Wiley
Advances in Agriculture
Volume 2025, Article ID 8863731, 11 pages
https://doi.org/10.1155/aia/8863731

WILEY

Research Article

Ecological Spread and Impact of Wild Sunflower (*Verbesina encelioides*) in Doba District, West Hararghe, Ethiopia

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Received 14 September 2024; Revised 19 September 2025; Accepted 17 October 2025

Academic Editor: Xinqing Xiao

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The wild sunflower is an emerging invasive weed that poses significant ecological and socioeconomic challenges to Ethiopian agriculture. This study assessed the distribution, phenology, morphology, and socioeconomic impact of *V. encelioides* in Doba district across three agroecological zones (highland, midland, and lowland) during the main rainy season of 2023. A field survey covering 240 sampling points revealed that wild sunflowers occurred in 72.5% of these lowland and midland zones. Greenhouse experiments demonstrated that the species allocates a substantial portion of its life cycle to seedling and vegetative stages, followed by prolific flowering and seed production, with midland-derived seeds producing the highest seed output (1603 seeds per plant). Morphological traits, including plant height, branching, leaf number, and flower head production, were positively correlated, indicating coordinated growth strategies that enhance reproductive success. Principal component analysis (PCA) identified two major trait clusters associated with reproductive potential and leaf/branch development. Socioeconomic surveys involving 240 respondents revealed that wild sunflower negatively affects crop yields, livestock productivity, and local biodiversity, with construction material transport, wind, and animals identified as primary dispersal mechanisms. Farmers employ slashing, cutting and burning, and hand weeding to manage infestations. These findings underscore the ecological and socioeconomic risks posed by wild sunflowers and highlight the need for integrated management strategies to mitigate their spread in Doba district and similar agroecological zones.

Keywords: invasive species; morphology; phenology; socioeconomic impact; *Verbesina encelioides*

1. Introduction

Invasive alien species (IAS) are a major driver of global biodiversity loss, contributing to nearly 60% of recorded extinctions and causing annual economic damages exceeding USD 400 billion [1]. Their spread is accelerating due to globalization, climate change, and land-use changes. In Africa, IAS are responsible for significant biodiversity and agricultural losses, with invasive plants alone costing the agricultural sector an estimated USD 65.58 billion annually, equivalent to 2.5% of the continent's combined gross domestic product [2]. These species threaten ecosystems, food security, and livelihoods across the continent.

Ethiopia's diverse ecosystems make the country particularly vulnerable to biological invasions, with more than 35 invasive alien weed species already documented [3, 4]. These invasive weeds threaten biodiversity, disrupt ecosystem services, and undermine agricultural productivity [5–8]. Among them, emerging invaders are of special concern due to limited knowledge about their spread and impacts. The wild sunflower (*Verbesina encelioides*), native to Mexico and the United States, has become a rapidly expanding invasive weed

across multiple continents [9, 10]. Initially rare in Ethiopia during the 1990s [11], it is now widespread, especially in West Hararghe. This species aggressively colonizes roadsides, grazing lands, and farmlands, displacing native flora through allelopathic effects and reducing biodiversity [12–14]. Despite its increasing presence, little is known about its ecological characteristics and socioeconomic consequences in this region.

Doba district, characterized by pronounced agroecological heterogeneity and a strong reliance on agriculture, is highly susceptible to invasion by *Verbesina encelioides*. Agroecological gradients significantly influence plant distribution, morphology, and phenology: lowland environments typically provide favorable soil moisture, temperature, and disturbance regimes that facilitate the establishment of invasive species, whereas highland zones impose climatic constraints that limit their proliferation [15]. However, the extent to which agroecological variation regulates the growth dynamics and phenological expression of *V. encelioides* has not been thoroughly examined. Similarly, its agricultural and ecological impacts remain insufficiently quantified, despite growing concerns regarding its competitive ability, allelopathic effects, and potential to displace native flora and reduce agricultural productivity. These knowledge gaps hinder the development of evidence-based management strategies, underscoring the urgency for integrated ecological studies combined with community-driven management approaches to mitigate the spread and impact of this invasive plant species. Therefore, this study was designed to: (i) assess the distribution of *V. encelioides* across agroecological zones; (ii) investigate its morphological and phenological characteristics under greenhouse conditions; and (iii) evaluate its socioeconomic impacts based on community perceptions.

2. Materials and Methods

2.1. Description of the Study Area. The study was conducted in Doba district, West Hararghe Zone, Ethiopia (9°15′ N, 41°00′ E), which lies between 500 and 2400 m.a.s.l. The area has a bimodal rainfall pattern, with a short rainy season from April to May and a longer season from June to August, receiving 500–1200 mm annually. Mean annual temperatures range from 11 to 27.5°C. Three major agroecological zones, highland, midland, and lowland, characterize the district. Sandy loam soils dominate, supporting mixed farming systems where both crop and livestock production are integral to livelihoods. Major crops include sorghum, maize, *Catha edulis* (chat), coffee, sweet potato, tomato, and onion, while cattle, goats, sheep, and camels constitute the primary livestock.

2.2. Survey and Experimental Procedures

2.2.1. Distribution and Abundance of Wild Sunflower. The biophysical survey was conducted between June and October 2023, coinciding with the peak growth period of wild sunflowers. A multistage sampling technique was used to select three agroecological zones (highland, midland, and lowland) based on the degree of infestation. Two sites were chosen from each zone, and at each site, 40 quadrats (1 m× 1 m) were established, resulting in 240 sampling points. Within each quadrat, the presence of wild sunflowers and other weed species, particularly IAS, was recorded.

The data on weed species were summarized using the frequency, abundance, and dominance of each species, described as follows:

$$F = 100 \times X/N,$$

where F is the frequency of a particular weed species, X is the number of samples in which the species occurs, and N is the total number of samples.

$$A = (\sum W \times 100)/N,$$

where A is the abundance of the species, $\sum W$ is the sum of individuals of that species across all samples, and N is the total number of samples.

$$D = A \times 100/\sum A,$$

where D is the dominance of a particular species, A is the abundance of the same species, and $\sum A$ is the total abundance of all weed species.

2.2.2. Phenological Stages and Morphology

2.2.2.1. Seed Collection and Handling. Mature seeds of wild sunflower were collected from the main stems to ensure uniform maturity, considering the species' indeterminate growth habit. Sampling was conducted in May 2023 from 10 randomly selected plants in each of the three agroecological zones (highland, midland, and lowland) within the Doba district. Seeds from individual plants within each location were pooled to obtain a representative sample. Immediately after collection, the seeds were sun-dried for 24 h to reduce moisture content and subsequently stored in paper bags at room temperature (~22–25°C) for 2 months before sowing. Precautions were taken to prevent contamination or fungal infection during storage.

2.2.2.2. Experimental Design and Establishment. A greenhouse pot experiment was conducted over 6 months (August–December 2023) at the Melkasa Agricultural Research Center using a completely randomized design (CRD) with three treatments (seeds from highland, midland, and lowland) and five replications, resulting in a total of 15 pots. Each pot (15 cm in height × 25 cm in diameter) was sown with three seeds, which were later thinned to one seedling per pot. Plants were irrigated regularly to maintain adequate soil moisture.

2.2.2.3. Phenological Data Collection. Phenological observations were conducted every 2 days, with growth stages defined as follows: emergence or early seedling stage (from cotyledon to rosette development); vegetative stage (characterized by the development of five or more true leaves); head formation stage (when the first flower head became visible);

Table 1: Description of variables used in principal component analysis.

Variables	Variable code
Plant height	PH
Leaf number	LN
Leaf width	LW
Leaf length	LL
Node number	NN
Branch number	BN
Head number	HN

flowering stage (when at least 50% of the flower heads were fully open); and maturity stage (when seed heads turned brown and seeds hardened) [16]. Observations at 2-day intervals ensured precise determination of stage onset, and the number of days required to reach each stage was calculated from the sowing date. Monitoring was performed consistently across all treatments to enable reliable comparisons of growth patterns among seeds originating from different agroecological zones.

2.2.2.4. Morphological Data Collection. Morphological traits were systematically monitored every week from sowing through physiological maturity to capture the growth dynamics. Plant height (cm) was measured from the soil surface to the tip of the main stem, while leaf dimensions, including leaf length (from base to tip) and leaf width (at the widest point across the lamina), were measured using a plastic ruler. In addition, the number of leaves, nodes, and branches per plant was recorded at distinct developmental stages to characterize structural changes over time (Table 1). The number of flower heads per plant was counted starting at the onset of head formation and continuously updated throughout the maturity period to track reproductive development. To ensure measurement consistency and minimize diurnal variation in plant morphology, all observations were conducted at the same time of day under uniform conditions.

2.2.2.5. Seeds and Biomass Measurement. Dry biomass was measured at all phenological growth stages to assess the dynamics of vegetative growth throughout the plant's development. At each measurement, plants were clipped at ground level and oven-dried at 80°C for 48 h until a constant weight was obtained, enabling the determination of biomass per plant. These measurements provided detailed insights into both vegetative and reproductive performance. At physiological maturity, seeds were harvested, and the number of seeds per plant was recorded.

2.3. Socioeconomic Impact Assessment. Preliminary field observations and a socioeconomic survey were conducted alongside the biological survey to assess the impact of wild sunflower on local communities. A multistage sampling approach, consistent with the biological survey, was employed. The sample size was determined using Cochran's formula [17] with a 95% confidence level, $p = 0.5$, and a 7% margin of error, resulting in 196 respondents. To account for clustering effects and potential nonresponse, the sample size was increased to 240 households. These households were evenly distributed across three agroecological zones (80 per zone), with two sites per zone and 40 households per site. Site selection was purposive, followed by systematic random sampling of households. Socioeconomic data were collected through household interviews, transect walks, and focus group discussions using a semi-structured questionnaire. The data were recorded, analyzed, and integrated with the biological survey to interpret infestation patterns and community perceptions.

2.4. Data Analyses. Weed species data were analyzed using ecological indices frequency, abundance, and dominance following the procedures described in Section 2.2. Experimental data were subjected to analysis of variance (ANOVA) using R software (version 4.0.5). Prior to testing for significance, the assumptions of normality and homogeneity of variances were verified, with homogeneity assessed using the *F*-test [18]. Principal component analysis (PCA) was conducted on the mean values of each variable (Table 1) in SPSS to identify major patterns in the data. Socioeconomic data collected through questionnaires, including both quantitative and qualitative responses, were coded and analyzed using SPSS. Descriptive statistics and cross-tabulations were applied to summarize the dataset and complement the experimental findings, thereby providing an integrated understanding of the study context.

3. Results and Discussion

3.1. Weed Species Community. A total of 20 weed species, representing 11 families, were identified. The study was conducted across three agroecological zones: highland, midland, and lowland, with weed species composition recorded at six distinct sites. Wild sunflower was commonly observed in the midland and lowland zones, whereas its occurrence in the highland areas was only occasional (Table 2). These variations in species composition across agroecological zones likely reflect the influence of environmental factors on plant community dynamics.

The results indicate that the most prominent plant families in the study area were Asteraceae, Poaceae, and Amaranthaceae, with Asteraceae being the most diverse, represented by seven taxa. This family includes species commonly found in lowland areas, making them particularly prevalent in agricultural settings. Poaceae, represented by three taxa, are resilient and adaptable to a wide range of growing conditions, while Amaranthaceae, with two taxa, also contributed to the overall weed diversity at the study sites (Table 2). The finding that Asteraceae and Poaceae were also reported as dominant families in the central Rift Valley of Ethiopia by Amare et al. [15] highlights a broader ecological pattern. These families are typically associated with agricultural landscapes due to their competitive growth strategies and their ability to thrive in disturbed soils.

Moreover, the predominance of annual over perennial weed species in the study areas suggests that these environments favor the rapid growth and reproduction of annuals. Because annual weeds complete their life cycle within a single

Table 2: Frequency, abundance, and dominance of major weed species along different agroecology in Doba district.

Scientific name	Family	Life cycle	Frequency			Abundance			Dominance		
			Ifa H	Meda B	Misra Ch	Ifa H	Meda B	Misra Ch	Ifa H	Meda B	Misra Ch
Alternanthera pungens	Amaranthaceae	Perennial	2.50	23.75	12.50	0.16	1.63	0.70	0.25	2.75	1.18
Amaranthus spinosus	Amaranthaceae	Annual	30.00	20.00	6.25	1.14	0.69	0.18	1.74	1.16	0.29
Argemone Mexicana	Papaveraceae	Annual	1.25	12.50	0.00	0.01	2.06	0.00	0.02	3.49	0.00
Bidens pilosa L.	Asteraceae	Annual	70.00	5.00	1.25	15.63	0.48	0.04	23.91	0.80	0.06
Commelina benghalensis	Commelinaceae	Annual	10.00	12.50	22.50	0.23	0.46	0.59	0.34	0.78	0.99
Convolvulus arvensis	Convolvulaceae	Perennial	3.75	2.50	6.25	0.06	0.06	0.28	0.10	0.11	0.46
Cyperus rotundus	Cyperaceae	Perennial	46.25	23.75	15.00	13.30	6.51	2.51	20.35	11.01	4.23
Datura stramonium	*Poaceae*	Annual	3.75	12.50	2.50	0.23	0.45	0.06	0.34	0.76	0.11
Digitaria sanguinalis	*Poaceae*	Annual	10.00	35.00	0.00	6.58	7.60	0.00	10.06	12.85	0.00
Eleusina indica	*Poaceae*	Annual	36.25	13.75	1.88	10.45	0.95	0.11	15.99	1.61	0.19
Euphorbia heterophylla	Euphorbiaceae	Annual	0.00	17.50	8.75	0.00	1.03	0.46	0.00	1.73	0.78
Galinsoga parviflora	Asteraceae	Annual	32.50	0.00	0.00	13.90	0.00	0.00	21.27	0.00	0.00
Guizotia scabra	Asteraceae	Annual	16.25	1.25	0.00	0.73	0.01	0.00	1.11	0.02	0.00
Malva neglecta	Malvaceae	Perennial	7.50	7.50	0.00	0.40	0.24	0.00	0.61	0.40	0.00
Parthenium hysrophorus	Asteraceae	Annual	0.00	78.75	63.75	0.00	9.48	9.55	0.00	16.02	16.07
Rumex crispus	Polygonaceae	Perennial	21.25	0.00	0.00	0.65	0.00	0.00	0.99	0.00	0.00
Solanum elaegnifolium	Solanaceae	Prennial	0.00	1.25	1.25	0.00	0.03	0.01	0.00	0.04	0.02
Tagetes minuta L.	Asteraceae	Annual	22.50	3.75	0.00	1.10	0.13	0.00	1.68	0.21	0.00
Verbesina encelioides	Asteraceae	Annual	20.00	95.00	97.50	0.81	26.45	44.71	1.24	44.73	75.26
Xanthium abssinicum	Asteraceae	Annual	0.00	12.50	2.50	0.00	0.90	0.21	0.00	1.52	0.36

Abbreviations: B, Bilisuma; Ch, Chifra; H, Haka.

Table 3: Occurrence of wild sunflowers in different agroecological zones of Doba district.

Surveyed site (kebele)	No. of sites	Total no. of sampling point	No. sampling point	
			Presence [a]	Absence
Lowland (Misra Chifra)	2	80	79 (98.75)	1
Midland (Meda Belisuma)	2	80	79 (98.75)	1
Highland (Ifa Haka)	2	80	16 (20)	64
Total	6	240	174 (72.5)	66

[a]Values in parentheses are percentage presence out of total.

growing season, they can quickly colonize available niches, particularly in the disturbed soils of cultivated fields [19]. This dominance poses challenges for crop production, as annual weeds often outcompete crops for essential resources such as light, nutrients, and water.

3.2. Distribution and Abundance of Wild Sunflower. Wild sunflower was recorded across all three agroecological zones in the six surveyed sites, occurring at 72.5% of the total sampling points, highlighting its widespread distribution. The species was more frequently observed in the lowland and midland areas than in the highland areas (Table 3). Mean abundance followed a similar pattern, with the highest density (44.71 plants m^{-2}) recorded in the lowland and the lowest (0.81 plants m^{-2}) in the highland (Table 2). This distribution suggests that wild sunflowers are better adapted to the environmental conditions of lowland agroecological zones, where moderate climates provide favorable conditions for establishment and growth.

The higher prevalence of wild sunflower in lowland and midland areas may be attributed to soil type, moisture availability, and temperature regimes that favor their growth. In contrast, its reduced occurrence in the highlands likely reflects harsher climatic conditions or stronger competition from species better adapted to high-altitude environments. Similar patterns have been reported elsewhere: Dai et al. [20] observed lower invasive plant densities at higher elevations, while Pathak et al. [21] documented decreased weed diversity in elevated regions. These limitations are often linked to restricted habitat availability and unfavorable conditions that impede establishment. Understanding these ecological preferences is essential for developing targeted management strategies, especially in cultivated fields where wild sunflower competes with crops for vital resources.

3.3. Phenological Stages and Morphology

3.3.1. Phenological Stages. The duration required to progress through each growth phase showed no significant differences

Table 4: Growth and reproductive parameters of wild sunflowers at different developmental stages across various agroecological zones, 2023.

Location	Stages	Duration (days)	Plant height (cm)	Biomass (g plant^{-1})	Branch plant^{-1}	Head plant^{-1}	Seed plant^{-1}
Ifa Haka		17.23^{a}	10.33^{a}	1.02^{b}	—	—	—
Meda Bilisuma	Seedling/rosette	18.33^{a}	9.50^{a}	1.67^{a}	—	—	—
Misra Chifra		18.12^{a}	9.76^{a}	0.90^{b}	—	—	—
p (<5%)		Ns	Ns	**	—	—	—
Ifa Haka		55.50^{b}	51.31^{c}	9.68^{ab}	6.25^{b}	—	—
Meda Bilisuma	Vegetative	55.95^{ab}	54.21^{b}	10.04^{ab}	7.25^{a}	—	—
Misra Chifra		56.35^{ab}	56.23^{a}	10.65^{a}	6.91^{a}	—	—
p (<5%)		Ns	***	Ns	*	—	—
Ifa Haka		69.00^{a}	58.38^{b}	13.23^{b}	9.60^{a}	6.67^{a}	—
Meda Bilisuma	Head formation	70.00^{a}	60.52^{ab}	14.64^{ab}	10.15^{a}	7.05^{a}	—
Misra Chifra		69.03^{a}	59.08^{b}	15.18^{a}	8.87^{b}	6.84^{a}	—
p (<5%)		Ns	Ns	*	*	Ns	—
Ifa Haka		89.72^{a}	78.26^{b}	35.92^{a}	12.00^{a}	12.60^{ab}	—
Meda Bilisuma	Flowering	90.51^{a}	81.70^{a}	34.74^{b}	12.25^{a}	13.45^{a}	—
Misra Chifra		90.32^{a}	79.36^{ab}	36.32^{a}	11.89^{a}	11.76^{b}	—
p (<5%)		Ns	*	*	Ns	*	—
Ifa Haka		138.20^{b}	79.18^{a}	33.14^{b}	11.64^{a}	10.95^{ab}	813.00^{c}
Meda Bilisuma	Maturity	140.15^{ab}	80.04^{a}	52.12^{a}	10.60^{ab}	11.40^{a}	1603.20^{a}
Misra Chifra		137.32^{b}	79.54^{a}	34.52^{b}	9.82^{b}	9.87^{b}	974.60^{b}
p (<5%)		Ns	Ns	**	*	**	***

Note: Means followed by the same letters are not significantly different.
***Significant at 0.0001.
**Significant at 0.01.
*Significant at 0.05.

among seeds collected from different locations (Table 4). This suggests that the phenological development of wild sunflowers is more strongly influenced by the environmental conditions in which the plants grow than by the sites from which their seeds were harvested.

Wild sunflower devotes a substantial portion of its life cycle to the seedling and vegetative stages, as well as to the period between flowering and maturity. During the seedling stage, the plant establishes a root system and produces initial leaves essential for photosynthesis. It then enters a vegetative phase characterized by vigorous leaf production, which enhances light interception and nutrient uptake. Similar findings were reported by Amare et al. [22], who observed that wild sunflowers invest much of their life cycle in these stages. Once flowering begins, resources are redirected toward reproductive development, with the interval between flowering and maturity being critical for pollination and seed set.

Previous studies indicate that plant age and phenological progression can vary across locations due to environmental factors such as rainfall variability [23]. For example, arid conditions have been shown to accelerate growth and shorten the lifespan of *Parthenium hysterophorus* [24]. These phenological shifts in response to climate provide important insights into the invasive potential of weeds. As highlighted in recent research [25], understanding how environmental conditions influence growth and reproduction is essential for assessing invasion risks and developing context-specific management strategies.

Understanding weed phenology is crucial for designing effective control measures. Taylor et al. [26] emphasized that management interventions are most effective when applied during the rapid growth phases of wild sunflowers. Similarly, Amare et al. [22] demonstrated that monitoring the phenology of Pennisetum ciliare enabled the identification of critical windows, such as reproductive development and green-up, when plants are most vulnerable to mechanical and chemical control. Incorporating phenological data into management strategies can therefore significantly enhance the effectiveness of weed control programs.

3.3.2. Morphological Characteristics of Wild Sunflower

3.3.2.1. Height, Branch, and Flower Head. The height of wild sunflowers varied significantly among plants grown from seeds collected at three different locations. The tallest plants (81.70 cm) were recorded at the flowering stage in pots established with seeds from the midland area. Plant height increased rapidly from the seedling to the vegetative stage, followed by a more gradual rise as the plants approached flowering (Table 4). During the vegetative phase, wild sunflowers initiated branch development, which continued progressively until flowering. The number of flower heads per plant closely mirrored the branching pattern, with maximum production observed during the flowering stage. At this stage, plants exhibited the highest counts of both open and closed flower heads (Table 4). This growth pattern illustrates the dynamic developmental strategy of wild sunflowers,

Table 5: Correlation matrix of morphological characteristics.

Variables	PH	LN	LW	LL	NN	BN	HN
Plant height (PH)	1.00	—	—	—	—	—	—
Leaf number (LN)	0.48	1.00	—	—	—	—	—
Leaf width (LW)	0.01	0.27***	1.00	—	—	—	—
Leaf length (LL)	0.03	0.24***	0.86***	1.00	—	—	—
Node number (NN)	0.42***	0.43***	0.25***	0.20**	1.00	—	—
Branch number (BN)	0.11	0.34***	0.39***	0.39***	0.49***	1.00	—
Head number (HN)	0.69***	0.45***	−0.09	−0.06	0.19**	0.64***	1.00

**Significant at 0.01.
***Significant at 0.0001.

highlighting their capacity to allocate resources efficiently across growth phases and maximize reproductive output during flowering.

These findings align with those of Amare et al. [15], who observed rapid height growth from the seedling to the vegetative stage, followed by a gradual increase until flowering. This growth was accompanied by branching and flower head production, which progressed concurrently. Collectively, these results highlight the competitive traits of wild sunflower, including rapid early growth, sustained branching, and prolific flower head production, all of which contribute to its invasive potential and persistence in both cropping and non-cropping systems. From a management perspective, understanding these growth dynamics is crucial, as interventions targeting the crop–weed competition window are likely to be most effective during the early vegetative phase, before significant investment in branching and reproductive development occurs.

3.3.2.2. Biomass and Seed Production. The results indicate that biomass accumulation in wild sunflowers is closely linked to their developmental stages, showing a steady increase from the seedling phase to maturity. A marked acceleration in biomass production occurs as the plants transition from the seedling stage to the vegetative and flowering phases, reaching a peak at maturity. This growth trajectory reflects the species' adaptive strategy of investing heavily in structural and reproductive tissues during the later developmental stages.

Seed origin had a significant effect on the reproductive performance of wild sunflower ($p < 0.001$). All plants that reached the flowering stage successfully produced seeds, confirming the species' strong reproductive capacity. However, seed output varied considerably among seed sources. Plants grown from seeds collected in the midland region produced the highest average seed number (1603.20 seeds per plant), whereas seeds from lowland and highland sites resulted in lower seed production, averaging 974.60 and 813.00 seeds per plant, respectively. This variation highlights the influence of seed provenance on reproductive success, suggesting that environmental factors associated with the maternal environment may play a pivotal role in determining seed yield.

These findings align with earlier reports indicating that a single flower head of wild sunflower can produce 300–350 seeds. With each plant bearing 2–6 flower heads, the total seed output can range from ~600–2100 seeds [11]. Variability in seed production is influenced by a combination of genetic, physiological, and environmental factors. The ability to produce large quantities of seeds provides wild sunflower with a distinct ecological advantage, ensuring prolific regeneration, rapid colonization of new habitats, and persistence under variable environmental conditions. The high reproductive potential observed in this study underscores the resilience of wild sunflower populations and highlights the challenges associated with their management. By sustaining robust seed production across diverse agroecological zones, wild sunflower reinforces its capacity to establish persistent seed banks, thereby enhancing its competitiveness in both cropping systems and natural ecosystems.

3.3.2.3. PCA. The analysis of the correlation matrix derived from the PCA revealed strong positive relationships among plant height, number of nodes, and number of flower heads, indicating that taller plants tend to be structurally more developed and capable of supporting higher reproductive output (Table 5). Similarly, the numbers of leaves and branches were positively associated with all measured traits, reflecting a coordinated growth strategy in which vegetative expansion supports reproductive development. This pattern underscores the ecological advantage of wild sunflowers, as increased height, branching, and leaf production collectively enhance light capture, photosynthetic efficiency, and seed production capacity.

These interrelated traits demonstrate the plasticity of the wild sunflower, enabling it to adapt and thrive across diverse environments. From a management perspective, the findings indicate that suppressing early vegetative growth is critical, as unchecked height and branch development directly contribute to increased reproductive success and seed bank replenishment. Effective management of wild sunflower, therefore, requires integrated strategies targeting early growth stages to limit the establishment of a robust vegetative framework, thereby reducing the plant's competitive ability and long-term persistence.

PCA identified two primary components that together explained ~62% of the total variation in the dataset, with the addition of a third component accounting for an extra 13% (Table 6, Figure 1). The first principal component alone explained 34% of the variation and was predominantly associated with plant height, leaf number, node count, and flower

Table 6: Eigenvectors of the first two principal components of measured variables and their respective loadings.

Variables	1st component (34%)[a]	2nd component (28%)[a]
Plant height	0.47	0.10
Leaf number	0.30	0.32
Leaf width	−0.10	0.51
Leaf length	−0.09	0.48
Node number	0.21	0.35
Branch number	−0.01	0.43
Flower head number	0.48	0.00

[a]Values in brackets represent the percentage of the variance explained by each component.

head count. The traits most strongly loaded on this component were the number of flower heads (0.48), plant height (0.47), and leaf number (0.30), indicating that these variables tend to increase concurrently. This pattern reflects a synergistic relationship among key morphological and reproductive traits, suggesting that vigorous vegetative growth directly supports reproductive potential in wild sunflowers.

In contrast, the second principal component was strongly associated with leaf width, leaf length, and branch number, representing a distinct cluster of interrelated traits separate from those captured by the first principal component (Table 6). These results suggest that while the first principal component reflects the coordinated influence of height, leaf production, and reproductive structures, the second principal component primarily represents variation linked to leaf morphology and branching. Overall, the PCA underscores the interconnected nature of wild sunflower traits and provides insights into how different morphological attributes collectively contribute to the species' growth dynamics and overall development.

3.4. Socioeconomic Impact Assessment Based on Community Perception

3.4.1. Household and Demographic Characteristics. A household survey was conducted with 240 farmers, evenly distributed across the lowland, midland, and highland agroecological zones (80 per zone), to collect demographic information. Key characteristics, including sex, age, and educational background, are summarized in Table 7. These data provide insights into the composition of the farming community and help to understand how demographic factors may influence agricultural practices and decision-making across different agroecological contexts.

The majority of surveyed households were male-headed (74.2%), while female-headed households accounted for 25.8%. Regarding age distribution, 72.9% of respondents were between 30 and 49 years old, 16.3% were over 50 years, and 10.8% were between 18 and 29 years (Table 7). In terms of educational attainment, 43.8% of respondents had completed primary education (grades 1–8), whereas 31.7% had no formal education. Approximately 18.3% were literate, possessing basic reading and writing skills; 5.4% had completed grades 9–12, and 0.8% had attained education beyond the diploma level (Table 7).

3.4.2. Introduction of Wild Sunflower. The majority of farmers (83.3%) reported that wild sunflower was introduced to the study area in 2017, particularly in the highland and lowland zones (Table 8). In contrast, a significant proportion of farmers in the midland areas were uncertain about when it was introduced in their localities.

This lack of awareness may suggest a gap in communication or outreach regarding agricultural changes in these areas, highlighting the need for better information dissemination to ensure all farmers are informed about new pests, particularly invasive plant species, and their potential threat.

3.4.3. Farmers' Views on Infested Habitats. All surveyed farmers reported the presence of wild sunflower across different land-use types. In the highland area (Ifa Heka), residential areas were identified as the most infested (37.5%), followed by grazing lands (36.2%). In the midland area (Meda Bilisuma), cropland was perceived as the most affected (46.2%), with residential areas following (21.2%). Farmers in the lowland area expressed equal concern for infestations in both cropland and residential areas (Table 9), highlighting variations in perceived impact across agroecologies.

Overall, the findings indicate a consensus among farmers regarding the infestation of wild sunflower, particularly in cropland and residential areas. This shared perception emphasizes the need for effective management strategies to curb the spread of wild sunflowers and mitigate its negative impacts on both agricultural productivity and community living conditions. The data presented in Table 9 further highlight these perceptions, reinforcing the importance of targeted interventions in the most affected areas.

3.4.4. Dispersal Mechanism and Spread Rate of Wild Sunflower. In the study area, a substantial proportion of interviewed farmers (35%) identified the transportation of construction materials, such as soil, sand, and gravel, as a primary factor contributing to the rapid spread of wild sunflower. This was followed by wind dispersal (22.1%) and animal movement (18.3%) (Table 9). Farmers noted that the transport of construction materials often inadvertently carries wild sunflower seeds to new locations, facilitating their establishment in areas where they might not naturally occur. Wind dispersal further aids in spreading seeds over distances, while animals can contribute by transporting seeds on their fur or through droppings. Understanding these dispersal mechanisms is essential for designing effective management strategies to control the spread of wild sunflower in agricultural landscapes.

Regarding the rate of spread, the majority of respondents (64.8%) perceived it as medium, suggesting that they consider the issue manageable but requiring attention. In addition, 21.7% of farmers reported a low spread rate, indicating that they do not view wild sunflowers as a significant threat to their crops or land, while 14.4% expressed concern over a high spread rate, reflecting more severe infestations or rapid

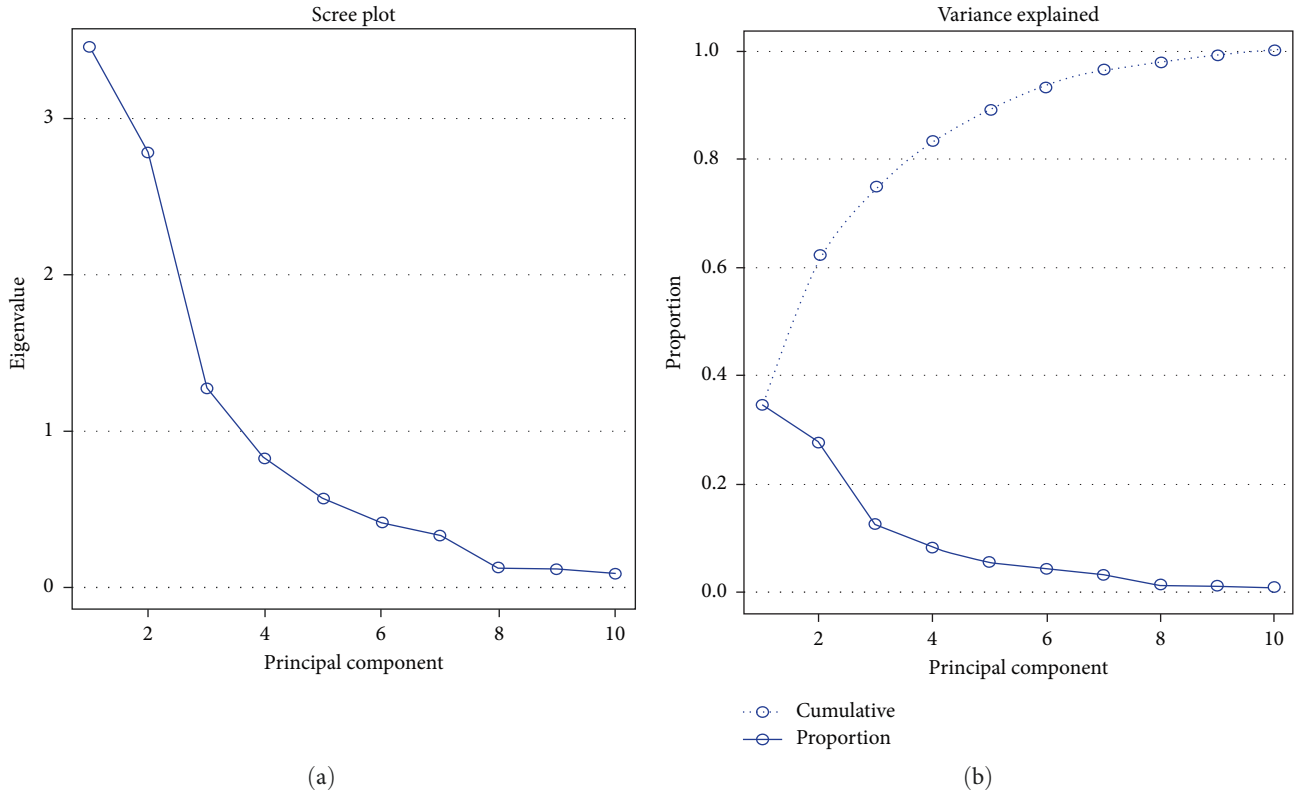


Figure 1: Scree plot (a) and variance explained (b).

Table 7: Demographic characteristics of respondent farmers ($N = 240$).

Variables	Kebeles/villages			
	Ifa Heka	Meda Bilisuma	Misra Chifra	Total
Sex				
Men	63.8	83.8	75	74.2
Women	36.2	16.2	25	25.8
Age				
18–29	2.5	12.5	17.5	10.8
30–49	81.2	71.2	66.2	72.9
Greater than 50	16.2	16.2	16.2	16.3
Level of education				
Illiterate	22.5	22.5	50	31.7
Literate	16.2	23.8	15	18.3
Grade 1–8	53.8	45	32.5	43.8
Grade 9–12	7.5	7.5	1.2	5.4
Diploma	0	1.2	1.2	0.8

Table 8: Mean number of respondents on time and means of introduction of wild sunflowers into Doba district ($N = 240$).

Variables	Kebeles/villages			
	Ifa Heka	Meda Bilisuma	Misra Chifra	Total
Introduction period				
Since 2017	100	50	100	83.3
Do not know	0	50	0	16.7

growth in their localities (Table 9). Similarly, Amare et al. [15] reported that wild sunflower is widely distributed at an alarming rate across different habitats in the Central Rift Valley of Ethiopia.

3.4.5. Impacts of Wild Sunflowers on Agriculture and Biodiversity. Farmers reported that wild sunflower imposes significant socioeconomic and ecological impacts, reducing crop and livestock productivity through the competition for nutrients and space, and threatening local biodiversity by displacing native plant species and disrupting wildlife habitats.

3.4.5.1. Farmers' Perception About the Effect of Wild Sunflowers on Crop Production. Farmers' perceptions of wild sunflowers play a critical role in addressing its impact on crop production. The majority (66.7%) of the respondent farmers in the study area have good awareness about the effects of wild sunflower on crop production, while a significant percentage (33.30%) of the farmers have no idea about the effect of wild sunflower on crops (Table 10). Differences in awareness likely reflect variations in experience with invasive species, crop types, and local ecological conditions, which influence both exposure to and concern about wild sunflower infestations.

For instance, farmers who have encountered issues with invasive plant species in the past are likely to be more informed about its potential threats to their yields. Conversely, those who have not faced such challenges may remain unaware of the

Table 9: Respondents' perception of habitats infested and the spread rate of wild sunflower weeds on the study areas ($N = 240$).

Variables	Kebeles/villages			
	Ifa Heka	Meda Bilisuma	Misra Chifra	Total
Land use types				
Crop fields	11.2	46.2	33.8	30.4
Fallow lands	6.2	13.8	17.5	12.5
Graze land	36.2	8.8	3.8	16.2
Residential area	37.5	21.2	33.8	30.8
Roadside	8.8	10.0	11.2	10
Rate of spread				
High	10.7	10.1	22.2	14.4
Low	14.3	26.2	16.6	21.7
Medium	75.2	63.8	61.2	64.8
Dispersal mechanism				
Wind	20	32.5	13.8	22.1
Construction materials	32.5	37.5	35	35
Animal	30	17.5	7.5	18.3
Flooding	8.8	6.2	17.5	10.8
Do not know	8.8	6.2	26.2	13.8

Table 10: Respondents' perceptions of the effects of wild sunflower on crop and livestock production and biodiversity.

Response category	Kebele			Total
	Misra Chifra	Meda Bilisuma	Ifa Haka	
Effect on crops				
Yes	33.4	33.3	0.00	66.70
No	0.00	0.00	0.00	0.00
Do not know	0.00	0.00	33.30	33.30
Effect on livestock				
Yes	33.4	33.3	0.0	66.7
No	0	0	0	0
Do not know	0.0	0.0	33.3	33.3
Effect on biodiversity				
Yes	33.4	33.3	0.0	66.7
No	0	0	0	0
Do not know	0.0	0.0	33.3	33.3

risks [27]. Moreover, the ecological conditions of different areas can influence the prevalence and impact of invasive plant species, leading to varying levels of concern among farmers [28].

3.4.5.2. Farmers' Perception About the Effect of Wild Sunflower on Livestock Production. A substantial percentage of farmers in the study area (66.7%) recognized that wild sunflower negatively impacts livestock production (Table 10). This awareness indicates that these farmers understand the potential harmful effects of wild sunflowers, which is possibly due to its competition for essential resources, such as forage plants, or its possible toxic properties. Previous studies stated that after identifying galegine as the main toxic compound in wild sunflower, studies in the United States confirmed it as "poisonous plant material" that could endanger livestock [29].

On the other hand, a remarkable percentage (33.3%) of the respondent farmers did not know about the impact of wild sunflower on livestock production, indicating a gap in knowledge or awareness regarding the interactions between this invasive plant and livestock. Conversely, a significant percentage of farmers (33.3%) expressed uncertainty about the effects of wild sunflowers on livestock production (Table 10). This lack of awareness points to a notable gap in knowledge regarding the interactions between this invasive species and livestock.

3.4.5.3. The Effect of Wild Sunflowers on Plant Biodiversity. More than 66% of the farmers surveyed recognized that wild sunflower poses a significant threat to biodiversity and contributes to the loss of various habitats. While the respondents noted that the negative impacts of wild sunflowers had not yet been formally documented in their area, they expressed concerns about its potential to endanger plant species, particularly forage plants and other economically valuable species essential for their livelihoods. Key informants emphasized that the wild sunflower ability to thrive in diverse habitats and adapt to various environmental conditions, combined with its prolific seed production, makes it a serious threat to local biodiversity.

Previous research has shown that the aggressive nature and dominant growth of wild sunflower can inhibit the growth of native plants [30]. Similarly, Amare et al. [15] found that wild sunflower remarkedly decreases the density and diversity of other plant species. Its competitive strength and aggressive behavior hinder the growth of native flora [15]. Moreover, wild sunflower competes with co-occurring plant species due to allelopathic interference [14]. This understanding highlights the urgent need for awareness and management strategies to mitigate the impact of this invasive species on agricultural ecosystems and the natural environment.

3.4.6. Farmers' Perception About Weed Control Mechanisms. The perceptions of farmers regarding the control methods for wild sunflower in the study area are detailed in Table 11. Among those interviewed, 42.9% identified slashing and mowing as effective strategies for managing wild sunflower populations. In contrast, 35.8% of respondents favored a combination of cutting and burning as the most effective control measures. In addition, 21.2% of the farmers believed that hand weeding is a viable method for managing wild sunflower infestations.

These findings highlight a diverse range of approaches among farmers, reflecting their varying experiences and preferences in dealing with this invasive plant. The predominance of slashing and mowing suggests a practical, mechanical approach favored by many, likely due to its immediate effectiveness and lower environmental impact compared to burning. Meanwhile, the significant support for cutting and burning indicates that some farmers may

Table 11: Control mechanisms implemented in the study area.

Variables	Kebeles/villages			
	Ifa Heka	Meda Bilisuma	Misra Chifra	Total
Control techniques				
Hand weeding	33.8	30.0	0.0	21.2
Cutting and burning	30.0	33.8	43.8	35.8
Slashing or mowing	36.2	36.2	56.2	42.9

prioritize more aggressive methods to ensure thorough eradication. Hand weeding, while less popular, shows that a segment of the farming community values manual intervention, possibly for its precision and selectivity in controlling wild sunflower without affecting surrounding crops. Overall, these insights reveal the complexity of managing wild sunflowers and underscore the importance of considering farmer perspectives when developing integrated control strategies.

Previous studies have shown that effective mechanical control methods for wild sunflower include the removal of flower heads, complete plant removal, and mowing [31]. These techniques aim to disrupt the plant's growth cycle and prevent it from reproducing, thereby reducing its spread. In contrast, Sade et al. [12] found that the use of preemergence herbicides can be highly effective in managing wild sunflower populations. In addition, they noted that postemergence herbicides can also yield successful results, but their effectiveness is significantly enhanced when applied during the 2–4 leaf stage of the plant's growth. This timing is crucial because the young plants are more vulnerable to herbicides at this stage, allowing for better absorption and control.

4. Conclusions and Recommendations

This study provides a comprehensive assessment of several key aspects related to the distribution and significance of wild sunflowers in the West Hararghe Zone, Doba district. The research details the composition and diversity of weed species present in the surveyed areas, highlighting the various families and species that coexist with wild sunflower. The occurrence of wild sunflowers was recorded at six sites across different land-use types. Notably, wild sunflower was frequently observed in both the midland and lowland areas. The study identifies patterns in its prevalence, noting that it is more abundant in lowland and midland areas compared to highland regions. An in-depth investigation of the growth stages of wild sunflowers is presented, detailing their life cycle from seedling to maturity. Furthermore, morphological traits such as leaf size, flower head formation, and overall plant size are described, providing insight into how these characteristics may affect its competitiveness in agricultural fields. The study includes qualitative data gathered from farmers regarding their experiences with wild sunflowers and their effects on crop yields. In addition, it examines how wild sunflower impacts livestock health and productivity. Moreover, the study explores the interactions between wild sunflowers and other plant species within the ecosystem, assessing whether its presence promotes or hinders biodiversity.

Finally, the study gathers insights from farmers regarding their methods for managing wild sunflower populations. These methods include slashing and mowing, cutting, burning, and hand weeding. If wild sunflowers are allowed to grow unchecked and unmanaged, they could significantly impact the country's agricultural and natural ecosystems. Given the current circumstances, it is essential to implement effective measures to prevent the spread of this invasive weed from areas where it is already established to new locations where it has not yet appeared. While Ethiopia does not currently have a formalized biological control program for this weed, future efforts should assess the application of host-specific pathogens or insect herbivores in a manner that is safe for non-targeted species. Accurate determination of allelopathic effects requires experimental approaches, such as controlled laboratory bioassays, greenhouse pot experiments, and field trials in future studies.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare no conflicts of interest.

Author Contributions

Dagne Amare was responsible for conceptualizing the study, curating the data, conducting the formal analysis, and securing funding and also contributed to data investigation, methodology design, and drafting the original manuscript. Both Amin Mohammed Yones and Amare Fufa Beyene contributed to the study's conceptualization, data investigation, drafting of the original manuscript, and reviewing and editing the final manuscript.

Funding

No funding was provided for this manuscript.

Acknowledgments

The authors would like to thank Melkasa Agricultural Research Center for the pot experiment and Oda Bultum University for technical support.

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