




Review

# Ethiopian Mustard (*Brassica carinata* A. Braun) as an Alternative Energy Source and Sustainable Crop

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**Abstract:** Energy and food source crop demand claims to be vulnerable to climate change impacts. The new and orphan crops, which in the past have received only limited research attention but are sustainable to environmental systems, are needed. In this review, we summarize the available literature about Ethiopian mustard as an alternative energy source and its sustainable economic importance as a new promising Brassicaceae crop for new opportunities in the face of producing sustainable environment and energy development. Ethiopian mustard has many advantages and can be adopted to replace crops that are susceptible to adverse environmental conditions. Ethiopian mustard is becoming a new promising Brassicaceae crop with the current global energy demand increases. However, researchers have only focused on energy source production which has resulted in developing high erucic acid varieties. This results partly in limited studies on developing Ethiopian mustard edible oil varieties. The adoption and scaling-up of this promising crop as an oilseed crop in developing countries and Mediterranean conditions can sustain the impact of climate change with the demand for food and energy debate concepts. Indeed, further agronomic, quality and genomic studies on oilseed nutritional traits for efficient breeding and utilization are needed.

**Keywords:** alternative energy source; Ethiopian mustard; sustainability

## 1. Introduction

Ethiopian mustard (*Brassica carinata* A. Braun) is mainly originated in the highlands of Ethiopia [1]. It is locally known as “Gomenzer” (“Yehabesha Gomen”) and “Hamli Adri” in Amharic and Tigrigna languages, respectively. It can well be adopted in the Mediterranean climate areas [2] and it is a drought and heat tolerant oilseed crop [3,4]. It is used as a food and oilseed crop [5], especially in the arid and semi-arid areas [6].

Nowadays, Ethiopian mustard has disseminated to most semi-arid climate countries, such as European and South Asian countries and is used as an alternative energy crop in marginal lands. It is used for biofuel, bio-industrial processes and soil remediations. This is because different Ethiopian mustard breeding programs are elucidated to develop and adopt a candidate variety for better adaptability and oil yield production [7,8] in different arid and semi-arid areas.

Biochemically, Ethiopian mustard has high erucic and linoleic acids [2] with less saturated fatty acids. Hence, having these characteristics makes it a desirable oilseed crop that can be processed into biofuel [8–10]. Additionally, the oil extracted from the Ethiopian mustard is considered as a nonfood oil because of the high concentration of erucic acid (35–51%) [11,12]. Therefore, the crop has the potential to supplement part of the renewable energy demand without displacing feed and food crops as recently used by some countries, such as the USA, Canada, Italy and Spain. For example, it is used as a bio-industrial crop and biofuel for jets (air-crafts) [6], and hence different researchers stated that the crop can be used for smart agriculture “from the seed to sky” or “from the field to flight” platforms [9,13].

Therefore, this review aims to elucidate the status of Ethiopian mustard, as one of the Brassicaceae species used as alternative energy sources and sustainable crops, and the benefits associated with its adoption as a new and promising crop for energy sources in new vulnerable agricultural systems. The review also tends to motivate researchers working on other underutilized edible oilseed crops so as to develop environmental sustainability to face the impact of energy source imbalances at the globe.

## 2. Ethiopian Mustard as a Preference Crop

Nowadays, many growers and researches are actively searching and prefer a more resilient oilseed Brassica species [14], such as the Ethiopian mustard which can withstand in highly vulnerable environmental conditions even no other crops growing areas (i.e., marginal lands) [8,15]. Therefore, it is one of the most interesting Brassicaceae crops, which can be used currently for energy purposes in the Mediterranean regions [2,16] and can also be considered as suitable for marginal and contaminated areas, as it is a strong candidate for phytoremediation properties [6,17]. It is also found that the crop has better agro-ecological adaptability and productivity than canola (*Brassica napus*) and Indian mustard (*Brassica juncea*) under unfavorable environmental conditions and even in low cropping systems [2,18]. This is preferred because producers can cultivate the crop without difficulty with the production cost and can indirectly develop an environmentally sustainable business.

Ethiopian mustard is now a new promising energy crop for most Mediterranean, arid and semi-arid climate countries [6,16]. Indeed, the presence of high yield levels requires fewer inputs, and the ability to adapt and resist abiotic and biotic stresses [19] makes it appreciated in terms of agronomy and energy balances. For instance, its adaptation has considerably expanded and increased its production in some drier areas of the USA (California) [8,20,21], Canada [6,19], Italy [18,22], Spain [23] and South Asian countries [24], due to the increasing demand for bioenergy and oilseed productions in these countries [2,12,19,25] and the incidence of global climate change effects on sustainable agricultural production and environmental systems.

## 3. Cultural Practices of Ethiopian Mustard Effects on Environmental Sustainability

Ethiopian mustard is suitable for crop rotation and intercropping with food crops, such as wheat [26], chickpea [27], barley and sorghum [28]. Mulvaney et al. [8] reported that neither row spacing nor seeding rate affected the Ethiopian mustard oil concentration, seed and yield traits. It also has a role in the low farming systems as a potential rotational crop for cereals and pulses [29]. It is noteworthy that the crop is widely used as biofumigant to break soil-borne diseases and pests; this is why farmers in Australia and New Zealand used it as a rotating crop during crop husbandry systems [9,30]. Ngwene et al. [31] also reported that health-related phytochemicals of Ethiopian mustard can be modified by intercropping with nightshade, an African indigenous vegetable crop. The benefits of growing Ethiopian mustard as a winter crop has two advantages over other crops: first, it can increase the income generation of farmers [8,32] and second, it helps in environmental sustainability [26]. For instance, in honeybee production, it decreases the use of plenty of herbicides and maintains soil biotypes. Therefore, growing the Ethiopian mustard followed by summer crops and pastures has an advantage on the sustainable development for many producers, such as a livestock feed [8,30], soil amendments and biofumigation, and it is also likely to be used as a source

of food for insect pollinators. In addition, Ethiopian mustard when cultivated as a winter crop, for instance, in Canada helps as a cover crop (green manure) to reduce soil erosion, herbicide use and to balance nutrient losses [9,33,34]; it then later increases soil organic matter, maintains soil biotypes and crop diversification.

The traditional practices of mixed cropping systems involving Ethiopian mustard have gained admiration in recent years in the form of intercropping with suitable modification in planting patterns. The intercropping of Ethiopian mustard with chickpea in the semi-arid tropics of India, has improved the consumptive use, moisture use efficiency (MUE) and moisture extraction pattern, and when combined with moisture conservation practices (MCP) and proper phosphorus (P) and sulfur (S) nutrients, better significant results have been obtained [27].

On the contrary, reducing the mechanical operation of Ethiopian mustard with minimum tillage and low production inputs has no significant impact on yield production and seed oil content [18,35]. Indeed, Debiase et al. [36] found that the replacement of conventional tillage and mineral fertilizer with minimum tillage and sewage sludge can be sustainable for the cultivation of Ethiopian mustard without significant changes in heavy metal concentrations in the Mediterranean environments. It can be emphasized that Ethiopian mustard can be grown under limited environmental conditions with minimum cultural practices and a lower cost of production. Furthermore, it has been shown that seeding rate does not affect the yield and nutritional properties of Ethiopian mustard [8].

### 3.1. Responses of Ethiopian Mustard to Heavy Metal Contaminated Soils

The major environmental factors that currently reduce plant productivity are drought, salinity and nutrient imbalances [37–39]. Saline soil types are one of the abiotic stresses that influence food and energy imbalances [40,41], which causes a formidable global challenge to existing crop production. Therefore, identifying plant species and cultivars that can contend with such environmental challenges is a key remedy for establishing a sustainable food and energy balance with climate change [42].

The genus Brassica species have significant importance to resist contaminated soils and can be used for phytoremediation purposes [26,43–45]. For instance, Akhtar et al. [46] studied the effect of salinity in four Brassica species: mainly, Ethiopian mustard, Indian mustard, Chinese cabbage and rapeseed. As a result, rapeseed and Ethiopian mustard were more tolerant and yielded better than Indian mustard and Chinese cabbage for seed yield, stem diameter, plant height, number of siliques and 1000 seed weight per plants.

The Ethiopian mustard has shown a high tolerance index and adaptability in multicontaminated soils with zinc (Zn), nickel (Ni), lead (Pb), manganese (Mn) and cadmium (Cd) [17,43]. Gezahegn et al. [47] also reported the highest accumulation of heavy metals in leafy vegetables of Ethiopian mustard than cabbage, cauliflower, lettuce and Swiss chard. On the other hand, they found no accumulation of Pb and arsenic (As) metals as compared to other leafy vegetables. Likewise, a pot culture experiment was also used to test the phytoextraction of Zn, copper (Cu), Ni and Pb from a contaminated soil among five Brassica species (Indian mustard, rapeseed, Ethiopian mustard, oilseed rape (canola) and black mustard) [17]. Accordingly, they found that among these Brassica species, the Ethiopian mustard has shown the highest concentration ( $\text{mg kg}^{-1}$ ) as well as uptake ( $\mu\text{g pot}^{-1}$ ) of Ni and Pb at maturity, and it is a promising phytoextractor for Zn, Ni and Pb when compared to Indian mustard.

### 3.2. The Response of Ethiopian Mustard to Plant Pests and Diseases

Ethiopian mustard is reported to be resistant to many diseases affecting crucifers in Canada, such as blackleg (*Leptosphaeria maculans*; [48]), white rust (*Albugo candida*; [49]), alternaria (*Alternaria brassicae*; [50]), sclerotinia stem rot (*Sclerotinia sclerotiorum* (Lib.) Masee) and aster yellows (*Candidatus phytoplasma asteris*) [51]. However, it is less susceptible to insect herbivores than oilseed rape (canola). However, it is also susceptible to clubroot (*Plasmodiophora brassicae*), a soil-borne fungus-like pathogen [52], but it has been widely reported for its ability to reduce soil-borne plant pathogens better

than other Brassicaceae species. In addition, the biological control methods through environmentally sound and effective means of reducing or mitigating pests using natural enemies for the Ethiopian mustard volunteers have not yet been developed [53].

In the USA, it has been evaluated further for weed risk assessment; nevertheless, it has low or no weed risk assessment. However, it can germinate and grow as a contaminant from discarded birdseed and bird-seed screenings due to the presence of uncertainty in seed dormancy. Taking these into account, Ethiopian mustard needs further research and breeding to protect from diseases such as sclerotinia that happens when it rotates with other energy crops [28] to obtain a better yield.

#### 4. Economic Sustainability of Ethiopian Mustard

##### 4.1. As Sources of Secondary Metabolites (Glucosinolates)

Different *Brassica* species have shown their allelopathic potential against noxious weeds of agroecosystems and are considered as a sustainable tool for integrated weed management [54]. The leaves of Ethiopian mustard are rich in glucosinolates, that is, a secondary metabolite that has been identified in Brassicaceae and is a volatile sulfur-containing compound that has antimicrobial and allelopathic effects [55,56] (Table 1).

Glucosinolates can also prevent microorganisms and insect infestation and nematode invasion in the roots through a process known as biofumigation. The presence of glucosinolate in seed cake is a limiting factor in Ethiopian mustard, although it is used as high protein feed for animals [57]. However, glucosinolates are also repellants to most insect pests due to their presence in the volatile oils released from Brassicaceae [30], of which Ethiopian mustard is used as a trap crop (an alternative pest management strategy) for massive butterfly infestation in Indian mustard by utilizing the pests' preference for these plants [58]. Additionally, Odongo et al. [59] and Martínez-Valdivieso [60] reported that the leaves and seeds of Ethiopian mustard are also rich in nutrients and health-promoting secondary plant metabolites, i.e., glucosinolates, especially 2-propenyl glucosinolate (sinigrin) as well as phenolic compounds. However, the concentration was different based on the plant parts used, stage of maturity and growth conditions.

**Table 1.** Secondary metabolites (allelochemicals) reported in Ethiopian mustard.

S.N.	Type of Allelochemicals	Activities	References
1	2-propenyl-glucosinolate (Sinigrin)	Health promoting effect, antimicrobial effects	[12,59,61]
2	Flavonoids	Antioxidant activity	[59]
3	Carotenoids	Antioxidant activity	[59]
4	Allyl Isothiocyanate	Insecticidal activity; weed suppresses (reduces the use of synthetic chemicals)	[59]

Ethiopian mustard has a larger sinigrin content ( $5.83 \text{ mg}\cdot\text{g}^{-1}$ ) [61] than cabbage ( $0.26 \text{ mg}\cdot\text{g}^{-1}$ ), Chinese cabbage ( $0.77 \text{ mg}\cdot\text{g}^{-1}$ ), Broccoli ( $0.33 \text{ mg}\cdot\text{g}^{-1}$ ) and Korean leaf mustard ( $5.56 \text{ mg}\cdot\text{g}^{-1}$ ) [62], which is the predominant glucosinolate content in the leaves of the crop. On the other hand, the presence of high erucic acid [12,63], makes Ethiopian mustard have an antinutritional effect such as tannins and sinigrin. Increasing the processability of orphan-crop entails focusing on the aspects of chemical composition that affect their products. Therefore, improved processability means decreasing the presence of antinutritional compounds that are present in the edible portions of crop plants [64]. However, through different breeding programs, there are few Ethiopian mustard varieties developed with zero erucic acids [11,13,65] and a high content of glucosinolates ( $100\text{--}200 \mu\text{moles g}^{-1}$ )—almost exclusively sinigrin [66]. Therefore, farmers, private companies and researchers can use these improved varieties based on their agronomic performance and the need for sustainable research preferences.

#### 4.2. As an Alternative Source of Energy Crop

Among the botanical species yielding high quantities of erucic acid, the Brassicaceae species is the most important genus in the production of this oil per hectare, particularly rapeseed and Ethiopian mustard species [7,67]. In the 1990s, European countries such as Italy searched and collected Ethiopian mustard lines from India, Germany and the Netherlands to screen for better agronomic performance and high potential oil productivity in winter conditions and marginal soils. Meanwhile, the Ethiopian mustard cultivar “Sincron” has been found as a candidate biodiesel production oilseed crop in Italy [7]. Likewise, the North Florida Research and Education Center (NFREC) has also developed a new commercial variety of Ethiopian mustard called AAC A120, which has a high yielding performance (i.e., both in seed and oil production), is disease resistant, early maturing and well adapted in the southeast USA. Hence, this variety may increase diversification, generate revenue and improve ecosystem sustainability. However, the target was pick up to develop region-specific agronomic traits and targeted for double crop production in the southeastern USA [9]. There are also other improved new promising Brassicaceae species adopted as supplementary oilseed crops (Table 2).

Increasing the demand for high erucate oils for industrial feedstocks, enforce researchers to develop high erucic acid (HEA) Brassicaceae cultivars with increased proportions of erucic acid and very-long-chain fatty acids (VLCFAs) to fulfill the industrial oil market needs [6,19,63]. Although more research and development for food and industrial use has been conducted using canola and Indian mustard has been practiced for food and industrial use, other Brassicaceae relatives such as camelina, Ethiopian mustard and *Sinapis alba* have also shown promise as potential Hydrotreated Renewable Jet fuel (HRJ) feedstock [2,20]. Therefore, the advocating and development of Ethiopian mustard as an alternative biorefinery and bio-industrial oil platform using traditional and molecular breeding techniques and tools is essential. Currently, Ethiopian mustard is also considered as a new molecular farming platform for delivering bio-industrial oil feedstock [2,19] that is improving through genetic modifications to produce more very long-chain fatty acids and oil contents in seeds of the crop.

In East Africa, particularly in Ethiopia, the Ethiopian mustard is cultivated as a leafy vegetable crop with limited commercial oil production. However, it is more commercially adapted as an alternative energy source and biofuel product in developed countries. This is why the interest of the crop is changing nowadays from more food (leafy vegetable) to more sustainable biodiesel crop production [20] for bio-industrial processes, as bio-energy sources increase from time to time in developed countries [25,28], which started in the mid-1980s [53].

Most governmental and nongovernmental organizations such as European countries, the University of Florida, North Florida Research and Education Center (NFREC) in Quincy, in South Eastern USA and Agrisoma Biosciences Inc. company (i.e., the world’s largest Ethiopian mustard breeding program company located in the University of Saskatchewan, Canada) have developed varieties for energy sources [9]. Meanwhile, researchers in the USA, such as California and Florida, Canada and European countries, have emphasized Ethiopian mustard as an alternative energy source (jet fuel) crop and bio-industrial feedstock, i.e., for more biodiesel crop production.

On the other hand, the oil extracted from Ethiopian mustard can be utilized as vegetable oil, later converted into jet fuel and biodiesel such as other oilseed crops via the existing technologies [20]. For instance, in 2018, Australian Qantas Airways, together with Canadian agritech company Agrisoma Biosciences, flew the first dedicated biofuel-powered flight between Australia and the USA, using a jet biofuel produced from the Ethiopian mustard oilseed [9]. Therefore, the Ethiopian mustard is an excellent raw material for the sustainable production of biofuels. It is becoming an interesting new complementary source of biofuel and industrial feedstock to mitigate the impact of global climate change effects on sustainable agricultural development by hindering the pollution that happened due to the use of excess petroleum gasoline in developed countries.

**Table 2.** The most promising oilseed Brassica species with a briefing of some agronomical characteristics and their industrial uses.

Cultivated <i>Brassica</i> Species	Native Areas	Positive Characteristics	Negative Characteristics	Stage of Commercial Development	Industrial Uses	References
<i>Brassica carinata</i>	Ethiopia	Drought resistant, low pod shattering, low bird predation, an alternative and interesting winter oilseed crop, a meal rich in glucosinolates and resistant to most pathologies, as a trap crop	Limited availability of commercial varieties, low seed yield stability, low harvesting index and low cold tolerance	Seeds of few improved varieties are available on the market, such as Dodalla, C90-14, AAC A100, AAC A110, AAC A120, AVANZA 641, 080814 EM	Biofuels, food processing, lubricant, plasticizers, antislipping agents, cosmetics, nylon erucamide (polyethylene, paints, etc.), jet fuel	[9,14,19,20,58]
<i>Brassica napus</i>	South-east Asia	Low erucic acid and glucosinolate, adapt to cool environment	susceptible to high heat and temperature	Seeds of many improved varieties are available on the market, with different environmental adaptability (e.g., DK3042 RR, Gem, Invigor L130 and SC28)	Consumable oil production, used in stews, soups and as a flavor enhancer	[20,25,30]
<i>Brassica juncea</i>	India	Drought resistant, domesticated crop, low-fiber meal, good adaptability to hot weather condition	Poor seed yield stability and high N requirements	Seeds of many improved varieties are available on the market, with different environmental and adaptability (e.g., Oasis, Pacific Gold)	Biofuels, food processing, lubricant, plasticizers, antislipping agents, cosmetics, nylon erucamide (polyethylene, paints, etc.), jet fuel, antidiabetic activity	[20,25,30]

#### 4.3. As a New Promising Crop Offer for New Opportunities

Ethiopian mustard as a unique energy feedstock crop is preferable added to crop rotation by growers because they are unable to grow other crops due to the vulnerability of agricultural production to vulnerable environmental conditions. Thus, Ethiopian mustard attracts the interest of researchers in many countries, such as Canada, Spain and Italy, because of its good agronomic qualities. Impressively, this has been introducing Ethiopian mustard as a sustainable, scalable and economic oilseed and feedstock crop in other unfavorable environmental conditions. It is noteworthy that a crop with excellent agronomic traits will perform well in stressful conditions and has a ready market demand [13].

It has been proven that the crop residue of the Ethiopian mustard (straw) has a potential option for energy production (i.e., biofuel or for electricity and heat cogeneration), especially in the rural areas of developing countries that could increase the income of farmers. Besides this, the Ethiopian mustard pellet made from crop residues has been found to be modestly suited for energy use in terms of pellet quality compared to a wood pellet; it is then possible to sustain the valuable outputs of local agro-energy chains [16]. Additionally, the meal remaining after oil extraction is also protein rich (30–45%) and used as sources of protein in livestock feed [8], poultry, swine and aquaculture industries (if its glucosinolate level is reduced) or as an organic fertilizer [5,11,30]. These concepts can make the crop a new promising crop and have further benefits to adapt in unfavorable environmental conditions to support growers, consumers and researchers' perspectives of the chance to use the good agronomic characteristics of this crop for sustainable development.

As aforementioned, Ethiopian mustard has many advantages and dual purposes. Therefore, the cultivation of Ethiopian mustard can overcome problems in intensive nonrotational farming practices which have an impact on environmental sustainability. Indeed, not only this, but it has also been used for bioremediation effects as a traditional medicine to treat ailments and diseases such as analgesic activity [30] and anticancer activity [59]. Besides this, Ethiopian mustard has more production potential than rapeseed both under low-input and adverse environmental conditions [2,22], and it is usually cultivated as an alternative energy source and is well-indicated for biofuel production, such as in Italy [16].

#### 4.4. Future Prospects of Ethiopian Mustard

Conventionally, Ethiopian mustard is propagated by seeds and can hybridize successfully with other Brassicaceae species [68,69], which makes it an alternative oilseed crop for most Mediterranean, arid and semi-arid climate countries. For instance, the Ethiopian mustard genotypes demonstrate a potential as a winter biofuel crop in South East USA. There are essential traits to enable the adoption of Ethiopian mustard as a sustainable winter crop without interrupting the normal cycle of cultivation. Therefore, the inclusion of Ethiopian mustard as a winter crop will help bring underutilized fallow land under cultivation thereby potentially adding additional revenue streams for the producer while providing ecosystem services [70].

Ethiopian mustard as compared to other Brassica species has useful genes for the resistance to abiotic and biotic stresses and, therefore, has been used to intercross with other counterparts as a recurrent parent for the introgression of genes to improve and widen the gene pool of *Brassica* species germplasms for further breeding programs [71,72]. On the other hand, there is a limited genetic improvement due to the narrow genetic variation [73] of this crop, which has not been studied at a genomic level to date and lacks sufficient literature [74]. Indeed, the presence of a narrow genetic base shapes the population structure and linkage disequilibrium in Ethiopian mustard [75].

Based on the information reviewed, around 1308 Ethiopian mustard germplasms have been found in different gene banks of the world. As we have contacted different institutes, the majority of the germplasms are found in the Ethiopia Biodiversity Institute (<http://www.ebi.gov.et>); World Vegetable Center (<https://avrdc.org>); European Search Catalogue for Plant Genetic Resources (<https://eurisco.ipk-gatersleben.de/apex/f?p=103:1:::>); Plant Gene Resources of Canada (<http://www.agr.gc.ca/pgrc-rpc>); and the US National Plant Germplasm System, Germplasm Collection Gene Banks, (

[grin.gov/npgs](http://grin.gov/npgs)), with the total number of 653, 386, 139, 92 and 38 accessions, respectively, and are available in gene banks (personal communication, 2018). With these genetic resources, it is possible to conduct further research on molecular breeding and variety improvement. Khedikar et al. [75] reported that the assessment of genetic diversity, population structure and linkage disequilibrium in the worldwide Ethiopian mustard collection will enhance future crop improvement programs.

The six *Brassica* species and their closest relative species of Radish except Ethiopian mustard (*Brassica carinata* A. Braun) have been well sequenced by different researchers [76–80]. These species obviously promoted their genetic dissection of agronomic traits and were used for variety development. Bearing this in mind, to avoid Ethiopian mustard being neglected, it is important to start research on genomic sequencing and genome-wide association study (GWAS) as well as phylogenetic analysis to improve this sustainable oilseed *Brassica* species and also improve the nutritional quality for better economic and sustainability use.

## 5. Conclusions

Ethiopian mustard is native to the central highlands of Ethiopia and adjoining east African countries. In Ethiopia, it has been consumed as a food (leafy vegetable) and oilseed crop since ancient times. It can adapt in the arid and semi-arid conditions, and it is used as an alternative energy (biofuel and industrial oil) source crop with the current vulnerable climate change in crop husbandry systems. Indeed, there is a huge demand for a suitable crop that can be a clean energy source without competing for land use with food crops. Ethiopian mustard has emerged as one of such low-cost candidate crops with multiple desirable agronomic traits. Nowadays, it is becoming a new promising Brassicaceae vegetable, and it can be used for multiple purposes, such as increasing farmers' income and environmentally sustainable business. The leaves are used as a source of phenolic compounds and glucosinolates, and the seeds are used as an alternative energy source. However, researchers have mainly focused on energy production in terms of improving high erucic acid varieties rather than developing edible oil varieties. As a result, the production of edible oil from the Ethiopian mustard is neglected from crossbreeding improvement techniques. With this framework, Ethiopian mustard has the potential for many applications in food, energy and environmental sustainability. This creates interest in studying the agro-economic performance of cereal-based rotations and understanding the genetic architecture controlling these traits. It is also noteworthy that Ethiopian mustard can be a resilient crop for sustainable ecological services on oilseed production as it can tolerate biotic and abiotic stresses effectively more than other Brassicaceae crops. However, further study on leaf and seed nutritional compositions using genomic approaches is needed in order to enhance its use as an alternative oilseed crop for sustainable edible oil production with diversified crop rotations.

Cross-crop knowledge application can be further supported by the unification of advanced breeding-method designs, novel gene-editing approaches to generate new genetic variation and innovative participatory domestication models that facilitate stakeholder input. The adoption and scaling-up of this promising crop as a sustainable and alternative energy source crop in developing countries and Mediterranean conditions can create a resilience to the impact of environmentally unsustainable crop production systems with the demand for food and energy (fuel) debate concepts.

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