

Status of various sources of edible oil and prospects of oil palm cultivation in Pakistan[☆]

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Received 7 March 2025 – Accepted 19 August 2025

Abstract – Oilseeds are essential for food nutrition, cooking, and industrial uses like lubricants, paint, and soap. Pakistan requires about 4 million metric tons of edible oil annually, but only 0.5 million tons are produced indigenously. Cotton, rapeseed, mustard, and sunflower contribute to the oil supply, but additional sources like olive and rice bran could provide a further 0.25 million tons. Local crops have not met the food industry's needs, and the demand grows by 7% annually. Sesame has emerged as a new income source, yet self-sufficiency remains distant due to rising consumption outpacing production. The country is in high need of the olive and rice bran oil industry. Oil palm cultivation has been suggested for Pakistan's coastal regions, where up to 0.5 million hectares could be used. However, low precipitation, humidity, and heat stress during peak months hinder its growth. Early attempts to establish oil palm plantations showed promise, but the lack of an oil extraction industry led to failure. With rising palm oil demand, mostly imported from Indonesia and Malaysia, reviving domestic palm oil production is crucial. Palm oil environmental sensitivity limits its adaptation to local conditions. There is a need for international collaboration to introduce oil palm germplasm from various regions of the world, evaluate the germplasm that may better acclimate to the local conditions, and mass multiplication of the adapted genotypes for cultivation in the potential areas of Pakistan. Genetic improvement through traditional breeding methods supported by molecular tools could improve resilience and optimize oil production, making large-scale palm cultivation viable in Pakistan.

Keywords: Biotechnology / environmental adaptability / genetic modification / oil crop expansion / sustainable agriculture

Résumé – Statut des différentes sources d'huile comestible et perspectives de la culture du palmier à huile au Pakistan. Les oléagineux sont essentiels pour l'alimentation, la cuisine et les usages industriels tels que les lubrifiants, la peinture et le savon. Le Pakistan a besoin d'environ 4 millions de tonnes métriques d'huile comestible par an, mais seulement 0,5 million de tonnes sont produites localement. Le coton, le colza, la moutarde et le tournesol contribuent à l'approvisionnement en huile, mais des sources supplémentaires comme l'olive et le son de riz pourraient fournir 0,25 million de tonnes supplémentaires. Les cultures locales n'ont pas répondu aux besoins de l'industrie alimentaire, et la demande augmente de 7% par an. Le sésame est apparu comme une nouvelle source de revenus, mais le pays reste loin de l'autosuffisance en raison d'une hausse de la consommation qui dépasse la production. Le pays a un besoin urgent de développer les industries de l'huile d'olive et de son de riz. La culture du palmier à huile a été proposée pour les régions côtières du Pakistan, où jusqu'à 0,5 million d'hectares pourraient être utilisés. Cependant, les faibles précipitations, l'humidité et le stress thermique pendant les mois de pointe entravent sa croissance. Les premières tentatives pour établir des plantations de palmiers à huile ont tenu leurs promesses, mais l'absence d'industrie d'extraction d'huile a conduit à l'échec. Avec l'augmentation de la demande en huile de palme, principalement importée d'Indonésie et de Malaisie, la relance de la production nationale d'huile de palme est cruciale. La sensibilité environnementale de l'huile de palme limite son adaptation aux conditions locales. Il est nécessaire de collaborer au niveau international pour introduire du germoplasme de palmier à huile de différentes régions du monde, évaluer les ressources génétiques

[☆] Contribution to the Topical Issue: "Palm and palm oil / Palmier et huile de palme".

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susceptibles de mieux s'acclimater aux conditions locales, et multiplier massivement les génotypes adaptés pour la culture dans les zones potentielles du Pakistan. L'amélioration génétique par des méthodes traditionnelles d'élevage, soutenues par des outils moléculaires, pourrait améliorer la résilience et optimiser la production d'huile, rendant la culture à grande échelle du palmier à huile viable au Pakistan.

Mots-clés : Biotechnologie / adaptabilité environnementale / modification génétique / expansion des cultures oléagineuses / agriculture durable

Highlights

- Status of various oil crops in Pakistan
- Oil palm cultivation in Pakistan to help address the country's increasing edible oil deficit
- Environmental challenges for oil palm cultivation in Pakistan, including heat stress, low precipitation, and humidity, particularly in coastal regions like Sindh and Balochistan.
- Explore the use of CRISPR/Cas9 and other modern biotechnological methods to improve oil palm's resistance to local environmental conditions.
- Appropriate biotechnological interventions could successfully scale up oil palm production, reducing dependence on imported edible oils.

1 Introduction

Agriculture is pivotal in Pakistan's economy, contributing approximately 24% to the national GDP and employing around 50% of the population. It is also a significant source of foreign exchange earnings, with agricultural exports, including rice, sesame, fruits, and meat, totaling about \$8 billion in the fiscal year 2024 (TADA, 2024). However, despite the success in agricultural exports, Pakistan faces a significant challenge in meeting its domestic needs for agricultural imports, particularly edible oil.

The country has 22 million hectares of cultivable land, with 18 million hectares irrigated, mainly in Punjab and Sindh. The irrigated plains primarily focus on cotton, rice, citrus, sugarcane, and mango, while rain-fed areas grow wheat, peanuts, fodder crops, and olives. Pakistan's agriculture is increasingly challenged by climate change, including drought, erosion, salinity, and waterlogging, which damage agricultural land and reduce crop productivity.

Oil and fats are an essential part of our daily diet. They are an energy source and provide essential fatty acids, vitamins (D and K), and functional molecules such as tocopherols and sterols (Meijaard *et al.*, 2024). Vegetable oils supply food nutrients and provide raw material for soup, paint, nutraceuticals, cosmetics, perfumes, and pesticides. Broadly characterized as "oleo chemicals," they act as surfactants, lubricants, plasticizers, and bases (Meijaard *et al.*, 2024). Edible oil is one of Pakistan's most significant agricultural imports, with palm oil accounting for about 31% of total agricultural imports. Other key imports include soybean oil (11%), lentils (10%), and tea (8%). The total cost of these imports exceeds the value of agricultural exports, placing a considerable financial burden on the country. Edible oil, including palm and soybean oil, constitutes roughly 42% of agricultural imports, critical for a

country whose economy depends on agriculture. Pakistan is one of the largest importers of palm oil, predominantly sourced from Indonesia. It is the 3rd major importer of oil palm from Indonesia. During 2024, it spent around 4.08 billion USD on importing palm oil and other vegetable oils (Agriculture Statistics of Pakistan, 2024). Pakistan imported 860,260 tonnes of oil palm from Malaysia in 2024, a 14.2% increase from 2023. Pakistan has to import 4 million tons of palm oil in 2025, which will cost around 3.5 billion USD (Ali, 2021). Pakistan's food sector is projected to grow 7.5% annually; there is considerable demand for refined palm oil, specialty fats, and oleo chemicals.

Currently, Pakistan produces only about 15% of its total edible oil needs, relying on domestic crops such as cotton, canola, and sunflower. Cotton has historically been a key source of edible oil and vegetable ghee (Yadav and Chattopadhyay, 2024). However, over the years, the area dedicated to cotton cultivation has declined due to climate change in Southern Punjab, leading to a shortage of cottonseed for oil extraction. Crops such as sugarcane and maize have increasingly replaced cotton, resulting in a 100% reduction in cottonseed production—from 3.15 million metric tons (MMT) in 2018 to 1.57 MMT in 2022 (FAOSTAT, 2022). As the population grows and the demand for edible oil rises, driven by increased consumption in the local deep-frying industry, restaurants, and domestic cooking, the pressure on food security and sustainability will intensify. This growing demand is expected to worsen the country's challenges in achieving food security.

2 Substituting imported palm oil with field crops

In order to reduce the reliance on imported palm oil, one strategy might be to increase the production and area of various oilseed crops. Field crops such as cotton, sunflower, rapeseed, and mustard are characterized by a high linoleic acid content, constituting 60-80% of the total fatty acids in these crops. However, linoleic acid tends to denature at temperatures when used for deep frying, resulting in oil degradation due to excessive smoke, which compromises oil quality (Rauf *et al.*, 2017). Consequently, these oils are generally not recommended for deep frying in the food industry. There has been a need to modify the fatty acid profile of field crops, which has been highlighted as a goal already achieved in crops like canola, soybean, and sunflower (Rauf *et al.*, 2017). Breeding efforts, including mutation breeding in sunflower, have led to the development of "high oleic acid" sources such as "Pervenent" and "high stearic acid" "CAS-4" varieties (Hussain *et al.*, 2024). However, these lines have not been widely commercialized due to their relatively low yield

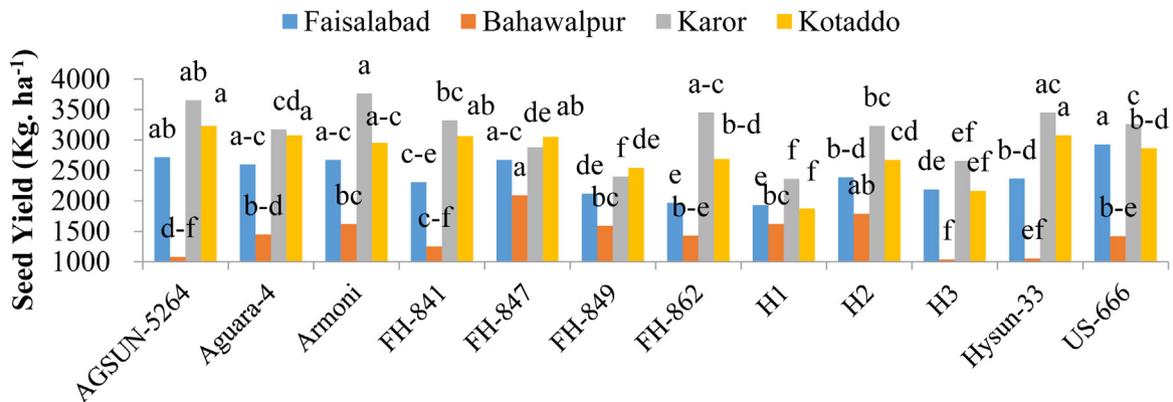


Fig. 1. Seed yield (Kg. ha^{-1}) potential of promising commercial hybrids in a micro yield trial conducted by the Oilseed Research Institute, Faisalabad. The principal author of this article provided seeds of the hybrids (H1-H3).

potential, a common limitation of crops developed through conventional mutation breeding methods. These varieties with modified fatty acids may be introduced, and their adaptability to local conditions and further utilization in breeding programs may be explored.

2.1 Rapeseed and mustard

In Pakistan, environmental conditions favor the cultivation of oilseed crops such as canola, rapeseed, mustard, sesame, and sunflower compared to tree crops (Khan *et al.*, 2024). These crops are cultivated over 1 million hectares (MinFAL, 2023), but they still fail to meet the local demand for edible oil. A large proportion of rapeseed and mustard is inedible due to toxic components (erucic acid and glucosinolates) in conventional varieties, while sesame has become an export commodity. The primary benefit of sesame exports is the foreign exchange earned, which can be used to import palm oil.

The country boasts well-established breeding and seed production infrastructures in both the public and private sectors. In Punjab, several varieties of Brassica napus (canola), including “Super Canola,” “Rachna Canola,” “Sandal Canola,” “Faisal Canola,” and “TM Canola,” are available for cultivation, with yield potentials ranging from 2.75 to 3.55 tons hectare⁻¹ and oil contents exceeding 40%. Additionally, “AARI-Canola,” developed from *B. juncea*, was the first variety developed in the species. *B. juncea* has a distinct advantage over *B. napus* in Pakistan due to its high adaptability to local conditions, shorter growth cycle, and resistance to biotic and abiotic stress. Despite marketing challenges, this crop has been gaining popularity in Pakistan and holds significant potential, especially in regions where wheat farming is no longer profitable.

However, the canola sector faces significant competition from traditional rapeseed and mustard crops, which, though unsuitable for human consumption due to high levels of erucic acid and glucosinolates, remain prevalent in the market. These compounds can pose health risks to both humans and animals. There has been a substantial increase in the area devoted to rapeseed and mustard cultivation, with a 70% increase in acreage—from 0.24 to 0.40 million hectares—alongside a 56% rise in production, reaching 0.67 million metric tons

(MinFAL, 2024). The expansion of this crop area is largely due to the shift of wheat farmers toward growing rapeseed and mustard varieties, following the discontinuation of the government subsidy system on wheat, which caused a significant decline in wheat prices in the market. Despite this, most of the rapeseed and mustard produce is consumed domestically, and the oilseed industry faces challenges in sourcing local crops, as imported sunflower, canola, and palm oil remain significantly cheaper. To promote local production and reduce reliance on imports, it is recommended that heavy taxes be imposed on the import of sunflower and canola oil.

2.2 Sunflower

Sunflower is a potential crop in Pakistan, with local and imported hybrids available for cultivation in Punjab and Sindh. It was cultivated on an area of 0.07 m ha with an oil production of 0.04 mMT (MinFAL, 2023). However, the sunflower crop faces several challenges, including diseases such as charcoal rot, downy mildew, powdery mildew, and head rot, all of which significantly reduce the yield potential of sunflower hybrid crops (Fig. 1). The yield potential of promising commercial hybrids is presented in Figure 1. The highest yield potential was observed at the “Karor” ($31^{\circ}13'0\text{N}$ $70^{\circ}57'0\text{E}$) site, followed by the “Kot addo” ($30^{\circ}28'34\text{N}$, $70^{\circ}57'52\text{E}$) site (Fig. 1). The yield potential at Bahawalpur was the lowest, with the hybrid “Armoni” showing the highest yield at the Karor site (Fig. 1). At the Bahawalpur site, FH-847 had the highest yield potential, followed by “H2” (C.112.P \times RH.344). The hybrid combination “H2” with high oleic acid content ranked the second-highest yielder among all promising commercial hybrids at the Bahawalpur ($29^{\circ}23'60.00\text{N}$, $71^{\circ}40'59.99\text{E}$) site. Bahawalpur may experience a stressful environment due to high temperatures and low fertility in sandy soils, which could have reduced the yield potential of the developed or foreign hybrids. Therefore, developing local hybrids could help mitigate yield losses caused by climate change and stress factors such as high temperatures. At the Faisalabad ($31^{\circ}25'0\text{N}$ / $73^{\circ}5'0\text{E}$) site, “H2” had a yield potential of $2,388 \text{ kg. ha}^{-1}$, which was comparable to the standard check variety “HYSUN.33” (low oleic acid hybrid), which had a yield potential of $2,364 \text{ kg. ha}^{-1}$. Furthermore,

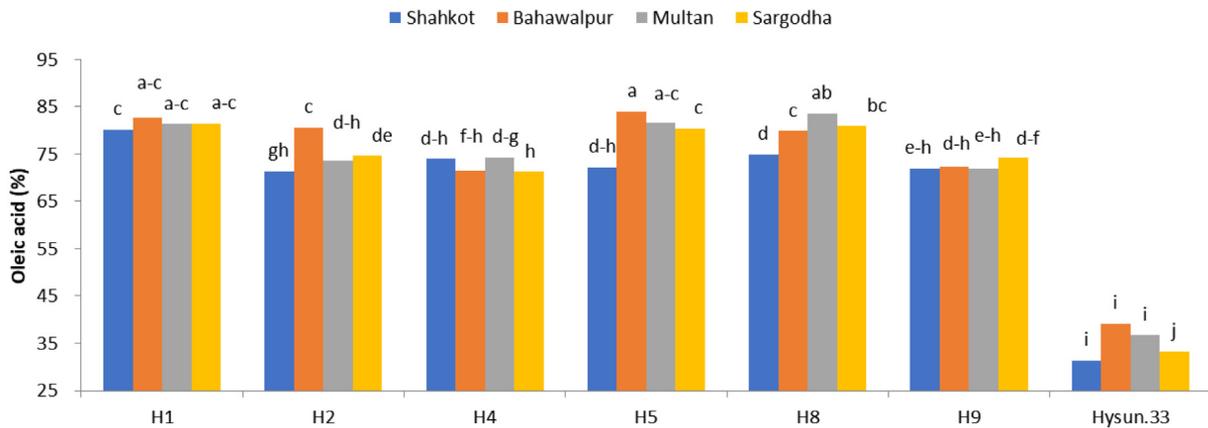


Fig. 2. Oleic acid (%) of hybrids across 4 locations in Punjab in a trial conducted by author, sponsored by the Agriculture Linkage Program, Pakistan Agriculture Research Council, Islamabad.



Fig. 3. Field view of sunflower hybrids developed by the author being evaluated ta Karj, Iran co-sponsored by Pakistan Science foundation.

“H2” outperformed the AARI hybrids FH-841, FH-849, and FH-862 in yield potential at the Faisalabad site (Fig. 1). Hybrid “H2” ($3,233 \text{ kg ha}^{-1}$) exhibited higher yield potential than “Agura-4” ($3,174 \text{ kg. ha}^{-1}$) and “FH-849” ($2,396 \text{ kg. ha}^{-1}$), with a yield potential statistically similar to that of “FH-841” ($3,323 \text{ kg. ha}^{-1}$) and “US-866” ($3,263 \text{ kg. ha}^{-1}$) (Fig. 1).

Efforts have been made to develop high oleic acid sunflower hybrids, and newly developed hybrids have shown oleic acid content ranging from 31% to 84% in trials conducted across four locations (Fig. 2). Hybrid “H5” (C.112.P \times RH.347) exhibited the highest oleic acid content (84%) at Bahawalpur. Hybrid “H8” (C.116.P \times RH.344) had the highest oleic acid content (84%) at Multan (Fig. 2). Hybrid “H1” (C112 \times RH.344) demonstrated high oleic acid content at three locations: Bahawalpur (82.62%), Multan (81.30%), and Sargodha (81.40%). In contrast, the commercial hybrid Hysun 33 had the lowest oleic acid content across all locations, ranging between 31.29% and 39.06%, and is characterized as a low oleic acid hybrid (Figs. 2 and 3).

2.3 Sesame

Sesame, another promising oilseed crop, has experienced notable growth, with the area cultivated expanding by 135% from 2020 to 2023, reaching 0.60 million hectares, and production increasing by 200%, to 0.30 million metric tons during the same period (FAOSTAT, 2023). Sesame has gained

recognition as an export commodity, with its expansion attributed to favorable market prices in 2023. According to an estimate, Pakistan earned 0.41 billion USD from the export of sesame (TADA, 2024). Traditionally grown in arid areas with sandy soils in Punjab, sesame’s cultivation has now spread to irrigated regions due to its high economic returns. However, this shift has led to significant crop failures in these areas due to an increase in diseases such as root rot, charcoal rot, wilting syndrome, and phyllody, as well as heavy infestations of pests like aphids and whiteflies, particularly during the monsoon season (Rauf *et al.*, 2024). There is a need to develop new crop varieties that are well-suited to irrigated environments and capable of providing high yields under humid conditions. In Pakistan, varieties can be broadly classified into single-stemmed and multi-stemmed branching. Single-stem varieties, such as “TH6” developed by the Oilseed Research Institute in Faisalabad, exhibit a determinate growth habit and produce large capsules. “NIAB-2016” is disease-tolerant and has demonstrated its potential in irrigated areas. Sesame oil is not used as an edible oil in Pakistan and is primarily consumed for confectionery purposes. New production technologies, such as growing sesame crops on seedbeds or ridges, have been introduced to mitigate wilting caused by excessive soil moisture.

Promoting sesame cultivation as an export commodity could offer significant economic opportunities. A potential strategy could involve the slogan “Money for palm oil,” encouraging farmers to grow high-quality sesame that can be

exported to countries like China and others at premium rates. The revenue generated from sesame exports could then be used to import cheaper palm oil in a scenario where a local oil palm plantation fails to yield an economic yield. This may balance local production with cost-effective oil imports and enhance the overall agricultural economy.

2.4. Rice bran oil

Pakistan produces approximately 14 million tons of rice annually (FAOSTAT, 2023), which can yield between 1.5 to 1.75 million tons of rice bran. Under optimal conditions, this could produce 80,000 to 100,000 tons of rice bran oil (RBO), presenting a valuable additional commodity for the country. Both rice and its by-products, including rice bran, are key export items for Pakistan, with rice bran being shipped to countries such as Vietnam. RBO, also known as “Oryzanol,” is highly valued for its balanced fatty acid profile, which combines both saturated and unsaturated fatty acids, making it an excellent choice for cooking oil (Goffman *et al.*, 2003). Major fatty acids in the oil are palmitic acid, oleic acid, and linoleic acid (13.9–22.1, 35.9–49.2, and 27.3–41.0%). The high saturated fatty acid ratio was recommended for deep frying and cooking due to their high smoke point (Goffman *et al.*, 2003). It has a high smoke point of around 232°C, which enhances its potential for use in the deep frying industry.

The oil content in rice bran typically ranges from 12–15%, but during processing, enzymatic activity causes some loss of oil, resulting in only a small proportion being available for extraction. This inefficiency makes the extraction process less economical. However, advancements in stabilizing rice bran have been made, leading to more efficient oil extraction. Oil yields can reach around 19% after stabilizing the rice bran (Raie *et al.*, 1990). There are significant differences among rice samples obtained from various varieties, with oil yields ranging from 14 to 35 g per 100 g. The maximum oil yield, reported to be up to 35%, was achieved using chloroform as the solvent and a particle size of 420 µm (Ajali and Emembolu, 2024). However, the solvent extraction method has several drawbacks, including toxicity, the potential for rancidity in the oil, high energy consumption, and flammability. Alternative approaches, such as supercritical carbon dioxide, subcritical water extraction, and ultrasonic processes, have been proposed. These methods offer lower toxicity and higher oil yields from the given samples (Garba *et al.*, 2017).

The concept of rice bran oil has been explored in various research studies over the past decades (Raie *et al.*, 1990). Despite the potential, the instability of Pakistan’s political and economic conditions has hindered the industry’s interest in using rice bran as a raw material. In the 1990s, several industrial units were set up to extract oil from rice bran using solvent extraction methods. However, the product quality was low, and the oil was not considered suitable for cooking. In contrast, countries such as Japan, the USA, India, and Vietnam have successfully branded rice bran oil commercially. The industry’s main challenge is the high input costs, which often outweigh the potential benefits of extracting rice bran oil. Despite these challenges, the oil industry in Pakistan attempted to introduce rice bran oil in 2-liter tin packages in major stores. However, the product struggled to gain traction in the domestic market due to the high retail price, branded packaging, and a

lack of consumer awareness regarding the health benefits of rice bran oil. Currently, only a single industrial unit operates in Pakistan with a 1,400-ton capacity of high-quality rice bran oil.

3 Unlocking the potential of oil palm cultivation in Pakistan

A potential solution to Pakistan’s edible oil deficit lies in the cultivation of oil palm (*Elaeis guineensis* L.), which is considered one of the most cost-effective and reliable sources of edible oil. Oil palm trees have a productive lifespan of up to 25 yr, with a relatively short juvenile period of 2–3 yr before they start bearing fruit (Murphy *et al.*, 2021). This rapid maturation makes oil palm an attractive option for improving food security. Studies and think tanks have recommended its adoption in Pakistan as a priority for enhancing food security (Hussain *et al.*, 2023).

One of the key advantages of oil palm cultivation is its high oil yield per unit area. On average, oil palm plantations (3.5 – 5 tons ha⁻¹) can produce up to 10 times more oil than other oilseeds like Brassicas (0.5–0.6 tons ha⁻¹) (Mathur *et al.*, 2023). Farmers can also earn additional income by intercropping oil palm with crops such as banana, papaya, and vegetables during the initial years before the palm trees mature.

3.1 Why is the cultivation of oil palm challenging

Oil palm thrives in specific regions where its unique photo-thermal requirements can be met. While native to West Africa, these plants are most successfully cultivated in the humid tropical climates of Southeast Asia and South America. Photo-thermal factors significantly influence their growth and reproductive cycles by activating specific transcriptional factors, which, in turn, trigger high flowering rates within a narrow temperature and photoperiod range. Oil palm has an optimal temperature range of 25–34°C with substantial precipitation requirements, averaging 1600 – 2500 mm per year, and needs a minimum of 1800 h of sunlight annually—conditions typically found near the equator, or at latitudes within 10° north and south (Punnuri and Singh, 2013). Oil palm cultivation is concentrated in localized regions of Latin America, Central America, and Southeast Asia, which meet global demand (Yadav and Chattopadhyay, 2025). However, further expansion of oil palm plantations along the equator is unlikely, given that these areas are home to critical tropical rainforests, often called the “lungs of the world” (Punnuri and Singh, 2013). The potential oil palm cultivation areas in Pakistan, including Badin, Thatta, Hub, Pasani, and Gwadar, face significant environmental challenges, such as low precipitation ranging from 151 to 203 mm per year and low humidity levels between 25% and 34% (Tab. 1). Peak temperatures in these regions often exceed 50°C, creating a hostile environment for oil palm growth. Additional irrigation systems, such as rain guns and drip irrigation, would support cultivation in these areas. Drought-tolerant breeding stock may be selected for the water-stressed areas Corely (2018). The initial studies showed that there was a significant ($P \leq 0.05$) progenies × irrigation regimes interaction, and yield in a non-stress environment did not predict the yield under a stress environment, which necessitates the selection of high-yielding

Table 1. Meteorological data of some potential sites for oil palm cultivation in Pakistan, and comparison with acclimatized region of China and along with Indonesian Riau Island.

Factor	Pakistan					Hainan, China		Indonesia
	Badin	Thatha	Hub	Pasani	Gwadar	Haikou	Sanya	Riau
Record high °C	56	52	50	47	49	40	40	33
Average high °C	39	36	28	30	31	18	18	29
Daily mean °C	34	32	25	26	27	14	14	28
Average low °C	26	24	17	18	19	6	6	27
Record low °C	19	17	8	8	8	-6	-6	20
Average precipitation mm	203	189	151	158	165	1315	1316	1410
Average precipitation days in month	2	2	25	2	2	13	13	17
Average relative humidity	37	35	22	23	24	67	67	77
Mean monthly sunshine hours	12	11	11	12	12	11	11	11

* Historical data obtained from weather and climate.com.

Table 2. Yield and its components of olive plantation in various location of Pakistan.

Yield	Cultivar	Yield component	Location	Reference
22.6 (kg tree ⁻¹)		Oil recovery (25%)Fruit mass (6 g)	Pothwar	Sumrah et al. (2021)
27.1 g bunch ⁻¹	Erlik	Fruit mass (4.5)	Chakwal	Ahmad et al. (2023)
35.81(kg tree ⁻¹)	Frontoio, Manzanilla	Fruit mass 4.3414.66	Mardan, KPK	Riaz Alam et al. (2021)
3000 kg ha ⁻¹ (2018)	Bari Zaitoon	Water use efficiency improved 17-25%	Chakwal	Aziz et al. (2022)
1800 kg ha ⁻¹ (2019)				
Oil yield (%)17.5	Arbequina	Oleic acid 62%Linoleic 17%Unsaturated 18.5%	Chakwal	Nazir et al. (2022)

progenies under a water stress environment to reduce yield losses [Corely \(2018\)](#). The extreme heat, particularly temperatures above 45°C, causes heat stress, which could hinder oil palm varieties' survivability, resulting in significant yield losses due to gametophytic sterility, reduced fruit setting, and lower oil content. Hainan in China offers a more favorable environment for oil palm, with rainfall closer to the ideal range and humidity near the optimal 70%. However, oil palm plantations in Hainan may still face challenges due to occasional low temperatures, which could result in sub-optimal growth and reduced productivity. As a standard check, Riau Island in Indonesia provides the ideal environmental conditions for oil palm, with an average temperature of 28°C, 11 h of sunlight, 77% humidity, and 1410 mm of annual precipitation, making it the most suitable location for oil palm cultivation ([Tab. 1](#)). While [Table 2](#) citation is missing. Kindly provide. current germplasm resources from Southeast Asia and Latin America could be adapted to Pakistan's coastal regions, with continued breeding and selection, oil palm cultivation could eventually be expanded to other areas ([Murphy et al., 2021](#)). A core set of germplasm may be evaluated under the targeted environment, and to accumulate favorable alleles, selected parents may be crossed to select the transgressive segregants with better tolerance to water stress and high temperature ([Murphy et al., 2021](#)).

4 Oil palm in Pakistan's coastal zones

Oil palm has been tested on an experimental scale along the coastal belt of Sindh, with support from the Malaysian Palm

Oil Board. The results showed higher oil content than the global average, confirming the region's feasibility for large-scale oil palm cultivation. The yield performance of oil palm germplasm in Pakistan was unavailable, but oil contents at various locations ranged between 62–68% in mesocarp, while kernel oil content ranged between 26–28%. Fatty acid profile showed that palmitic acid was the major fatty acid, ranging between 38-43% in fruit (mesocarp), and in kernel oil, lauric acid contents were 45% ([Saleem and Sultana, 2010](#)). Growth analyses of two oil palm varieties (3-way Cross and Yangambi PB14) at Dalda Agriculture Research Station (DARS) in Mirpur Sakro, district Thatta (Latitude N 24o39'58.24385" Longitude: E 67 o34'1.01598") was carried out against various treatments of NPK fertilizer and FYM in pot experiment put under open field trial which showed that the maximum seedling height of variety "Yangambi PB 14" was 94 cm, seedling trunk girth was 21 cm, number of maximum leaves were 14, and leaf area index 0.52 after 7 months of planting ([Memon et al., 2023](#)).

Pakistan's coastal regions, particularly the coastline of Sindh and Balochistan, spanning 880 km, offer opportunities for oil palm cultivation ([Memon et al., 2023](#)). These areas, with temperatures ranging from 24°C to 35°C and access to irrigation, provide sub-optimal conditions for palm oil production. The oil palm fruiting potential was 50 – 60 kg per tree (14 -16 bunches per tree) as opposed to 80 – 90 kg per tree in Malaysia and 50 – 60 Kg in Thailand ([Shaikh et al. 2019](#)). The government has identified 500,000 acres of land, with 300,000 acres in Sindh and 200,000 acres in Balochistan, as a potential area for oil palm cultivation. This includes coastal zones in districts like Thatta, Badin, Karachi, and



Fig. 4. Oil palm fruiting and Palm oil Extraction at Thatta Sindh, Pakistan.

Gwadar, where fertile soil and established irrigation systems are available. In Punjab, the Chakwal belt could be considered a potential point for introducing and cultivating palm species. According to some reports, the total area for oil palms has reached more than 1200 acres, but due to a lack of oil palm milling and refinery, the farmers must abandon the crop (Metts Global News, 2022). There was also a plan to set up a Palm Oil & Coconut Research & Development Station, but it was rolled back at some point due to unexplained reasons. However, an oil extraction facility was established in Thatta in 2016, which can extract 2 tons of oil daily (Akhtar *et al.*, 2020) (Fig. 4).

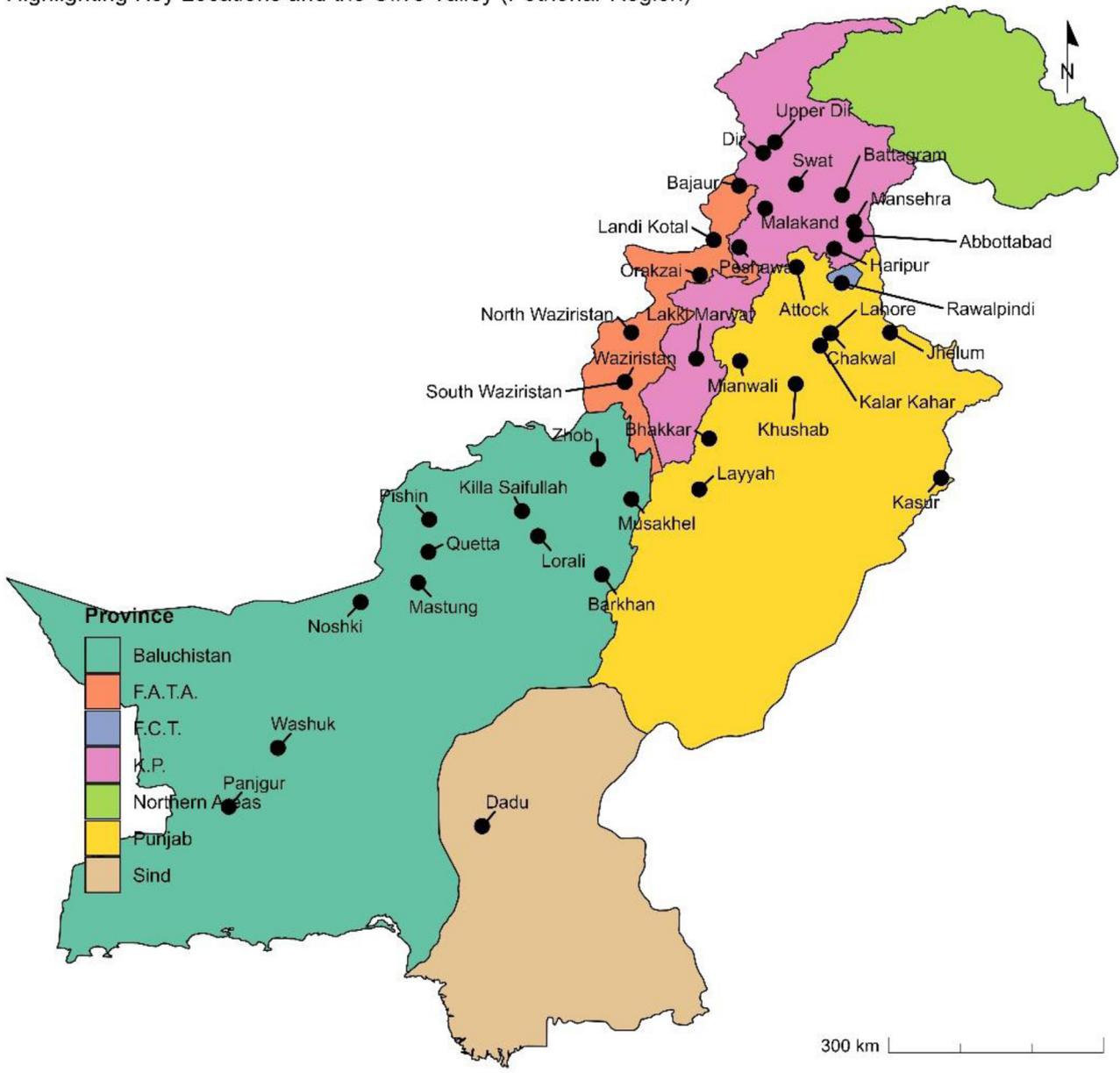
The potential oil palm cultivation in Gwadar has gained international importance due to the China-Pakistan Economic

Corridor (CPEC), which connects Kashgar in China to the port city of Gwadar (Fig. 5). The development of an oil palm industry alongside CPEC could significantly boost Pakistan's economy, create new economic activities, reduce imports, save foreign exchange, and stimulate overall economic growth. This initiative can potentially strengthen Pakistan's agricultural sector, improve food security, and increase sustainability in the future.

5 Revitalizing olive cultivation: a promising initiative for the oilseed sector

Recently, the government of Pakistan launched an olive oil project aimed at transforming the Pothohar region

Areas feasible for olive farming in Pakistan
 Highlighting Key Locations and the Olive Valley (Pothohar Region)



Olive Valley (Pothohar Region) includes: Attock, Chakwal, Jhelum, Khushab, Mianwali, and Rawalpindi.

Fig. 6. Potential Areas for Olive Plantation in Punjab, Khyber Pakhtunkhwa (KPK), and Baluchistan. The map was created in the computer-based software “R”.

observed in Chakwal, Punjab, in 1991. Pakistan has approximately 80 million wild olive trees (*Olea cuspidata*) and 5 million cultivated olive trees. The government has set an ambitious target to plant more than 50 million olive trees across 10 million acres by 2026 (Ali et al., 2024). Wild olive plants have also been grafted with cultivated scions to improve yield. However, the yield of olive plants’ fruit and oil (approximately 14 kg) is lower than that of oil palm (40 kg), with extracted oil contents ranging from 20% to 30%. An analysis of various exotic olive cultivars in Chakwal district revealed a yield potential ranging from 3 to 22 kg tree⁻¹, oil

content between 11% and 21%, and fruit mass ranging from 0.33 to 7 g (Iqbal et al., 2019). The cultivar “Coratina” showed the highest oil content (21%) and fruit yield (21 kg per tree) (Iqbal et al., 2019). Notably, there is significant variability in yield potential across different locations. For example, the cultivars “Coratina” and “Frantoio” demonstrated high yield potential in the dry and warmer conditions of Chakwal. At the same time, “Leccino” and “Ottobratica” produced higher yields in cooler regions, such as Nowshera in Khyber Pakhtunkhwa (Iqbal et al., 2023). There were significant differences among the germplasm accessions for their oil

contents, which ranged between 65% in a variety (Gemlik variety) collected from Lorallia and the lowest oil content (17.5%) “Dolece-agogia” collected from Queta (Khaliq *et al.*, 2019). The canopy characteristics of local cultivars “Bari Zaitoon-1”, “Bari Zaitoon-2”, and “Balkasar” were compared with exotic cultivars at Bahawalpur, which revealed that the local cultivars had larger plant heights and leaf area indices than the exotic cultivars (Sarwar *et al.*, 2023).

Regarding oil quality, the fatty acid composition of olive cultivars grown in Zhob, Baluchistan, showed that mono-unsaturated fatty acid (Oleic acid) was the predominant fatty acid with 59%. The olive fruits’ polyunsaturated fatty acids (20%) and saturated fatty acids were 21% (Masood *et al.*, 2023). The fatty acid composition of olive oil (oleic acid) does not support the local deep frying industry due to the low smoke point of olive oil (216 °C) as compared to the oil-palm (232 °C). Moreover, the olive grower may face difficulties marketing the olive oil due to the absence of a related industry in Pakistan. The same could be applied to oil palm cultivation, which could be handicapped without industry presence.

6 Challenges and the way forward

A significant challenge for oil palm cultivation in Pakistan is the lower yield due to the limited adaptability of imported plant material. The current world germplasm oil palm resources are adapted to humid tropics, and currently introduced accessions may not perform optimally in Pakistan’s hot, arid conditions. In this regard, new germplasm resources may be introduced and characterized in various regions of Pakistan. These germplasm resources may be evaluated for yield, their components, diseases, and plant height. One problem of the oil palm plant is its high adaptation to specific environmental conditions, such as a humid environment, with an optimum temperature for its growth and survival. Oil palm is highly susceptible to water scarcity and supra-optimal temperature and may not be able to provide full-scale yield potential in a stressful environment (Murugesan *et al.*, 2017). To overcome this challenge, it is essential to introduce improved oil palm varieties with better heat tolerance and drought resistance (Li *et al.*, 2019a; Wei *et al.*, 2021). Introgression with its wild relative, more resistant to the environmental conditions, could be achieved through field techniques and augmented through *in vitro techniques* such as the *embryo rescue* method or protoplast fusion (Alves *et al.*, 2011).

However, research groups and infrastructure related to oil palm breeding must be initiated to collect diverse germplasm that is adaptable to stress conditions. The breeding work to develop highly adaptable progenies may be imitated. Funding resources may be regenerated through local and international collaborative efforts.

Conventional breeding and selection of oil palm progenies are challenging due to the long generation time. In later stages, when ample germplasm will be available for breeding and transformation, molecular techniques may help to identify the genes related to oil palm adaptability, *i.e.*, loci related to photo-thermal responses. One of the major impediments in the coastal areas is the salinity, which could be managed through cultural practices but may also require suitable adaptations to

tolerate stress conditions. Further expansion of oil palm cultivation in the subtropical region involves environmental stress factors such as high temperature and less precipitation (Murugesan *et al.*, 2017). Tolerance to high temperatures is a prerequisite for survival under stressful conditions (Vieira *et al.*, 2020).

6.1 Research infrastructure and skills

Pakistan’s research infrastructure for palm research and development remains fragmented, with various institutions working in isolation on different aspects of palm species. Key research entities such as the Oil Seed Program and the Plant Genetic Resources Institute at the National Agricultural Research Center (NARC) in Islamabad, the Date Palm Institute in Khairpur, and universities like the University of Agriculture, Sindh, Jamshoro, and Tandojam have the mandate to conduct research related to palms, with a primary focus on date palm. Meanwhile, institutions like the National Institute of Genetic Engineering, the Center of Excellence for Molecular Biology and Biotechnology in Lahore, and the Biotechnology Labs at the University of Karachi possess the necessary plant tissue culture, genome modification, transformation, and cell biology research capabilities.

Despite the presence of these specialized institutes, there is a significant lack of coordination and collaboration among them, resulting in limited sharing of research expertise and resources. This disjointed approach hampers the potential for groundbreaking research and slows the progress of palm-related advancements. Strengthening the links between these institutions and fostering collaboration would significantly enhance Pakistan’s research capacity and contribute to developing sustainable and efficient palm crops.

6.2 Tools for the improvement of palm oil species

Oil palm genetic improvement is the cornerstone of species adaptability to environmental conditions. Generally, seed yield of the oil palm accessions may be lower in the acclimatized area due to the unadaptability of introduced germplasm to multiple factors such as Photo-thermal conditions, humidity, soil fertility, water, or salinity factors (Murugesan *et al.*, 2017; Vieira *et al.*, 2020). Introduction of oil palm germplasm from humid tropics to tropical conditions requires the appropriate selection of accessions with abiotic resistance and high yield traits. Hybridization is generally carried out between identified accessions with functional genetic variation. The hybrid formed could be evaluated for its better growth rate and tolerance to environmental conditions, and its fruit setting could be used for progeny selection in the F₂ generation. The breeding result in “tenera” between “dura” × “pisifera” has been successfully employed in Southeast Asia to improve the oil contents and fruit yield (Shaari *et al.*, 2023). The genetic gain from direct selection of oil palm oil productivity was 11.5%, and indirect selection of oil contents of bunch (9.1%) and indirect selection for fresh fruit bunches was 8.1% at 20% selection intensity in Brazil (Gomes *et al.*, 2021). Heritability of yield components (weight of fresh fruit bunches, the number of bunches per plant in F₁ populations) was high, ranging between 0.9 and

0.93 (Gomes Jr *et al.*, 2014). Molecular markers such as SNPs or SSR may be employed to predict the breeding value and subjected to genomic selection for traits of interest, developing specific training populations and test sets (Cros *et al.*, 2015). The accuracy of predicted breeding value through SSR markers ranged between -0.41 and 0.94 , depending on the relationship between the training population and test sets. Incorporation of resistance genes through genetic transformation could help to improve the water stress tolerance, disease and insect resistance in oil palm. At the same time, CRISPR/Cas9-based genome modification may be achieved to knock down genes related to photoperiod sensitivity and genes related to prolonged vegetative growth cycles (Yeap *et al.*, 2021; Rauf *et al.*, 2023).

6.3 Socio-economic aspects of crop

The Sindh Coastal Development Authority has been involved in the plantation of oil palm in various coastal areas and districts of Sindh, Pakistan. However, the initial oil palm plantation efforts, undertaken nearly two decades ago, faced failure primarily due to marketing challenges encountered by the farmers. Farmers who failed to market their crop at proper prices may have learned a harsh lesson in crop marketing, making it difficult to convince them to replant. After spending years cultivating the crop, they realized that no one was willing to purchase their produce at a profitable margin. Lessons learned from the initial failure indicate that agro-climatic conditions do not solely determine the success of a crop in acclimatized areas. Secondary factors, such as the demand for local produce by agro-industries, the marketing price of the produce, and initial incentives for both farmers and the industry, also play crucial roles in the crop's success. Additionally, there is a need to establish a robust fruit crushing sector along with oil refineries to accommodate both local and imported crops. Farmers should be provided with free seedlings subsidies and incentives for cultivating oil palm crops to mitigate the risks of crop and marketing failures. Generally, farmers in the region are poor, with agriculture being their only livelihood. Therefore, strategies and research may be needed to explore intercropping with other crops during the juvenile period of the oil palm. Moreover, farmers need highly vigorous, disease-free seedlings with the shortest juvenile period. Healthy and resilient seedlings should be developed, and a system for delivery should be established after years of research to ensure that the crop does not face another failure in the future.

6.4 Environmental consideration

Ongoing oil palm cultivation practices should be promoted in alignment with environmental sustainability criteria. These practices must maintain soil fertility, minimize pesticide use, and prevent deforestation, particularly in the mangrove areas along Pakistan's coastal belt. To enhance the export value of Pakistani palm oil, plantations should seek certification through the Roundtable on Sustainable Palm Oil (RSPO). Both farmers and the industrial community must receive training on sustainable oil palm cultivation practices that promote agriculture while minimizing environmental impact

and protecting farmer and public health. Additionally, incorporating rainwater harvesting technologies and drip irrigation systems will enhance water use efficiency. New and innovative water management techniques should also be developed to optimize water availability and improve productivity for oil palm crops.

7 Future framework for oil palm plantation

A national body with the mandate to promote oil palm plantation, research, and development should be established to fund oil palm-related activities within the country. The Ministry of National Food Security and Research (MNFSR), the Ministry of Science and Technology (MOST), and provincial agricultural departments should develop strategies to promote oil palm cultivation across Pakistan. Additionally, the Pakistan Agricultural Research Council (PARC) and the Sindh Coastal Development Authority (SCDA) will play pivotal roles in advancing the research through their project sponsorship program. This body would coordinate with various stakeholders, including farmers, researchers, and the industry, to create a cohesive national policy for oil palm production and align the efforts of provincial bodies.

The provincial governments of Sindh and Balochistan should allocate land in coastal areas for oil palm cultivation. Farmers in these regions should be provided with incentives to transition to oil palm farming, including subsidies for seedlings, fertilizers, irrigation systems, and the installation of drip irrigation systems. To reduce the risks associated with oil palm cultivation, crop insurance and guaranteed crop purchases at profitable margins should be offered.

Public-private collaboration is essential for advancing the oil palm sector. Local edible oil industries could be encouraged to invest in research and development. These industries could also fund the acquisition of germplasm resources, establish acclimatized nurseries, and provide solar panels to farmers in exchange for a commitment to purchasing the crops after they reach fruiting.

Government bodies should ensure that farmers have secure land tenure, allowing them to benefit from all the fruiting years of their oil palm crops. Significant investment is needed in research and development, especially in improving the crop's genotypic response to environmental conditions, expanding yield potential, enhancing oil recovery, and modifying the fatty acid composition. This includes incorporating alleles to increase stearic acid content in oil palm for the edible oil industry and improving disease, insect resistance, and abiotic stress tolerance, such as salinity and high temperatures.

Further investment in biotechnology is required to develop transgenic oil palms with enhanced tolerance to environmental and biotic stresses. Collaborations with research institutions such as the Malaysian Palm Oil Board, the Indonesian Palm Oil Research Institute (IOPRI), and the Coconut Research Institute of China would provide valuable insights into research excellence, industry practices, and export strategies. Technology transfer from these countries should be pursued to optimize oil palm production, acclimatization, cultivation, and harvesting techniques.

Research should focus on sustainable practices, including organic farming and integrated pest management (IPM). Micro trials of selected accessions should be conducted across suitable zones of oil palm cultivation, alongside agronomic trials, to assess their performance under various agro-environmental conditions. The best-performing accessions and farming practices should be identified and recommended to farmers.

The success of oil palm cultivation also depends on developing infrastructure for harvesting, transportation, and processing. Establishing crushing and refining industries in the region should be incentivized through tax exemptions, fast-tracked approvals, and priority access to power and water supplies. This will ensure the sector has the infrastructure to support large-scale oil palm production and processing.

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Cite this article as: Rauf S. 2025. Status of various sources of edible oil and prospects of oil palm cultivation in Pakistan. *OCL* 32: 30. <https://doi.org/10.1051/ocli/2025028>