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Advances in genetic resource enhancement of noug (*Guizotia abyssinica* L.) for sustainable oilseed production

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Critical Review

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Abstract

Noug (*Guizotia abyssinica* L.) is among the key oilseed crops of Ethiopia and India and is valued for its tolerance to drought, with its very nutrient-dense oil being rich in essential fatty acids, protein and minerals. Despite the economic potential of noug, its production is limited by biological factors such as self-incompatibility, seed shattering, parasitic weeds and disease susceptibility. This review consolidates advances in the past decade, highlighting the transition from conventional breeding to the application of genomic tools. We critically assess how the development of self-compatible lines, transcriptome sequencing and linkage mapping are being used to produce improved germplasm. There is, however, a huge gap between research products and farmer-preferred variety development. This review suggests an integrative approach that brings genomics, phenomics and participatory breeding to realize the faster generation of high-yielding, durable noug cultivars. This is an important strategy to ensure that noug is a sustainable crop that ensures food security and financial empowerment of Ethiopian smallholder farmers.

Introduction

Noug (*Guizotia abyssinica* L.) is the most popular and native oilseed crop in Ethiopia, grown for its edible oil and seeds. It is mainly grown by smallholder farmers and contributes half of the Ethiopian oilseed production (Geleta and Ortiz 2013; Tsehay *et al.* 2021; Gebeyehu *et al.* 2024). Roasted noug seeds are eaten mixed with pulses, roasted cereals and flour to make sweet cakes. The oil is used in cooking, painting, soap and as an illuminant. Ethiopian farmers prefer growing noug because it requires minimal management due to its low response to management inputs (Getinet and Sharma 1996; Teklewold and Wakjira 2004; Adarsh *et al.* 2014).

Noug's national average productivity is about 1.1 tons (t) per hectare (CSA 2021). Recently, noug has been added to the list of Ethiopian Commodity Exchange (ECX) traded commodities, which is expected to create better market incentives for farmers to scale up seed production in the coming years. Furthermore, expansion in local edible oil processing facilities and new integrated agro-industries within the country also spur the demand to produce noug to meet the rapidly increasing local demand for cooking oils and animal feed (Ethiopian Investment Commission (EIC) 2023; Ethiopian Pulses, Oilseeds and Spices Processors-Exporters Association (EPOSPEA) 2023). The expansion of acreage (CSA 2021; USDA-GAIN 2021; Ministry of Agriculture (MoA) 2022) and improved yields due to good weather conditions (Ministry of Agriculture (MoA) 2022) were expected to increase noug production by nearly 2% (Fig. 1).

However, its cultivation is plagued by several critical problems (Geleta and Ortiz 2013; Tsehay *et al.* 2021). The key factors include susceptibility to pests, diseases, parasitic weeds, pod shattering and low yields (Getinet and Sharma 1996; Teklewold and Wakjira 2004; Tesfaye 2007; Gebeyehu *et al.* 2021). This critical review is timely because, after a decade of extensive genomic progress, including the development of self-compatible (SC) lines, transcriptomic resources, and preliminary quantitative trait loci (QTL) mapping, there have been no new improved cultivars released in Ethiopia since 2010 (Table 2). This indicates a significant translational gap. The novelty of this review is that it brings together these new developments and its proposal of a concrete, holistic route to overcome the key limitations of self-incompatibility, lodging and shattering and, therefore, positions noug as an adoptable and sustainable crop for Ethiopia.

Overview of noug as an oilseed crop

Taxonomy and botany

Noug is a diploid ($2n = 30$), dicotyledonous, herbaceous annual plant in the Compositae family. It is characterized by strict outcrossing and self-incompatibility. The domesticated crop,

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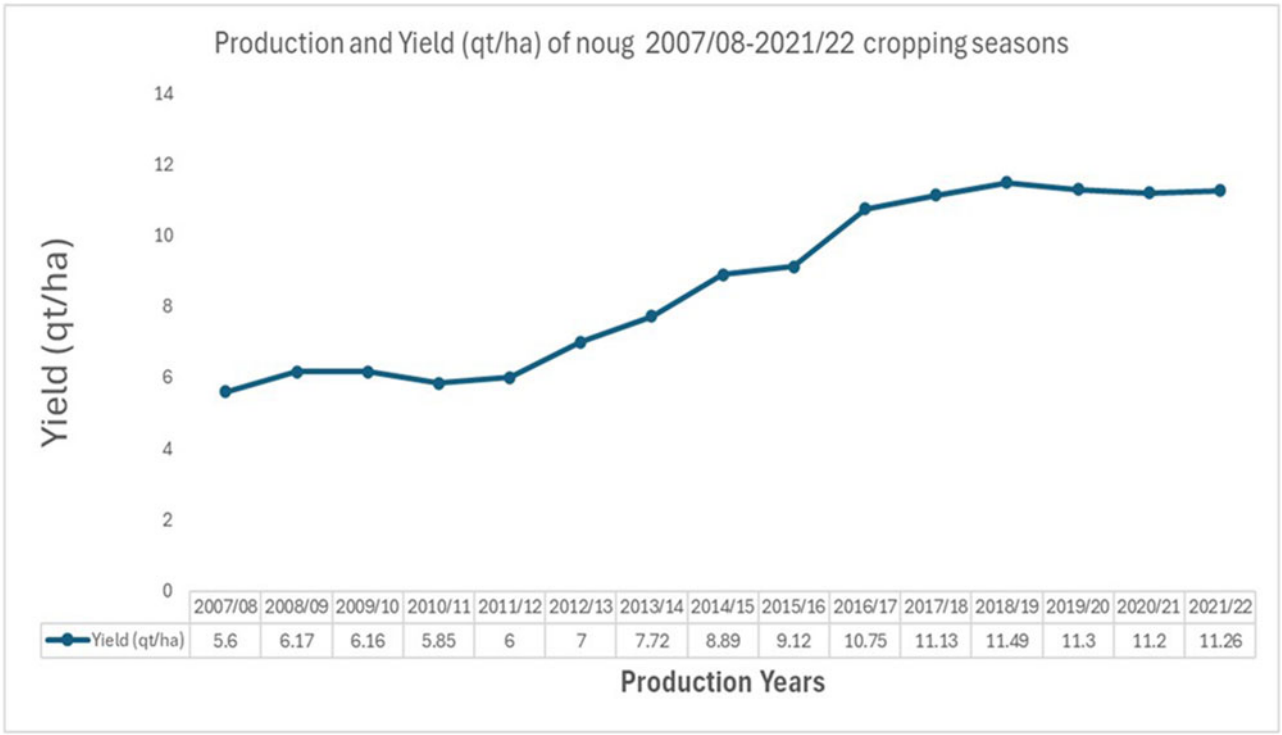


Figure 1. Trends of an average yield increase of noug in the last 15 years in Ethiopia.

Guizotia abyssinica, is near and cross-compatible with its wild relative, *Guizotia scabra*, an abundant weed in Ethiopia (Dagne 1994, 1995; Geleta 2007). Comprehensive taxonomic treatments are given in detail (e.g., Getinet and Sharma 1996; Geleta 2007).

Origin and distribution

Noug is native to the Ethiopian highlands, which is guaranteed as its origin and diversity pointer by the presence of wild relatives. It was domesticated from *Guizotia scabra* subsp. Schimperi was introduced to India centuries ago (Getinet and Sharma 1996; Dempewolf *et al.* 2015). In Ethiopia, it is grown mostly by small-scale farmers at mid-to-high altitudes (1600-2500 masl) in regions including Gojjam, Gondar, and Wellega. The Ethiopian Biodiversity Institute has conserved over 1170 germplasm accessions (Ethiopian Biodiversity Institute (EBI) 2025).

Economic values

Noug is an economically important oilseed crop for domestic consumption by households. It also generates income for farmers, foreign exchange earnings, and import substitution of about $50–60 million annually from edible oil imports (Abebe *et al.* 2022). Furthermore, the oilcake remaining after oil extraction serves as high-quality animal feed (Getinet and Sharma 1996; Deme *et al.* 2017). It is the main source of edible oil for the local consumption of millions of Ethiopians. Its seed is used as bird food in the United States and Europe, especially for finches (Petros *et al.* 2008). It is also used in soap making and as a scent carrier in the perfume industry (Seegler, 1983; Kandel and Porter, 2002). Noug oil also protects against cardiovascular diseases and treats burns (Adarsh *et al.* 2014).

Nutritional profile

Noug oil is characterized by a high level of unsaturated fatty acids, with linoleic acid being the predominant component, followed by oleic acid. The primary saturated fatty acids are stearic and palmitic (Table 1). The Ethiopian noug materials exhibit significant oil content and quality variation depending on the seeds' maturity level, the materials' origin, and climatic conditions, especially temperature (Petros *et al.* 2009; Geleta *et al.* 2011; Tsehay *et al.* 2021; Gebeyehu *et al.* 2024). It is also a good source of protein (25–28%) and macro- and micro-minerals that can significantly combat malnutrition (Tsehay *et al.* 2021). It contains mineral elements P, K, Ca, Mg, S, Na, B, Cu, Fe, Mn, Se and Zn (Deme *et al.* 2017; Tsehay *et al.* 2021). The mineral composition of noug suggests its possible contribution towards the mitigation of high levels of micronutrient malnutrition in Ethiopia. For example, its zinc and iron composition would be in support of controlling high rates of iron deficiency among lactating mothers (Roba *et al.* 2018) and stunting due to zinc deficiency in children (Harika *et al.* 2017; Ayana *et al.* 2018). Clinical trials confirm that noug oil taken daily improves lipid profiles by reducing cholesterol by 12–18% (Gebremariam *et al.* 2024), and Fe (29.6 mg/100 g) and Zn (8.2 mg/100 g) present therein directly fight prevalent micronutrient deficiencies among Ethiopian populations (Ayana *et al.* 2018; Berhanu *et al.* 2018; Roba *et al.* 2018). This is in line with the Agricultural Transformation Plan of Ethiopia (2021–2030), which strongly focuses on nutrient-dense indigenous foods like noug towards improving food security (Ministry of Agriculture (MoA) 2021). Public health programs based on noug products can therefore enhance dietary diversity and help achieve national agricultural targets, as encouraged by FAO's 2023 policy guidelines on underutilized crops for nutrition security (FAO, IFAD, UNICEF, WFP, and WHO 2023). Hence, noug should be increasingly used as a food source for oil, protein,

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Table 1. Composition (%) of major fatty acids and oil content in Ethiopian noug materials

Noug materials used	Trait tested	Mean (%)	References
Various accessions and 4 improved cultivars (Sendafa, Fogera-1, Esete-1, and Kuyu) of noug	Linoleic acid	76.60	Getinet and Sharma (1996)
	Oleic acid	6.50	
	Palmitic acid	8.20	
	Steric acid	6.50	
	Oil content	41.00	
Various accessions, wild relatives (*G. scabra, G. arborescens, G. villosa, G. zavattarii*) and 3 improved cultivars (Sendafa, Fogera-1, and Esete-1) of noug	Linoleic acid	63.55	Dagne and Jonsson (1997)
	Oleic acid	16.10	
	Palmitic acid	8.90	
	Steric acid	6.80	
	Oil content	43.00	
Seeds from single plants were collected in farmers' fields, and bulked seeds from each of 87 plant progenies from 78 fields in three regions (Wellega, Gojjam and Jimma).	Linoleic acid	47.50	Petros *et al.* (2009)
	Oleic acid	38.80	
	Palmitic acid	6.60	
	Steric acid	4.70	
	Oil content	NA	
153 noug populations that were sampled directly from farmers' fields in Ethiopia	Linoleic acid	72.10	Geleta *et al.* (2011)
	Oleic acid	8.20	
	Palmitic acid	9.40	
	Steric acid	7.90	
	Oil content	38.90	
28 landrace populations collected from Amhara, Oromia, SNNPs and Tigray; 10 F_4 breeding populations, and 7 released cultivars (Fogera-1, Esete-1, Ginchi, Kuyu and others)	Linoleic acid	75.00	Tsehay *et al.* (2021)
	Oleic acid	6.75	
	Palmitic acid	8.70	
	Steric acid	8.60	
	Oil content	39.10	
Five cultivars of noug (Esete-1, Fogera-1, Ginchi, Kuyu and Shambu-1)	Linoleic acid	75.50	Deme *et al.* (2021)
	Oleic acid	6.72	
	Palmitic acid	7.99	
	Steric acid	6.72	
	Oil content	NA	
75 genotypes comprising both self-compatible and self-incompatible lines	Linoleic acid	57.31	Gebeyehu *et al.* (2024)
	Oleic acid	22.51	
	Palmitic acid	8.48	
	Steric acid	5.18	
286 F_2 Population and 2 parental lines C19 (Gojjam) and K13 (Tigray)	Oil content	43.29	Gebeyehu *et al.* (2025)

NA = not available.

and minerals in Ethiopia and elsewhere to enhance human wellness.

Noug genetic resources enhancement

Systematic genetic improvement of noug in Ethiopia was initiated in 1961, with preliminary breeding already underway in the Debrezeit and Holeta Agricultural Research Centres (Alemaw and Alemayehu 1992). Throughout the next three decades, the program resulted in the release of four principal cultivars: Sendafa, Fogera-1, Esete-1 and Kuyu by 1994 (Getinet and Sharma 1996). Since 1995, only two improved cultivars of noug (Ginchi-1 and Shambu-1) have been released. However, only six improved cultivars are still being developed by selection (Table 2) and released in different

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Table 2. Lists of improved cultivars, year of release, maturity, yield and oil content

Cultivars	Year of release	Maturity (days)	Yield (kg/ha)	Oil content (%)
Ginchi-1	2010	146	884	46
Shambu-1	2002	142	970	39
Kuyu	1994	138	1060	41
Sendafa	1994	145	780	40
Fogera-1	1988	146	820	41
Esete-1	1988	146	830	39
Landraces	–	150	724	38

Data Source: Getinet and Sharma (1996) and Ministry of Agriculture (MoA) (2016).

Table 3. Agronomic and economic performance of major oilseed crops in Ethiopia (2019–2023)

Crop	Average yield (t/ha)	Oil content (%)	Market price (USD/t)	Gross profit (USD/ha)	Water requirement (mm/season)
Noug	1.1 ± 0.2	38–46	320	352	500–600
Linseed	1.8 ± 0.3	35–42	440	792	550–700
Ethiopian Mustard	2.2 ± 0.4	40–48	500	1,100	600–675

*Data source: (*Ministry of Agriculture (MoA) 2022).

years (Ministry of Agriculture (MoA) 2016). The absence of new cultivar releases since 2010 starkly illustrates the limitations of conventional breeding and underscores the urgent need for innovative approaches.

Conventional breeding in noug

In Ethiopia, conventional breeding of noug cultivars is mostly on-farm farmer selection of high-yielding plants with improved oilseed yield and quality (Geleta and Ortiz 2013). Farmers save seeds from top-performing plants and have achieved documented genetic advances. Studies show that this participatory breeding approach has raised seed oil content by 3–5% and yield stability by 15–20% in local landraces within a decade (Terefe *et al.* 2023). Similar success has been described in other indigenous oilseeds like sesame (Rauf *et al.* 2024) and Ethiopian mustard (Ambaw *et al.* 2025), showing the relevance of combining traditional and conventional breeding practices.

However, the yield of noug is economically uncompetitive with major oilseeds, necessitating further improvement (Table 3). The Ethiopian national averages present noug yields less than linseed and Ethiopian mustard under similar growing conditions (CSA 2021; Ministry of Agriculture (MoA) 2022). A yield gap of this size translates into a substantial profitability disadvantage, with noug grossing $440–748 less per hectare than linseed and Ethiopian mustard (ECX 2023; Abebe *et al.* 2022). One of the major issues hindering noug is its comparatively lower economic competitiveness compared to other oilseeds like linseed and Ethiopian mustard with higher average yield and gross profit per hectare under the same Ethiopian environmental conditions (Table 3; CSA 2021; Ministry of Agriculture (MoA) 2022). This yield gap gives a serious profitability disadvantage to farmers (ECX 2023; Abebe *et al.* 2022). One of the most crucial morphological restraints is the architecture of the plant; while additional branching can be associated with increased potential for yield, over-vegetative growth is likely to lead to lodging, hence effectively reducing seed yield (Getinet and Sharma 1996; Tesfaye 2007). Modern breeding, therefore, not only aims to increase the yield and oil content (Tesfaye 2007) but also to modify plant architecture. Genetic selection for smaller, less-branched plants could also improve harvest index and lodging resistance (Belayneh 1987), making yield advances more reliable and predictable.

Seed oil content is another major trait in the noug breeding program. Fortunately, Ethiopian and Indian germplasm collections harbour considerable genetic variation for this trait, representing a valuable source of material for breeding programs looking to enhance oil content (Alemaw and Teklewold 1995; Tesfaye 2007; Gebeyehu *et al.* 2024). Single-head and dwarf-type noug cultivars must be developed to reduce seed loss from shattering. Production of single-headed plants is more desirable than many heads per plant due to the variation among many heads (Tesfaye 2007; Gebeyehu *et al.* 2021). According to Gebeyehu *et al.* (2021), tall cultivars with a plant height of 120–180 cm and with 3–5 heads per plant shatter 25–30%, which was observed in field trials conducted at Debrezeit research centre. In contrast, dwarf types (70–90 cm) with 1–2 heads per plant have 10–15% losses due to better resistance to lodging. Single-head cultivars with a plant height of 100–130 cm perform well in terms of shattering (8–12%) and maturity due to synchronization of maturation time (Gebeyehu *et al.* 2021). These cultivars performed the best, combined with limited shattering and synchronized maturity. Besides, dwarf plants may be more effective in fertilizer use than tall ones (Tesfaye 2007; Gebeyehu et al. 2021). Application of fertilizer may result in increased yields of seeds (Getinet and Sharma 1996). Fertilizing the taller noug plants may, sometimes, result in a negative response since it stimulates vegetative growth, which causes lodging in the crop (Gebeyehu et al. 2021). Hence, breeding programs should focus on developing compact, single-headed genotypes to improve the noug yield potential.

Breeding programs in Ethiopia and India claim that breeders themselves began such population improvement methods, which is quite plausible. Simple mass selection had improved a few populations in Ethiopia (Riley and Belayneh, 1989; Getinet and Sharma, 1996), and recurrent selection with participatory breeding efforts on crops like sorghum, pearl millet and chickpea is reported from India (Rai and Witcombe, 1999; Saxena *et al.* 2016). The two countries' approaches to population improvement capture a larger trend.

Selection

Mass selection is a basic and effective breeding method, especially for highly heritable and largely additive gene-controlled traits such as plant height, days to maturity, lodging resistance and oilseed yield (Alemaw and Teklewold 1995; Allard 1999; Acquaah 2012). Mass selection approaches have also been found to be used in the breeding of noug to create unique genotypes with superior agronomic traits (Dagne and Jonsson 1997).

Recurrent selection is a widespread breeding technique that has been applied in cross-pollinated species for the development of open-pollinating varieties (OPVs) or cultivars because it allows

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for the accumulation of beneficial alleles while keeping the diversity among them (Poehlman and Sleper 1995; Acquaah 2012). The common practice is choosing elite plants for target traits, blending equal portions of their seeds, growing them in isolation to facilitate intercrossing, saving seed from chosen plants, and field-testing progeny rows in future breeding cycles (Hallauer *et al.* 2010). This method is based on the fundamental principle of increasing allele frequency for quantitative inherited traits at each cycle, particularly for polygenic characters with significant additive genetic variance (Falconer 1996; Allard 1999; Bernardo 2002). In noug, both mass and half-sib recurrent selection were found to be very effective in creating significant genetic gains for yield, adaptation traits, and economic traits like early-to-medium maturity, larger head size and reduced plant height (Alemaw and Teklewold 1995; Getinet and Sharma 1996).

Crossing

Similar to sunflower, noug exhibits a high outcrossing pollination behaviour (Getinet and Sharma 1996). Because of its floral biology and naturally high outcrossing rate (30–50%; Lavania, 2005), it is a good candidate for hybrid breeding, where heterosis was successfully exploited in related Asteraceae crops like sunflower (Rathod *et al.* 2013). Flowers of two parental lines can be rubbed with each other to obtain controlled crosses (Rilay and Belayneh, 1989), though it may result in self-pollination owing to incomplete emasculation. To achieve F_1 hybridization, the researchers suggest that disc florets (male organs) should be removed at the bud stage and ray florets (female) kept whole, a technique adapted from sunflower breeding procedures (Getinet and Sharma 1996).

Modern breeding in noug

One of the biggest challenges to noug improvement is its obligate outcrossing through self-incompatibility (Geleta and Ortiz 2013). This is because this makes breeding harder by preventing the establishment and maintenance of pure inbred lines, which is an important step in most contemporary breeding programs. This is due to the limited number and type of pollinating agents and self-incompatibility. The crop's indeterminate nature makes it liable for shattering (Nemomissa *et al.* 1999). Modern breeding approaches are therefore essential to overcome these intrinsic constraints.

Tissue culture

Tissue culture techniques, namely anther or microspore culture, offer a way to rapidly generate homozygous lines (haploids) that can be doubled to create pure lines, thus avoiding the self-incompatibility barrier (Forster *et al.* 2007). While protocols for callus induction and shoot regeneration from hypocotyls, cotyledons (Tesfaye 2007) and anthers (Misteru 2008) in noug exist, an efficient and reliable doubled haploid production system is not yet available. Development of such a system is a critical step towards the realization of genetic gain acceleration in noug breeding.

Molecular markers and marker-assisted selection

Molecular markers were important in the description of the vast genetic diversity of the noug germplasm (Table 4). The utilization, however, has been confined to diversity analysis via RAPD, AFLP, ISSR and SSR techniques. However, these markers have been restricted to such high-resolution genetic analysis and must be complemented with other high-throughput markers, which can be used for targeted marker-assisted selection (Collard and Mackill 2008). This is true and especially for the improvement of oilseed crops, as they proved their utility in marker-trait associations, which helped in accelerating genetic progress for yield and quality traits (Pandey *et al.* 2020). The recent SNP markers and transcriptomic resource development (Tsehay *et al.* 2020; Gebeyehu *et al.* 2022) is a success. The grand challenge now is to move beyond diversity analysis to the application of such tools to marker-assisted selection (MAS). This requires the establishment of robust marker-trait relationships for key agronomic traits that are currently missing.

Linkage and QTL mapping

Noug is an outcrossing crop, and the production of inbred lines is consequently not feasible, though imperative as the foundation for linkage and QTL mapping (Dagne and Jonsson 1997). Development of SC lines (Geleta and Bryngelsson 2010) was an achievement, making the production of mapping populations possible. SC-genotypes were subsequently generated by cross- and selfing, which were used for RNA-seq-based sequencing (Gebeyehu *et al.* 2022). To date, no study has established pure-line development with generational stability in noug. This limitation is in direct contrast to related oilseed crops, such as sunflower, for which pure lines have enabled significant advances in QTL mapping (Putt, 1997). Inability to develop stable pure lines is a main limitation for noug improvement (Tadele 2019). Linkage mapping in SC lines has recently identified the first QTL for oilseed yield and tolerance to stress (Gebeyehu *et al.* 2025a). This is a first step, but the stability of these QTL over environments and genetic backgrounds needs to be established before they can be effectively applied in MAS.

Genome-wide association study

Genome-wide association studies (GWAS) are a potential alternative to linkage mapping in outcrossing species such as noug, as they can potentially make use of natural diversity without the need to develop inbred lines. GWAS would allow marker-trait associations to be detected by genotyping a diverse panel of germplasm together with high-density SNP markers. While no GWAS has been conducted in noug to date, it represents an enormous opportunity to unravel the genetic architecture of complex traits like yield, lodging and shattering with direct breeding implications.

Genome editing

Genome editing technologies, in particular CRISPR-Cas9, hold enormous potential for the precision improvement of orphan crops like noug. While no work has been reported in noug, its utility for removing undesirable traits (e.g., indeterminate growth genes or susceptibility to shattering) or enhancing desirable ones (e.g., oil quality genes) has been proven in very closely related oilseeds like sunflower and rapeseed. The two prerequisites for applying CRISPR in noug are a stable genetic transformation system and a sequenced genome. Initial transformation protocols exist (Murthy *et al.* 2003), though genome sequencing needs to be prioritized in order to maximize the potential of genome editing.

Pathogens, weeds and pests in noug

Noug is economically relevant despite the fact that its productivity is still low due to biological and management issues. Severe limitations include low harvest index, seed lodging and shattering (Fig. 2), indeterminate growth type, self-incompatibility and weak sensitivity to inputs like fertilizer (Dagne and Jonsson 1997; Tesfaye 2007; Gebeyehu et al. 2021). The erect, branching growth habit of

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Table 4. Diversity study, genotype-by-environment interaction and mapping quantitative trait loci (QTL) in Ethiopian noug (*Guizotia abyssinica*) materials using different DNA markers

Markers used/research	Noug materials used	Objectives of the study	References
Simple sequence repeats/ microsatellites (SSR)	29 noug populations and 4 wild ancestors	Patterns of domestication and genetic diversity study	Dempewolf *et al.* (2015)
SSR	65 Ethiopian accessions	Genetic diversity assessment	Abebaw and Solomon (2017)
SSR	100 Ethiopian accessions	SSR-based genetic diversity study	Aboye *et al.* (2020)
Single nucleotide polymorphisms (SNP)/Kompetitive Allele Specific PCR (KASP)	24 Ethiopian accessions	New marker development for population diversity analysis	Tsehay *et al.* (2020)
SNP/SSR	30 genotypes of Ethiopian origin	Development of novel genomic resources and tools; identify genes regulating self-compatibility, flowering time, and oil biosynthesis	Gebeyehu *et al*. (2022, 2025b)
SSR	161 Ethiopian and Eritrean accessions	Genetic diversity and population structure	Terefe *et al.* (2023)
Genotype-by-environment interaction (G × E)	31 Ethiopian accessions	Genotype-by-environment interaction study	Tsehay (2023) PhD thesis
Mapping quantitative trait loci (QTL)	288 (2 genotypes of Ethiopian origin + 286 F_2 interspecific hybrids)	High-density single-nucleotide polymorphism-based linkage mapping to reveal novel quantitative trait loci for noug (*Guizotia abyssinica*).	Gebeyehu *et al.* (2025)



Figure 2. A field of noug showing its typical tall, branched growth habit prone to lodging (A), and a close-up of the flower heads (B), illustrating the potential for shattering.

the plant and asynchronous head maturation of the flowers are the immediate causes of pre-harvest shattering and lodging losses, and one of the main yield losses (Getinet and Sharma 1996; Gebeyehu et al. 2021).

Although noug is reported to have relatively fewer biotic issues than other oilseeds like sunflower and sesame (Alemaw and Teklewold 1995), its growth is also limited by some of the most significant pests and diseases. Some of the most widespread diseases are bacterial leaf spot (*Xanthomonas* spp.) and blight (*Alternaria* spp.), which have been reported to cause huge yield loss (Tadesse *et al.* 2017). The crop's productivity is also threatened by the insect pests, the noug fly (Dioynasorocula spp. and Eutretosoma spp.) and black pollen beetles (Meligethes spp.), that bring direct injury to flowers and reduce seed set (Tsehay et al. 2023). Moreover, parasitic weeds are increasing. Dodder (*Cuscuta campestris*) is now becoming a serious concern in major noug-producing regions of Ethiopia (Terefe *et al.* 2023). But one more parasitic plant, Orobanche minor, is present, but so far has not been associated with widespread, serious damage (Getinet and Sharma 1996; Tsehay et al. 2023).

The most frequently observed diseases of noug include noug blight (*Alternaria* spp.), powdery mildew (*Erysiphe* spp.), bacterial leaf spots (*Xanthomonas* spp.) and shot holes (Getinet and Sharma 1996; Tadesse *et al.* 2017). Among these, shot hole disease (coryneum blight), caused by Wilsonomyces carpophilus, results in a 10% yield loss under severe infection conditions, as recorded at the Holeta Research Centre (Terefe *et al.* 2023). This disease is widespread in noug-growing areas with varying intensity across the Amhara and Oromia regions (Terefe *et al.* 2023).

Several species of noug insect pests have been reported, with noug flies (*Dioynasorocula* spp.), black pollen beetles (*Meligethes* spp.), aphids and thrips among the major ones requiring research priority in Ethiopia (Medhin and Mulatu, 1992). Noug flies alone reduce seed set by 15–20% (Medhin and Mulatu, 1992). Hence, noug improvement programs should emphasize the introduction

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and identification of pest and pathogen-resistant characters in improved cultivars to enhance yield stability and minimize yield losses. This can be achieved by: (i) systematically screening the extensive noug germplasm collections and wild relatives (*G. scabra*) for sources of resistance; (ii) employing marker-assisted selection to introgress identified resistance QTL into elite breeding lines; and (iii) exploring the possibilities of genetic engineering or genome editing to transfer resistance genes from other organisms if natural variation is found to be lacking.

Conclusions and future prospects

This review identifies a translational deficit of significance in noug improvement: whereas there has been the development of large genetic resources and genomic tools, their application to breeding programs has not been translated into new cultivars after over a decade. To bridge this gap and realize the potential of this strategic crop, there must be an integrated and combined effort. The future direction will need to target the development of dwarf, single-headed plant structures to address lodging and shattering head-on, and to speed up genetic advance by finishing doubled haploid systems to escape self-incompatibility. Application of proven QTL and conducting genome-wide association studies will be critical to evolve towards genomics-assisted breeding for significant traits. Moreover, exploration of the promise of genome editing technologies like CRISPR-Cas provides a frontier for precise genetic improvement. Lastly, the success of these efforts will lie in linking participatory variety selection with smallholder farmers so that new varieties are not only high-yielding but also suit local taste and agronomic conditions. Through this multi-modal route, Ethiopia stands to turn noug into a competitive, climate-tolerant staple of its oilseed sector, enhancing national food security and incomes for millions of smallholder farmers.

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