out by INRA (Institut National de la Recherche Agronomique) showed that early and mechanical sowing, low planting density, and localized irrigation increased the seed yield (INRA, 2010). Also, water use efficiency reached 2.87 kg/m$^3$ through drip irrigation, against 1.75 kg/m$^3$ for gravity irrigation.

Planting density and fertilization should be known for practical purposes, as they are major management variables to improve crop yield (Smith and Hamel, 2012). The competition between plants becomes more intense when plant density is high, which affects plant growth, development, and production. For efficient canopy development, water use, nutrients, pest control, and row planting of sesame are recommended (Çalıskan, 2004). Growing sesame in well-spaced rows leads to an increase in the number of capsules/plant and the number of seeds/capsules, seed weight and oil content (Olowe and Busari, 2003; Roy *et al.*, 2009). However, narrow row cultivation has also been reported to increase seed yield and reduce weed density due to faster canopy closure (Harder *et al.*, 2007; Saitoh *et al.*, 2007; Matsuo *et al.*, 2018). In contrast to popular dissemination methods used by smallholder farmers that typically result in narrow or widely spaced planting, it is quite clear that proper plant spacing could increase sesame yield. Unfortunately, this is not well respected by farmers, which considerably reduces sesame yield. Therefore, optimization of plant density and row spacing is very important to improve sesame seed yield and quality in Moroccan environments.

Adequate nutrient supply is also one of the most important agronomic practices to improve crop productivity. The supply of mineral fertilizers such as N, P, and K has positive effects on the productivity and quality of sesame seeds (Sohi *et al.*, 2010; Haruna, 2011). Also, the type and quantity of inputs should be applied reasonably and according to the needs of the crop (Haruna, 2011; Mian *et al.*, 2011; Buriro *et al.*, 2015). The timing and method of application of inorganic fertilizers should also be followed. Fertilizers P and K are applicable in full doses at sowing, while the first dose of N is applied at sowing and the second dose at the beginning of flowering (Mian *et al.*, 2011; Buriro *et al.*, 2015; Gebrelibanos, 2015). It is worth reminding that fertilizer application should coincide with sufficient soil moisture to guarantee fertilizer availability to the plant (Wacal *et al.*, 2019).

As mentioned above, it is well known that sesame crop has very little competition with weeds due to its delayed germination and low early growth rate. Under irrigated conditions, it suffers heavily from weeds during the initial stages limiting, thus, its yield (Bennett and Condé, 2003). There are several techniques to minimize weeds such as adopting seeding rate (Islam *et al.*, 2014), tillage (Theisen and Bastiaans, 2015; Zimdahl, 2018), fertilizer application (Bajwa *et al.*, 2014), direct seeding (Santín-Montanyá *et al.*, 2016), herbicide use (Haggblade and Tembo, 2003; Gianessi, 2009), and biological control (Jamil *et al.*, 2009; Cheema *et al.*, 2013). Hoeing, as close to the crop rows as possible, is also recommended (Ahmed *et al.*, 2009; Amare, 2011; Islam *et al.*, 2014). In addition, a good combination of pre-and post-emergence herbicides could be used to control weeds in sesame and achieve seed yield comparable to weed-free conditions (Vafaei *et al.*, 2013). Cultural practices, mainly herbicides and mechanical/manual weeding, are often effective in improving crop competition to avoid sesame yield losses (Khaliq *et al.*, 2012). However, these traditional methods of weeds control (herbicides and manual weeding) are costly and threaten the environment. In addition to eco-degradation and their health risks, herbicides accelerate herbicide resistance in weeds (Bajwa *et al.*, 2015). Finding an appropriate mix of weed control strategies is essential to encourage smallholder farmers to adopt and maintain conservation agriculture practices (Lee and Thierfelder, 2017). Nevertheless, it is preferable to use certified seeds with high germination power to reduce weed pressure on the crop (Ijlal *et al.*, 2011).

Sesame crop is also susceptible to several diseases and pests, thus, limiting its productivity and quality. Pests and diseases could be controlled through the adoption of good agronomic practices such as intercropping (Egonyu *et al.*, 2005), crop rotation (Munyua, 2013), and chemical control (Egonyu *et al.*, 2005). However, these techniques are ineffective for sustainable cultivation. On the other hand, using tolerant/resistant varieties would be an effective and sustainable strategy to control diseases and pests. Also, limiting the use of chemical pesticides as much as possible and replacing them with organic pesticides is strongly recommended. In fact, many studies found that biopesticides were effective against leaf moth, boll borer, stink bug, corn borer, leafhopper and sesame bud fly (Jyoti and Basavana, 2008; Sundria, 2009; Sabry and El-Sayed, 2011; Lalitha *et al.*, 2012; Sasikumar and Kumar, 2014; Thirumalaisamy and Nataraja, 2015; Basappa and Duraimurugan, 2018). Biofungicides have also been shown to be more effective in inhibiting mycelial growth and reducing sesame seedling mortality (Tandel *et al.*, 2010; Bharathi *et al.*, 2013; Savaliya *et al.*, 2015).

Irrigation optimization is a very important crop management practice that reduces both energy and water losses and maintains high yields. Water needs differ among genotypes and abiotic conditions (Sepaskhah and Andam, 2001). Indeed, four irrigations per cycle are applied in Pakistan (Nadeem *et al.*, 2015), five in Egypt (Tantawy *et al.*, 2007) and Iran (Hassanzadeh *et al.*, 2009), six in Thailand (Detphirattanamongkhon, 2002), and seven irrigations in Turkey (Karaaslan *et al.*, 2007). These examples highlight the importance of irrigation management in sesame cultivation for each region, as plant water consumption is mainly dependent on growth stage, soil and climatic conditions (Uçan, 2010). Therefore, it is essential to develop the most appropriate irrigation schedule for each region to produce optimal sesame yields (Uçan *et al.*, 2007).

### 5.2 Improvement of the existing genetic material

All over the world, agricultural production is facing both increasing demands for food and climate change (Hickey *et al.*, 2019). To be more competitive, like other oilseed crops, sesame needs more scientific researches (Sebillotte *et al.*, 2004). The low competitiveness of sesame is generally related to wild traits. Lack of rapidly adaptable cultivars, capsule dehiscence, irregular maturity, weak responses to fertilizer, high branching, low harvest index, indeterminate growth, and disease susceptibility are the limiting factors of sesame production worldwide (Tripathy *et al.*, 2019). Capsule dehiscence is the major problem responsible for high seed losses (up to 50%) at sesame harvest (Purseglove, 1972). As a result, mechanized harvesting is impossible and commercial production will be limited due to costly labor (Langham and Wiemers, 2002). On the other hand, even though sesame is known as a drought-tolerant crop, it is susceptible during germination and flowering (Hassanzadeh *et al.*, 2009; Boureima *et al.*, 2011; Komivi *et al.*, 2016; Dossa *et al.*, 2017; Kouighat *et al.*, 2021). Sesame cultivars grown in Morocco have wild traits including capsule dehiscence, long plant cycle, and sensitivity to biotic and abiotic stresses (El Harfi *et al.*, 2021). Therefore, genetic improvement of this crop, through an effective breeding program, is imperative to address various socio-economic and agro-economic challenges in the current climate change context (Takeda and Matsuoka, 2008; Newton *et al.*, 2011). Conventional breeding in Moroccan sesame may not be successful due to the limited existing genetic diversity (El Harfi *et al.*, 2021). In such a situation, other techniques such as mutagenesis and genetic engineering are adopted as alternatives to overcome the shortcomings of conventional breeding, and various innovative approaches are being applied to sesame breeding (Shashidhara *et al.*, 2011; Chowdhury *et al.*, 2017; Zimik and Arumugam, 2017; Debnath *et al.*, 2018; Asad, 2019). Mutagenesis is one of the main sources of induced genetic variation in all plants, including sesame, which contributes to modern plant breeding (Jayaramachandran *et al.*, 2020). In the last five decades, it has played a major role worldwide in the development of superior plant varieties with characteristic and specific benefits (Kharkwal and Shu, 2009). In this context, mutagenesis work on sesame in Morocco has been undertaken and resulted in interesting mutant lines (Kouighat *et al.*, 2020).

### 5.3 Need for more researches on sesame crop

Limited research on sesame has been highlighted by low yield in most growing areas, which has hindered its adoption and expansion worldwide (Dossa *et al.*, 2017). To maximize the production potential in sesame, farmers should combine good crop management with high-performing sesame varieties. However, there are a few studies on sesame cultivation practices in Morocco, including mechanization, irrigation, fertilization, harvest, and pest and disease control (INRA, 2010; El Harfi, 2016). Regarding breeding and varietal selection, some studies focused on phenotypic, genotypic, and biochemical characterization of the existing cultivars have been carried out (Rizki *et al.*, 2014, 2015; El Harfi *et al.*, 2016, 2018, 2021; Gharby *et al.*, 2017; Nabloussi *et al.*, 2017). Both the phenotypic and genotypic characterization showed there was a very limited genetic variability among the Moroccan sesame cultivars (El Harfi *et al.*, 2018, 2021). Therefore, a mutagenesis-breeding program has been launched recently to expand the existing genetic variability and obtain novel germplasm to be used for developing high-performing varieties (Kouighat *et al.*, 2020). As a result, several interesting mutant lines were isolated and, currently, they are being characterized and evaluated for their agronomic performance, tolerance to water stress, and their seed and oil quality. Finally, more research works, mainly related to crop management, are still needed to reach the production potential of Moroccan sesame.

### 5.4 Expansion of the area dedicated to sesame cultivation

As indicated before, the irrigated perimeter of Tadla ensures more than 90% of the domestic production while the rest (10%) is produced in Meknes and Safi. In addition to seed yield improvement, the production may be strengthened by increasing the cultivation area. In Morocco, many other regions than those aforementioned are suitable for sesame crop, in particular those located in some irrigated perimeters like as Souss-Massa, Haouz, Doukkala, Chaouia and Moulouya. To reduce the imports of sesame seeds and satisfy the increasing consumption needs, it is necessary to design and implement a plan of expansion of sesame area in the country. This may be done as a main component of a program-contract to be agreed between the Government and the Interprofession to upgrade and develop the sesame sector.

### 5.5 Improvement of Moroccan sesame value chain and marketing

In the sesame value chain, there are several trade intermediaries, which significantly reduces the profit margin of sesame-producing farmers. To overcome this handicap, farmers should organize themselves into associations or cooperatives that would facilitate the sale of their production to wholesalers or even directly to end-consumers at attractive prices. Also, these sesame producers' organizations could sign agreements with some domestic and foreign companies to get stronger and more profitable markets. Furthermore, with financial support from private and governmental partners, sesame cooperatives may engage themselves in processing sesame seeds from raw form into other more profitable products (oil for example). This will, certainly, provide an added value to sesame production for both the national and international markets, improve the farmers' income, and create more jobs. It is needless to remind that agricultural cooperatives in Morocco have played, during the recent decades, an essential role in the partial achievement of some social, economic, and environmental development objectives.

## 6 Conclusions

Sesame seed production in Morocco has decreased drastically between 2000 and 2020, due to an exorbitant decline in the sown area, which has led to an important increase in the quantity imported of sesame seeds. One could observe there is a downward trend in sesame production, although the Moroccan government has aimed to increase it in the frame of the Green Morocco Plan (2008–2020). Several constraints such as drought, low-yielding cultivars, pests and diseases, declining harvested area, and poor cultivation practices might be behind this harmful situation. Particularly, the decline observed in the sesame-sown area may be explained by the restrictions and shortages in irrigation water supply from dams. However, sesame seed production could be improved by increasing seed yield *via* the use of more productive and drought-tolerant varieties and the adoption of appropriate crop management. Upstream, the ongoing studies and works on breeding and crop management improvement should be stepped up. Downstream, sesame-producing farmers should organize themselves in associations or cooperatives to ensure an added value of their production and improve their profit margin and income. Even though sesame is a minor crop in Morocco, it has some advantages and potentialities that can make it an important industrial crop to include in and diversify the cropping system.

## Conflict of interest

The authors declare that they have no conflicts of interest with regard to this article.

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