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Diversity of weed communities in cereal crops of traditional dryland oases of SW Algeria (North Africa)

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ABSTRACT

Cereals are among the most important crops in arid and semi-arid regions and are widely cultivated in the traditional oases of southwestern Algeria. However, their productivity is constrained by several biotic and abiotic factors, particularly weeds. This study aimed to analyse weed communities associated with cereal crops in these oasis agroecosystems. Data were collected from 30 phytoecological relevés and analysed using species richness, density, frequency, importance value index, Shannon-Weaver diversity index, equitability, plant functional traits, and phytogeographic spectra. A total of 34 species belonging to 33 genera and 17 families were recorded. The most represented families were Asteraceae (17.6%), Amaranthaceae (14.7%), Poaceae (14.7%), and Brassicaceae (11.7%). The flora was dominated by eudicots (80.4%), while monocots represented 19.5%. Therophytes were the dominant life form (95%). Biogeographic analysis showed a predominance of cosmopolitan (48.6%) and Mediterranean (22.8%) species. Anemochory (50.4%) was the main dispersal mode, and C_3 species dominated (92.9%). The most damaging weeds with the highest importance values were: *Sonchus oleraceus*, *Anagallis arvensis*, and *Emex spinosa*. The results of this study provide valuable information for developing effective weed management strategies to help improve cereal yield and quality in oasis agro-systems.

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INTRODUCTION

The Algerian Sahara, covering more than 84% of the national territory (~2 million km^2), is characterised by extreme aridity, scarce water resources, and sparse vegetation (Bessaoud et al., 2019). Vegetation is mainly confined to specific habitats where water availability allows plant establishment, particularly in oasis environments (Le Houérou, 1990; Bouallala et al., 2020; Souddi and Bouallala, 2023). These oases represent traditional agroecosystems with high phytogenetic diversity, covering approximately 180,000 ha and hosting more than 18 million date palms (*Phoenix dactylifera* L.) (~950 cultivars), producing about one million tonnes annually (Rahal Bouziane et al., 2010; Moulai and Yahaya, 2020). Oasis agroecosystems are typically structured into three vertical layers: (i) an upper layer of date palms providing microclimatic protection, (ii) an intermediate layer of fruit trees (olive, pomegranate, fig, apricot, plum), and (iii) a lower layer of herbaceous crops such as cereals and vegetables (Allam et al., 2013; BenAradj et al., 2020). However, this organisation varies with environmental and management conditions.

In the Algerian Sahara, the expansion of cereal cultivation has been supported by land and groundwater availability, suitable climatic conditions, and increasing market demand (Idder et al., 2011). Cereals occupy about 3.2 million hectares (~37% of the utilised agricultural area), with durum wheat (*Triticum durum* Desf.) dominating (47%), followed by barley (*Hordeum vulgare* L.) (33%) and soft wheat (*Triticum aestivum* L.) (17%) (ONS, 2019). Oat (*Avena sterilis* L.), mainly grown for animal feed, is also cultivated in oasis systems due to its adaptability to harsh conditions. Despite their importance, cereal crops are strongly affected by weeds, which constitute a major biological constraint (Dangwal et al., 2010; Etiabi et al., 2021; Ibrahim et al., 2022). Weeds reduce productivity through competition for resources, allelopathy, rapid reproduction, and high adaptability (Andreasen et al., 1991). Yield losses can exceed 70% under poor control and range from 13.8% to 97% depending on infestation levels and environmental conditions (Tanji, 2005; Oerke, 2006). These losses depend on several factors, including crop variety, weed composition, infestation level, duration of competition, and environmental conditions (Tamado and Milberg, 2002). Effective weed management requires a thorough understanding of weed flora composition and its dynamics under different agricultural practices. Such knowledge is essential for developing appropriate and sustainable control strategies (Chafik et al., 2013). Although numerous studies have addressed weed flora and their agronomic characteristics (Hanitet et al., 2021; Cherif et al., 2022; Deghiche-Diab et al., 2022), weed communities in oasis agroecosystems of southwestern Algeria remain poorly documented.

The weed flora of the oasis agrosystems in southwestern Algeria remains poorly documented to this day. Therefore, the present study aimed to characterize weed communities in wheat and oat fields within arid oasis agrosystems. Specifically, we analyzed species composition, diversity (Shannon–Weaver index and evenness), plant functional traits, and phytogeographic spectra to identify the most dominant and potentially problematic weed species under these extreme environmental conditions.

MATERIAL AND METHODS

Study area

The study area is located in the Wilaya of Adrar in the Algerian Sahara. This wilaya is bounded to the north by the Wilaya of Timimoune, to the east by the Wilaya of In Salah, to the west by the Wilaya of Tindouf, and to the south by the Wilaya of Bordj Badji Mokhtar (Fig. 1). Geographically, the study area lies between latitudes 27° and 29° North and longitudes 3° West and 1° East, covering an area of approximately 20 970 km^2. It is bounded to the north by the daïras of Adrar and Aougrout, to the south by the daïra of Zaouiet Kounta, to the east by the daïra of Aoulef, and to the west by the daïra of Tabelbala. The climate of this region is hyper-arid, characterised by very low and irregular rainfall (Bouallala et al., 2020; Souddi and Bouallala, 2021, 2022, 2023). According to meteorological data for the Wilaya of Adrar obtained from the ClimateCharts database (https://climatecharts.net/) for the period 1990–2019, the maximum monthly rainfall recorded was 1.3 mm in April, while the minimum was 0.3 mm in December. The mean monthly temperature reached a maximum of 36.6°C in July and a minimum of 12.7°C in March. Based on the ombrothermic diagram of Bagnouls and Gaussen (1953), which defines the dry period according to the relationship between temperature and precipitation, the dry season extends throughout the entire year (Fig. 2). The soil texture is predominantly sandy or sandy-loam, which contributes to low plant biomass (Berrached, 1996).

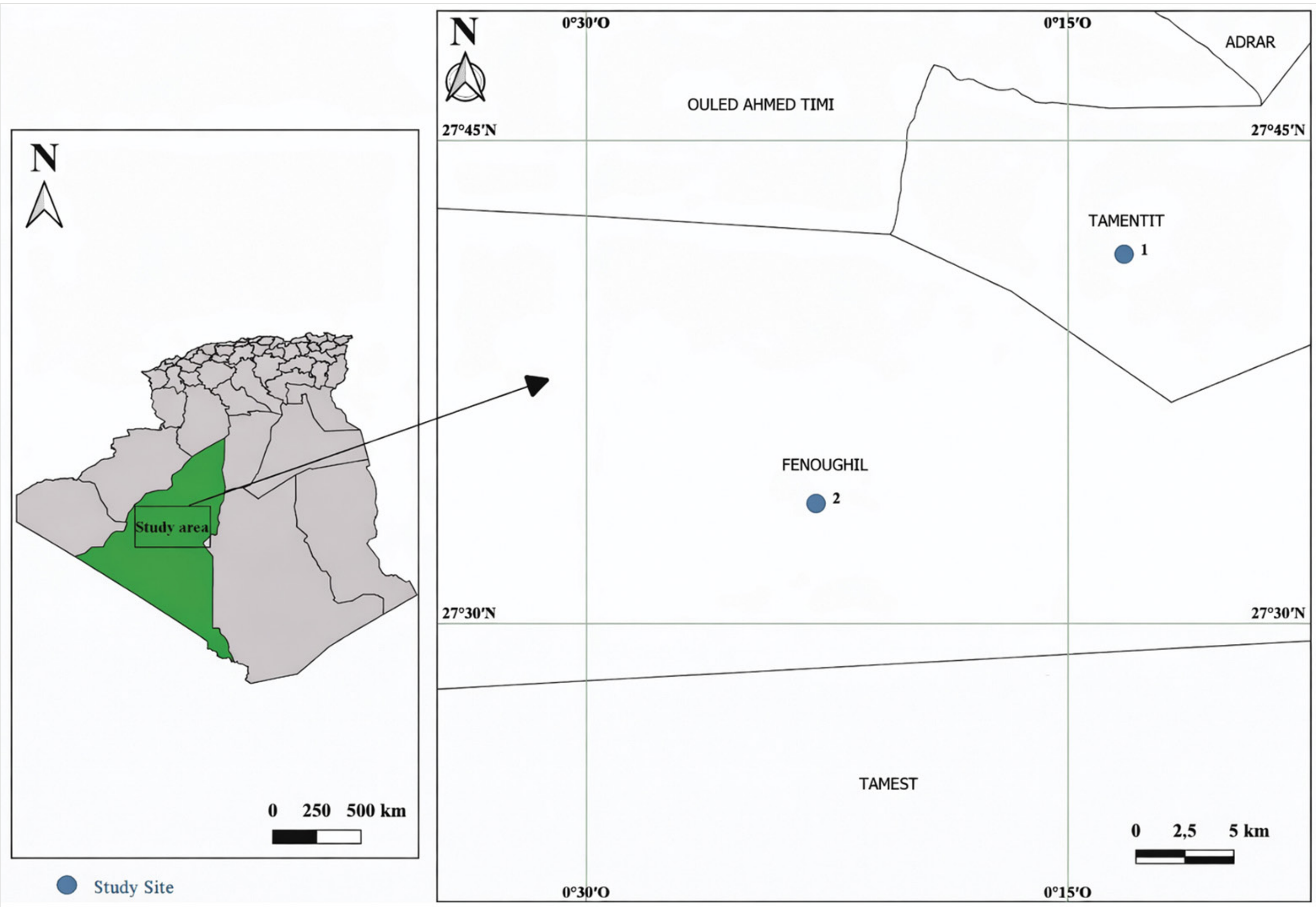

Figure 1. Location of the study area, with the Wilaya of Adrar highlighted in green

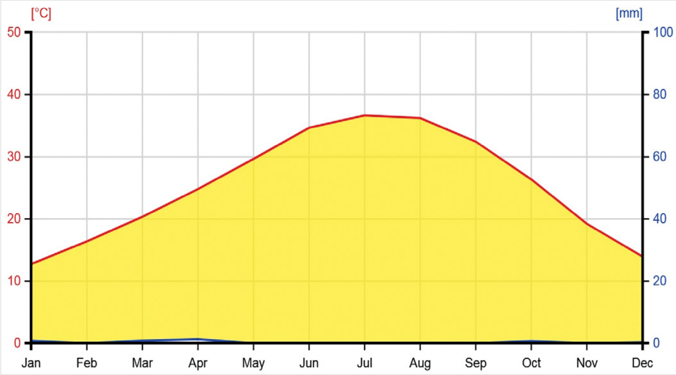

Figure 2. Ombrothermic diagram of the Adrar region (1990-2019) of SW Algeria (from Bagnouls & Gaussen, 1953)

Sampling and phytoecological relevé

Sampling was subjective for the wheat and oat plots selected in the agrosystems of southwest Algeria (Fig. 1). The floristic method adopted was the "field tour", which provides an exhaustive inventory of all species present within a plot (Maillet, 1981; Le Bourgeois, 1993; Chicouène, 2000). This method involves traversing the cultivated plot in different directions until no new species are discovered (Le Bourgeois 1993; Chicouène, 2000). This technique allows for the inclusion of rare species, which may have significant agronomic importance (Le Bourgeois and Guillerm, 1995), particularly species with rapid spread or those indicating specific environmental conditions. A total of 30 floristic relevés were conducted from February to May 2022 (15 relevés in a wheat crop and 15 relevés in an oat crop). Each relevé covered an area of 1 m^2, which is considered sufficient to obtain an exhaustive representation of weed flora. The selection of the study plots was supported by several studies on weeds (Singh et al., 2018; Satriawan and Fuady, 2019; Pala et al., 2020). For each relevé, the abundance (number of individuals) of each species was recorded and used to calculate absolute and relative densities (Shukla and Chandel, 1989). Species identification was carried out using the floras of Quézel and Santa (1962-1963) and Ozenda (2004).

Ecological groups

To obtain floristically homogeneous ecological groups, a hierarchical ascending classification based on species abundance was applied to define survey groups (Souddi and Bouallala, 2022). This classification considers the similarities among relevés within the same dataset in order to identify subsets of similar relevés (Bouallala et al., 2020). This approach has been widely used in numerous phytoecological studies conducted in arid and semi-arid regions (Macheroum et al., 2021; Souddi and Bouallala, 2022, 2023; Belhadj et al., 2023).

Diversity Index

The characterisation of floristic diversity is a key component of ecosystem assessment (Le Floc'h and Aronson, 1995). For each phytoecological group, weed diversity was evaluated using species richness (S), Shannon-Weaver index (H'), and evenness (E) (Magurran, 2004). Species richness (S) is defined as the total number of species present within each phytoecological group and across the entire study area.
The Shannon diversity index (H') is widely used to compare diversity among different habitats. It is calculated using the formula: $H' = -\Sigma\, p_i \log_2 p_i$, where $p_i = n_i / N$ and represents the relative abundance of individuals of the species *i* in the total sample, n_i is the number of individuals of species *i*, and *i* ranges from 1 to S (the total number of species), and N is the total number of individuals of all species (total sample). The Shannon index is sensitive to the diversity of common species (Shannon and Weaver, 1949); higher values of H' indicate greater diversity (Kent and Coker, 1992).
The evenness index (E) was used to quantify the regularity component of diversity and was calculated as follows: $E = H' / H_{max}$, where $H_{max} = \log_2 S$ represents the theoretical maximum diversity (Piélou, 1966). The value of E ranges from 0 to 1, with E = 1 indicating a completely even distribution of individuals among species (Kent and Coker, 1992).

Frequencies, densities and importance value index

For species within each phytoecological group, several relative indices were calculated: frequency (F), relative frequency (RF), density (D), relative density (RD), and relative abundance (RA), which were subsequently used to compute the Importance Value Index (IVI) (Concenço et al., 2013).
Species frequency (F) is defined as the number (n) of relevés in which a species occurs out of the total number (N) of relevés sampled. Five frequency classes were distinguished: Class I: very rare species ($0 < F < 20\%$); Class II: rare species ($20\% \le F < 40\%$); Class III: frequent species ($40\% \le F < 60\%$); Class IV: abundant species ($60\% \le F < 80\%$); Class V: constant species ($80\% \le F \le 100\%$) (Duretz, 1920).
Relative frequency (RF) is defined as the proportion of the frequency of a given species relative to the sum of frequencies of all species, expressed as: RF = (frequency of species / total frequency of all species) × 100.
Density (D) is expressed as the number of individuals per unit area and represents a key parameter in sustainable weed management (Odum and Barrett, 1971).
Relative density (RD) represents the numerical contribution of a species relative to the total number of individuals of all species and is calculated as: RD = (density of species / total density of all species) × 100.
Relative abundance (RA) refers to the proportion of individuals of a given species relative to the total number of individuals of all species. It is calculated as: $RA = (Aa / N) \times 100$, where Aa is the absolute abundance and N is the total number of individuals (Triplet, 2023).
The dominant weed species within each phytoecological group were identified using the Importance Value Index (IVI) (Abd El-Hamid and Kamel, 2010; Ahmed and Shaukat, 2012; Ibrahim et al., 2022). This index provides an estimate of the overall ecological importance of each species within a plant community (Brower and Zar, 1990). Higher IVI values indicate a greater ecological role. The IVI is calculated as the sum of relative frequency, relative density, and relative abundance of each species (Concenço et al., 2013; Pala et al., 2020).

Functional traits of weed groups studied

The floristic composition of weed communities was analysed using functional traits. These traits are essential for a better understanding of the relationships between plant communities and their environment (McGill et al., 2006). Functional traits of weeds were determined for each phytoecological group and for the entire study area based on the following references: Quézel and Santa (1962-1963), Ozenda (2004), and the Tela-Botanica database (https://www.tela-botanica.org/). Both raw spectra (species richness) and real spectra (density) of weed functional traits were used to characterise each phytoecological group.

Life Forms

The classification of taxa according to their growth form or morphology is crucial for the physiognomic description of vegetation, as these traits reflect the evolutionary adaptations of plants to their environment (Orshan, 1953). According to Raunkiaer (1934), plant adaptation strategies to environmental conditions, particularly climatic factors, can be better understood through the biological spectrum. This classification is based on the position of survival organs (persistent buds) relative to the soil surface during unfavourable periods of the year. It distinguishes five biological types: phanerophytes, chamaephytes, hemicryptophytes, geophytes, and therophytes.

Dispersion types

Plant dispersal strategies represent a set of adaptations that ensure species propagation. Depending on the internal and external factors involved, as well as the biotic and abiotic agents responsible for diaspore dissemination, van der Pijl (1982) distinguished five main dispersal types: anemochory, hydrochory, zoochory, barochory, and autochory. In this study, dispersal types were determined based on reference works (Quézel and Santa, 1962-1963; Ozenda, 2004; Bouallala et al., 2020; Souddi and Bouallala, 2022, 2023) and the Tela-Botanica database (https://www.tela-botanica.org/).

Life cycle

Each species was classified according to its life cycle (annual or perennial), based on the persistence of the aerial vegetative parts during the unfavourable season (Bouallala et al., 2020). This classification was based on the works of Quézel and Santa (1962-1963) and Ozenda (2004).

Photosynthetic metabolism

The spectrum of photosynthetic metabolism refers to the diversity of metabolic pathways used by plants during photosynthesis. Plants can be classified according to the type of pathway used to fix carbon dioxide (CO_2) from the atmosphere (Sage, 2004). C_3, C_4, and CAM plants represent the three main types of photosynthetic metabolism, depending on their photosynthetic pathways. Species were classified according to their photosynthetic pathway based on information reported by Wang (2005) and Rauber et al. (2018).

Morphotype

The morphotypes of the species recorded in the study area were determined based on the works of Quézel and Santa (1962-1963), Ozenda (2004), and the Tela Botanica database (https://www.tela-botanica.org/).

Phytogeographic types

The phytogeographic types of the taxa recorded in the study area were determined based on the works of Quézel and Santa (1962-1963), Ozenda (2004), and Bučar et al. (2022).

Statistical tests and multifactorial analysis

Before each test, normality and homogeneity of variances were assessed using the Shapiro-Wilk and Bartlett tests, respectively. Analysis of variance (ANOVA) was used to evaluate differences between groups in terms of plant abundance (N), species richness (S), Shannon diversity index (H'), and evenness (E). Tukey's honestly significant difference (HSD) *post hoc* test was applied for pairwise comparisons when significant differences were detected ($p < 0.05$). When the assumptions of normality and homogeneity of variances were not met, the non-parametric Kruskal-Wallis test was used instead. In addition, Pearson's chi-square (χ^2) test was performed to examine the null hypothesis of independence between plant density and species richness across the categories of each functional trait within groups. All statistical analyses were performed using R version 4.2.2 (R Core Team, 2022).

RESULTS

Floristic composition

A total of 34 weed species belonging to 33 genera and 17 families were recorded (Table 1). Monocots comprised two families, six genera, and six species (17.65%), while eudicots were represented by 15 families, 27 genera, and 28 species (82.35%). The most species-rich family was Asteraceae (six species), followed by Amaranthaceae and Poaceae (five species each), Brassicaceae (four species), and Apocynaceae (two species). Twelve families were monospecific.

Weed Community Characterisation

The ascending hierarchical classification identified three functionally and ecologically distinct weed groups (communities): G1, G2, and G3 (Fig. 3).

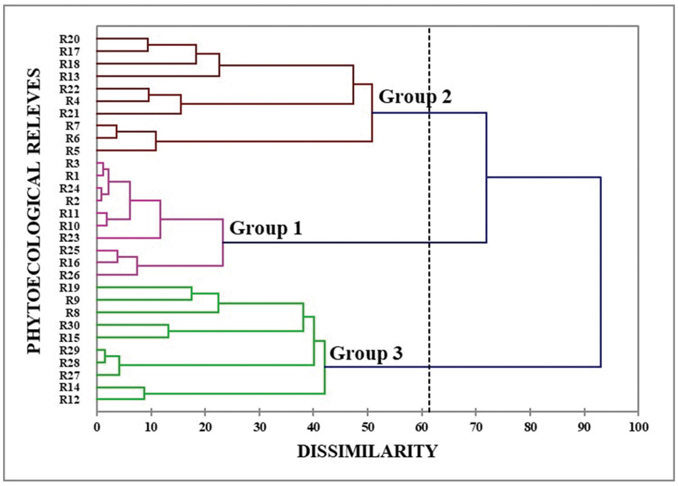

Figure 3. Weed phytoecological groups of cereal crops of SW Algeria

Group 1 (G1)

The first group included 16 species recorded across ten relevés, with a total weed density of 150 individuals / m^2 (Table 2). The highest species densities were observed for *Anagallis arvensis* (66 individuals), followed by *Sonchus oleraceus* L. (44 individuals). Seven species (*Bassia muricata* (L.) Asch., *Brassica rapa* L., *Calotropis procera* Act., *Chenopodium album* L., *Launaea glomerata* (Cass.) Hook. f., *Pergularia tomentosa*

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Table 1. List of species recorded in cereal crops of SW Algeria. **Life forms** [Ther: therophyte, Hemi: hemicryptophyte, Cham: chamaephyte, Phan: phanerophyte,] **Chorological types** [M-SA: Mediterranean Saharo-Arabian, Cosmop: cosmopolitan, Med-As: Mediterrano-Asian, Med: Mediterranean, PSTr: Paleo-subtropical, PTm: Paleo-temperate, SA: Saharo-Arabian, Tr-SA: Tropico-Saharo-Arabian, Euras-Med: Eurasian-Mediterranean, Tr-SA: Tropical Saharo-Arabian, Med.-Iran-Tour: Mediterranean Irano Tour, Macar-Med: Macaroon-Mediterranean]. **IVI: Importance Value Index** = sum of relative frequency + relative density + relative abundance of each species

Family	Species	Life form	Dispersion types	Life cycle	Photosynthetic Metabolism	Morphotype	Chorological type	Relative abundance	Relative frequency	Relative density	IVI
Amaranthaceae (14.71%)	*Bassia muricata* (L.) Asch.	Ther	Zoochore	Annual	C4	Eudicots	M-SA	0.35	1.07	0.37	1.79
	Chenopodium album L.	Ther	Barochore	Annual	C3	Eudicots	Cosmop	1.4	3.22	1.42	6.04
	Chenopodium murale L.	Ther	Barochore	Annual	C3	Eudicots	Cosmop	2.81	3.76	2.79	9.36
	Beta vulgaris L.	Ther	Barochore	Annual	C3	Eudicots	Euras-Med	0.35	1.07	0.37	1.79
	Spinacia oleracea L.	Ther	Barochore	Annual	C3	Eudicots	Cosmop	0.17	0.54	0.16	0.87
Apocynaceae (5.88%)	*Calotropis procera* Ait.	Phan	Anemochore	Perennial	C3	Eudicots	Tr-SA	0.17	0.54	0.16	0.87
	Pergularia tomentosa L.	Cham	Anemochore	Perennial	C3	Eudicots	SA	0.17	0.54	0.16	0.87
Liliaceae (2.94%)	*Asphodelus tenuifolius* Cava.	Ther	Barochore	Annual	C3	Monocots	Macar-Med	4.57	2.15	4.59	11.31
Asteraceae (17.66%)	*Calendula aegyptiaca* Desf.	Ther	Zoochore	Annual	C3	Eudicots	SA	4.39	4.3	4.37	13.06
	Launaea glomerata (Cass.) Hook.	Ther	Anemochore	Annual	C4	Eudicots	M-SA	0.53	1.07	0.53	2.13
	Launaea resedifolia (L.) O. Kuntze.	Ther	Anemochore	Annual	C4	Eudicots	M-SA	0.35	1.07	0.37	1.79
	Leontodon muelleri Ball.	Ther	Anemochore	Annual	C3	Eudicots	Med	1.93	3.22	1.95	7.1
	Senecio massaicus Maire.	Ther	Anemochore	Annual	C3	Eudicots	SA	0.53	1.61	0.53	2.67
	Sonchus oleraceus L.	Ther	Anemochore	Annual	C3	Eudicots	Cosmop.	21.97	15.59	21.98	59.54
Brassicaceae (11.76%)	*Brassica rapa* L.	Ther	Barochore	Annual	C3	Eudicots	Med	0.35	1.07	0.37	1.79
	Brassica tournefortii Gouan	Ther	Barochore	Annual	C3	Eudicots	Med	0.53	0.54	0.53	1.6
	Lobularia libyca (Viv.) Webb.	Hemi	Anemochore	Annual	C3	Eudicots	Med	0.17	0.54	0.16	0.87
	Sisymbrium irio L.	Ther	Anemochore	Annual	C3	Eudicots	Med-Iran-Tour.	3.69	4.3	3.69	11.68

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Continued. Table 1

Family	Species	Life form	Dispersion types	Life cycle	Photosynthetic Metabolism	Morphotype	Chorological type	Relative abundance	Relative frequency	Relative density	IVI
Caryophyllaceae (2.94%)	*Silene rubella* L.	Ther	Anemochore	Annual	C3	Eudicots	Med.	1.07	0.53	2.13	1.07
Fabaceae (2.94%)	*Melilotus indica* (L.) All.	Ther	Zoochore	Annual	C3	Eudicots	Med. As.	5.1	6.44	5.11	16.65
Frankeniaceae (2.94%)	*Frankenia pulverulenta* L.	Ther	Barochore	Annual	C3	Eudicots	Med	0.7	0.54	0.68	1.92
Heliotropiaceae (2.94%)	*Heliotropium bacciferum* Forsk.	Cham	Barochore	Perennial	C3	Eudicots	SA	0.35	0.54	0.37	1.26
Malvaceae (2.94%)	*Malva parviflora* L.	Ther	Barochore	Annual	C3	Eudicots	Med	4.57	7.53	4.59	16.69
Fumariaceae (2.94%)	*Fumaria numidica* Pomel	Ther	Zoochore	Annual	C3	Eudicots	Circumboreal	0.88	0.54	0.9	2.32
Poaceae (14.71%)	*Cutandia dichotoma* (Forsk.) Trab.	Ther	Anemochore	Annual	C4	Monocots	Med	1.93	1.07	1.95	4.95
	Cynodon dactylon (L.) Pers.	Hemi	Barochore	Perennial	C4	Monocots	Cosmop	3.87	3.22	3.85	10.94
	Lolium multiflorum Lamk.	Ther	Barochore	Annual	C3	Monocots	Med	2.81	1.61	2.79	7.21
	Phalaris minor Link.	Ther	Zoochore	Annual	C3	Monocots	PSTr	4.22	2.69	4.22	11.13
	Polypogon monspeliensis (L.) Desf.	Ther	Zoochore	Annual	C3	Monocots	PSTr	2.11	1.07	2.11	5.29
Polygonaceae (2.94%)	*Emex spinosa* (L.) Campd.	Ther	Zoochore	Annual	C3	Eudicots	Med	7.38	10.21	7.38	24.97
Primulaceae (2.94%)	*Anagallis arvensis* L.	Ther	Anemochore	Annual	C3	Eudicots	Cosmop	18.45	13.44	18.45	50.34
Ranunculaceae (2.94%)	*Adonis dentata* Del.	Ther	Zoochore	Annual	C3	Eudicots	Med	2.28	2.69	2.27	7.24
Rubiaceae (2.94%)	*Galium aparine* L.	Ther	Zoochore	Annual	C3	Eudicots	PTm	0.17	0.54	0.16	0.87
Scrophulariaceae (2.94%)	*Veronica anagallis-aquatica* L.	Hemi	Barochore	Perennial	C3	Eudicots	Circumboreal	0.17	0.54	0.16	0.87

L. and *Veronica anagallis-aquatica* L.), consistently showed the lowest density and importance values (IVI = 3.56). Frequency analysis placed these seven, along with *Fumaria numidica* Coss. et Dur., into Class I (very rare), while Class II (rare) included five other species (Table 2). Class III (common) was represented by a single species (*Emex spinose* (L.) Campb.), whereas Class V (constant) included two species (*Anagallis arvensis* and *S. oleraceus*). The importance value index (IVI) indicated that *A. arvensis* (IVI = 110.22) and *S. oleraceus* (IVI = 80.88) were the most important species in this group.

Group 2 (G2)

In the second group, 25 species were recorded across ten relevés, with a total weed density of 280 individuals / m² (Table 3). Species abundance was highly uneven, with *S. oleraceus* (49 individuals) and *A. arvensis* (29 individuals) were most abundant. Six species occurred as single individuals; all were classified in frequency Class I (very rare), along with nine additional species (Table 3). Species were distributed across five frequency classes. Class I included 15 very rare species (*Bassia muricata* (L.) Asch., *Beta vulgaris* L., *Brassica tournefortii* Gouan, *Chenopodium album* L., *Galium aparine* L., *Launaea glomerata* (Cass.) Hook. f., *Launaea resedifolia* O.K., *Leontodon Muelleri* (Sch.Bip.) Fiori., *Lobularia libyca* (Viv.) Webb., *Lolium multiflorum* Lamk., *Melilotus indica* (L.) AIL, *Polypogon monspeliensis* (L.) Desf., *Senecio massaicus* Maire., *Silene rubella* L. and *Sisymbrium irio* L.). Class II (rare) comprised four species (*Adonis dentate* Del., *Asphodelus tenuifolius* Cava., *Chenopodium murale* L. and *Cynodon dactylon* (L.) Pers.). Class III (common) included two species (*Calendula aegyptiaca* Desf. and *Phalaris minor* Link.), while Class IV was represented by a single species (*Malva parviflora* L.). Class V (constant) included *Emex spinosa* and *A. arvensis*. The highest importance values were recorded for *S. oleraceus* (IVI = 47.82), *A. arvensis* (IVI = 32.26) and *E. spinosa* (IVI = 30.1). The lowest IVI values (IVI = 2) were observed for *Bassia muricata*, *Beta vulgaris*, *Galium aparine*, *Launaea resedifolia*, *Lobularia libyca* and *Sisymbrium irio*.

Group 3 (G3)

In the third group, 22 weed species were recorded across ten relevés (Table 4). The highest density was observed for *S. oleraceus* (32 individuals), followed by *Melilotus indica* (L.) AIL (23 individuals). The lowest densities were recorded for *Beta vulgaris* L., *Brassica rapa* L., *Chenopodium murale* L., *Launaea resedifolia* O.K., *Lolium multiflorum* Lamk., *Senecio massaicus* Maire., *Silene rubella* L. and *Spinacia oleracea* L. Species were distributed across five frequency classes. Class I included 15 very rare species (Table 4). Class II (rare) comprised four species (*Chenopodium album* L., *Leontodon Muelleri* (Sch. Bip.) Fiori., *Malva parviflora* L. and *Sisymbrium irio* L.). Class III (frequent) included *A. arvensis* and *E. spinosa*. Class V (constant) included *Melilotus indica* and *S. oleraceus*. The highest importance values were recorded for *S. oleraceus* (IVI = 60.32) and M. indicus (IVI = 47.38).

Table 2. Importance values of the weed species in group 1 (G1) of SW Algeria

Species	Total density (ind/m²)	Species frequency	Frequency class	Relative abundance	Relative frequency	Relative density	Importance Value Index
Anagallis arvensis L.	66	100	Class V	44	22.22	44	110.22
Bassia muricata (L.) Asch.	1	10	Class I	0.67	2.22	0.67	3.56
Brassica rapa L.	1	10	Class I	0.67	2.22	0.67	3.56
Calendula aegyptiaca Desf.	4	20	Class II	2.67	4.44	2.67	9.78
Calotropis procera Ait.	1	10	Class I	0.67	2.22	0.67	3.56
Chenopodium murale L.	3	30	Class II	2	6.67	2	10.67
Chenopodium album L.	1	10	Class I	0.67	2.22	0.67	3.56
Emex spinosa (L.) Camp.	8	40	Class III	5.33	8.89	5.33	19.55
Fumaria numidica Pomel	5	10	Class I	3.33	2.22	3.33	8.88
Launaea glomerata (Cass.) Hook.	1	10	Class I	0.67	2.22	0.67	3.56
Malva parviflora L.	6	30	Class II	4	6.67	4	14.67
Melilotus indica (L.) All.	4	20	Class II	2.67	4.44	2.67	9.78
Pergularia tomentosa L.	1	10	Class I	0.67	2.22	0.67	3.56
Sisymbrium irio L.	3	30	Class II	2	6.67	2	10.67
Sonchus oleraceus L.	44	100	Class V	29.33	22.22	29.33	80.88
Veronica anagallis-aquatica L.	1	10	Class V	0.67	2.22	0.67	3.56

Table 3. Importance values of the weed species in group 2 (G2) of SW Algeria

Species	Total density (ind/m²)	Species frequency	Frequency class	Relative abundance	Relative frequency	Relative density	Importance Value Index
Adonis dentata Del.	11	30	Class II	3.93	3.85	3.93	11.71
Anagallis arvensis L.	29	90	Class V	10.36	11.54	10.36	32.26
Asphodelus tenuifolius Cavan.	26	40	Class II	9.28	5.13	9.28	23.69
Bassia muricata (L.) Asch.	1	10	Class I	0.36	1.28	0.36	2
Beta vulgaris L.	1	10	Class I	0.36	1.28	0.36	2
Brassica toumefortii Gouan	3	10	Class I	1.07	1.28	1.07	3.42
Calendula aegyptiaca Desf.	21	60	Class III	7.5	7.69	7.5	22.69
Chenopodium murale L.	12	30	Class II	4.28	3.85	4.28	12.41
Chenopodium album L.	2	10	Class I	0.71	1.28	0.71	2.7
Cynodon dactylon (L.) Pers.	19	40	Class II	6.78	5.13	6.78	18.69
Emex spinosa (L.) Camp.	26	90	Class V	9.28	11.54	9.28	30.1
Galium aparine	1	10	Class I	0.36	1.28	0.36	2
Launaea glomerata (Cass.) Hook.	2	10	Class I	0.71	1.28	0.71	2.7
Launaea resedifolia (L.) O. Kuntze.	1	10	Class I	0.36	1.28	0.36	2
Leontodon muelleri Ball.	6	20	Class I	2.14	2.56	2.14	6.84
Lobularia libyca (Viv.) Webb.	1	10	Class I	0.36	1.28	0.36	2
Lolium multiflorum Lam.	15	20	Class I	5.36	2.56	5.36	13.28
Malva parviflora L.	16	70	Class IV	5.71	8.97	5.71	20.39
Melilotus indica (L.) All.	2	10	Class I	0.71	1.28	0.71	2.7
Phalaris minor Retz.	24	50	Class III	8.57	6.41	8.57	23.55
Polypogon monspeliensis (L.) Desf.	7	10	Class I	2.5	1.28	2.5	6.28
Senecio massaicus Maire	2	20	Class I	0.71	2.56	0.71	3.98
Silene rubella L.	2	10	Class I	0.71	1.28	0.71	2.7
Sisymbrium irio L.	1	10	Class I	0.36	1.28	0.36	2
Sonchus oleraceus L.	49	100	Class II	17.5	12.82	17.5	47.82

Table 4. Importance values of the weed species in group 3 (G3) of SW Algeria

Species	Total density (ind/m²)	Species frequency	Frequency class	Relative abundance	Relative frequency	Relative density	Importance Value Index
Adonis dentata Del.	11	30	Class II	3.93	3.85	3.93	11.71
Anagallis arvensis L.	29	90	Class V	10.36	11.54	10.36	32.26
Asphodelus tenuifolius Cavan.	26	40	Class II	9.28	5.13	9.28	23.69
Bassia muricata (L.) Asch.	1	10	Class I	0.36	1.28	0.36	2
Beta vulgaris L.	1	10	Class I	0.36	1.28	0.36	2
Brassica toumefortii Gouan	3	10	Class I	1.07	1.28	1.07	3.42
Calendula aegyptiaca Desf.	21	60	Class III	7.5	7.69	7.5	22.69
Chenopodium murale L.	12	30	Class II	4.28	3.85	4.28	12.41
Chenopodium album L.	2	10	Class I	0.71	1.28	0.71	2.7
Cynodon dactylon (L.) Pers.	19	40	Class II	6.78	5.13	6.78	18.69
Emex spinosa (L.) Camp.	26	90	Class V	9.28	11.54	9.28	30.1
Galium aparine	1	10	Class I	0.36	1.28	0.36	2
Launaea glomerata (Cass.) Hook.	2	10	Class I	0.71	1.28	0.71	2.7
Launaea resedifolia (L.) O. Kuntze.	1	10	Class I	0.36	1.28	0.36	2
Leontodon muelleri Ball.	6	20	Class I	2.14	2.56	2.14	6.84
Lobularia libyca (Viv.) Webb.	1	10	Class I	0.36	1.28	0.36	2
Lolium multiflorum Lam.	15	20	Class I	5.36	2.56	5.36	13.28
Malva parviflora L.	16	70	Class IV	5.71	8.97	5.71	20.39
Melilotus indica (L.) All.	2	10	Class I	0.71	1.28	0.71	2.7
Phalaris minor Retz.	24	50	Class III	8.57	6.41	8.57	23.55
Polypogon monspeliensis (L.) Desf.	7	10	Class I	2.5	1.28	2.5	6.28
Senecio massaicus Maire	2	20	Class I	0.71	2.56	0.71	3.98
Silene rubella L.	2	10	Class I	0.71	1.28	0.71	2.7
Sisymbrium irio L.	1	10	Class I	0.36	1.28	0.36	2
Sonchus oleraceus L.	49	100	Class II	17.5	12.82	17.5	47.82

Structure and diversity of weed groups studied

In terms of species richness, G2 and G3 were the richest groups, with 25 and 22 species, respectively, whereas G1 was the least rich group, with 16 species. The highest mean richness is recorded in G2 and G3, with 7.8 ± 2.20 and 6.3 ± 1.34 species per relevé, respectively (Fig. 4). ANOVA revealed a significant difference in species richness among the phytoecological groups ($F_{2,27}$ = 10.81, p<0.001). Additionally, G1 and G3 showed lower mean abundances (15 ± 2.40 and 13.9 ± 5.63 individuals, respectively), whereas G2 exhibited a higher mean abundance (28 ± 12.40 individuals). The Kruskal-Wallis test indicated a significant variation in abundance among the phytoecological groups (χ^2 = 14.24, p = 0.0008).

Groups G2 (H' = 1.85 ± 0.28, E = 0.91 ± 0.03) and G3 (H' = 1.64 ± 0.19, E = 0.90 ± 0.05) displayed the highest mean Shannon diversity index and evenness values. The lowest values were recorded in G1 (H' = 1.23 ± 0.19, E = 0.84 ± 0.09). ANOVA showed a significant difference in Shannon index values among the phytoecological groups ($F_{2, 27}$ = 20.1, p<0.001). The Kruskal-Wallis test also revealed significant differences in evenness among groups (χ^2 = 7.49, p = 0.02) (Fig. 4).

Functional traits of studied weeds

Biological spectra

Across all groups and at the study area level, both raw and real spectra showed a high dominance of therophytes (82.36% and 95.08%, respectively), followed by hemicryptophytes (8.82% and 4.22%). In contrast, chamaephytes (5.88% and 0.53%) and phanerophytes (2.94% and 0.17%) were poorly represented (Fig. 5a). The chi-square test revealed a significant difference in the distribution of biological types in the real spectrum among phytoecological groups (χ^2 = 18.384, p = 0.005), whereas no significant difference was observed in the raw spectrum (χ^2 = 4.701, p = 0.583).

Dispersion spectra

In the raw spectrum, anemochorous species showed the highest proportions in G1 and G2 (37.5% and 36%, respectively), whereas barochorous species were dominant in G3 and at the study area level (45.46% and 38.24%, respectively). In the real spectrum, anemochorous species dominated in G1 and G3 and at the study area level (77.33%, 56.11%, and 50.44%,

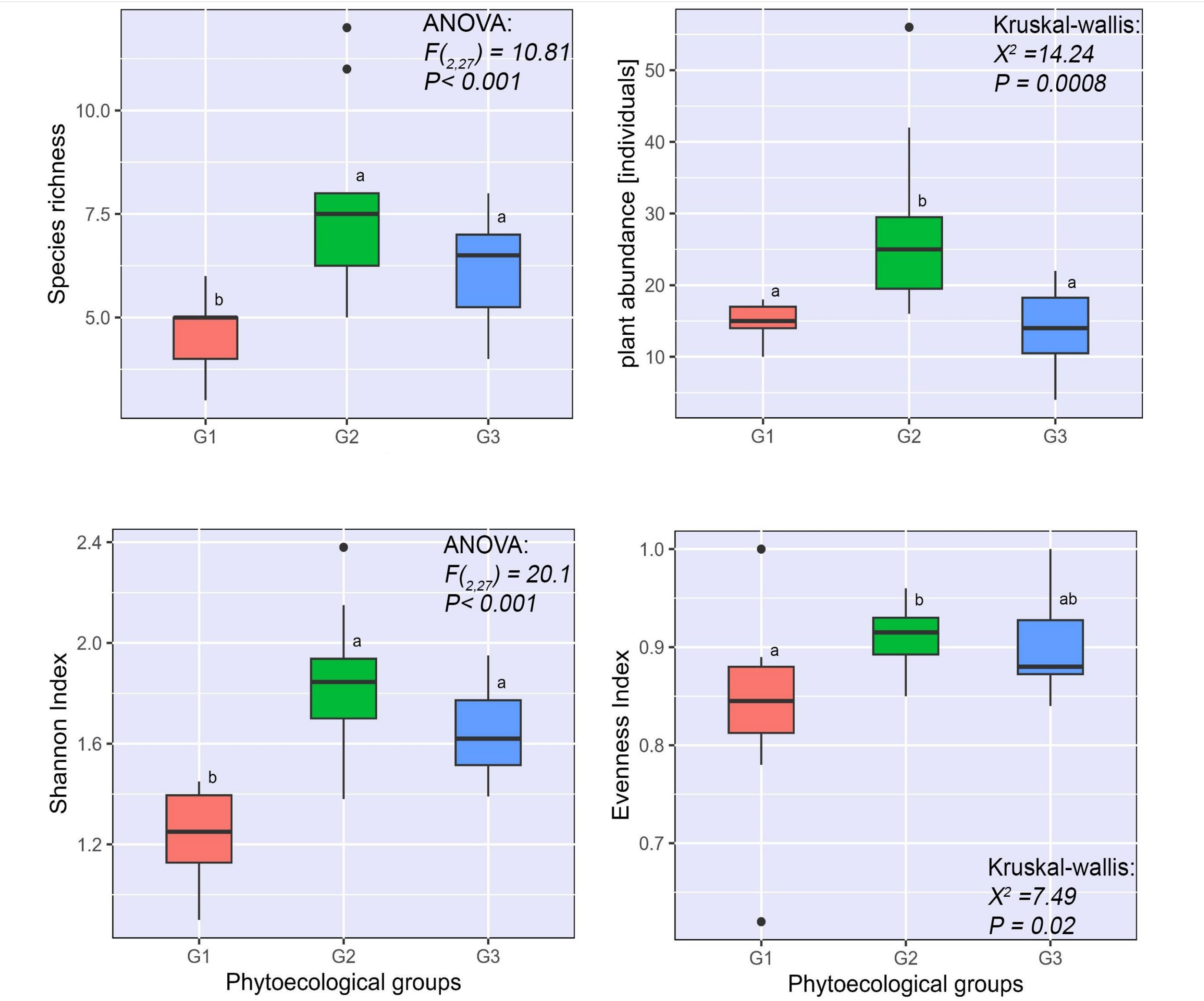

Figure 4. Boxplots showing the variation of plant diversity parameters for different phytoecological groups of weed communities studied in the agrosystems of SW Algeria

respectively), while in G2, barochorous species were the most represented (33.58%) (Fig. 5b). The chi-square test indicated significant differences among phytoecological groups in the real spectrum (χ^2 = 82.593, p<0.001), whereas no significant difference was found in the raw spectrum (χ^2 = 1.722, p = 0.787).

Life cycle spectra

Both raw and real spectra showed a clear dominance of annual species (85.29% and 95.25%, respectively) (Fig. 5c). The chi-square test indicated no significant differences among phytoecological groups in either the real spectrum (χ^2 = 5.486, p = 0.064) or the raw spectrum (χ^2 = 2.471, p = 0.291).

Spectra of photosynthetic metabolism

At the regional scale, the real spectrum showed a clear dominance of C_3 species (92.97%) (Fig. 5d). The chi-square test revealed significant differences among phytoecological groups in the real spectrum (χ^2 = 11.058, p = 0.004), whereas no significant difference was found in the raw spectrum (χ^2 = 0.109, p = 0.947).

Morphotype spectra

Both raw and real spectra showed a strong dominance of eudicots (82.35% and 80.49%, respectively) (Fig. 5e). The chi-square test indicated significant differences among phytoecological groups in the real spectrum (χ^2 = 68.773, p<0.001), but not in the raw spectrum (χ^2 = 3.606, p = 0.165).

Phytogeographic spectra

The raw phytogeographic spectra showed high proportions of Mediterranean species in G2 and G3 and at the study area level (32%, 40.91%, and 32.35%, respectively), whereas cosmopolitan species dominated in G1 (25%). The real spectrum showed a high proportion of cosmopolitan species (48.69%) (Fig. 5f). The chi-square test revealed significant differences among phytoecological groups in the real spectrum (χ^2 = 209.768, p<0.001), while no significant differences were observed in the raw spectrum (χ^2 = 16.876, p = 0.770).

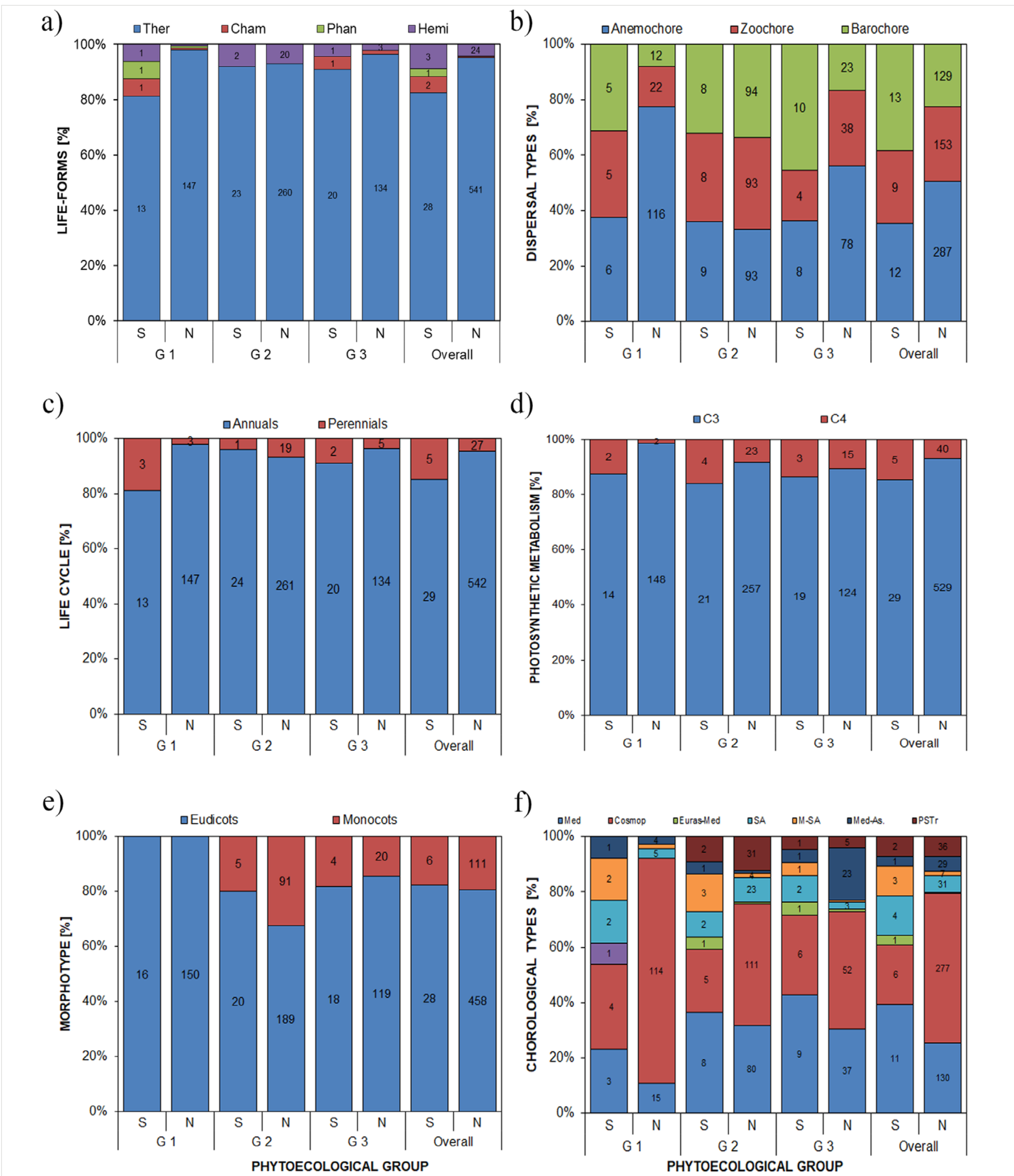

Figure 5. Raw (based on specific richness "S") and real (based on abundance "N") spectra of functional plant traits of weed groups studied in SW Algerian agrosystems; The numbers represent the actual number of species/individuals per category

DISCUSSION

The weed flora of cereal crops in the study area included 34 species from 33 genera and 17 families, a higher richness than that reported by Medjber-Teguig et al. (2018) in the palm groves of Ouargla (Algeria), where 27 species were recorded. However, the flora recorded in this study is less rich compared to that reported in cereal crops (83 species) in the Tessala region, Sidi bel Abbés (Fertout-Mouri, 2018), in wheat fields of Aurès (77 species; Melakhessou et al., 2020) and in the El-Maadher agrosystem (Boussaada Oasis) (41 species; Zedam et al., 2021). The differences observed in floristic composition and biodiversity between the three groups and those reported in other studies can be attributed to environmental conditions shaped by agricultural practices, such as tillage systems, herbicide use, crop history, soil types and the type and quality of irrigation water, as well as weed control methods and overall crop management (Martínez-Ghersa et al., 2000; Booth and Swanton, 2002; Chafik et al., 2010, 2013; Rauber et al., 2018). In winter crops, weeds are mainly controlled through hand-pulling and manual hoeing (Abd El-Hamid and Kamel, 2010). Ghersa et al. (1996) and Ghersa and León (1999) explained that variations in weed community composition are influenced by seasonal changes, agricultural cycles, and long-term environmental processes such as soil erosion and climate change. Four families (Asteraceae, Amaranthaceae, Poaceae, and Brassicaceae) account for 58.84% of the total flora and are considered the most common in agroecosystems. These families are species-rich and include a large number of weed taxa (Abd El-Ghani et al., 2013). Tanji et al. (1984) attributed their importance to high seed production and long seed longevity. Several studies have reported that Asteraceae is the dominant weed family in cereal crops (Zidane et al., 2010; Hannachi and Fenni, 2013; Fertout-Mouri, 2018; Melakhessou et al., 2020). This family occurs in a wide range of habitats due to its broad ecological amplitude (Haq et al., 2023), as well as the production of small, lightweight seeds that are easily dispersed by wind (Akedrin et al., 2020).

The biological spectra reveal a high proportion of therophytes across all phytoecological groups in the study area. This predominance of therophytes in the weed flora is attributed to their adaptations to agrosystem conditions (Nikolić et al., 2018; Ka et al., 2019), their very short life cycle (Kazi Tani et al., 2010; Chafik et al., 2013), the progressive elimination of perennial species (Noba et al., 2004), and their high seed production capacity (Fertout-Mouri, 2018). Indeed, therophytes represent an adaptive strategy to harsh climatic conditions (El-Saied et al., 2015; Abbas et al., 2021) and serve as indicators of ecosystem disturbance (Mashaly et al., 2013; Al Shaye et al., 2020). Their dominance has been widely reported in several studies, including those by Boudjedjou and Fenni (2011), Bassence et al. (2012), Fertout-Mouri (2018), and Medjber-Teguig et al. (2018). Furthermore, Taleb et al. (1997) noted that agricultural practices promote the development of therophytes compared to other biological types. The presence of hemicryptophytes is associated with higher organic matter content and soil moisture (Floret et al., 1990). These species are well adapted to arid and semi-arid environments and persist through specialised vegetative organs such as bulbs, rhizomes, and stolons (Taleb et al., 1998; Souddi et al., 2022). The occurrence of chamaephytes in the study area is linked to their drought-adaptive strategies, including reduced leaf area and well-developed root systems (Bradai et al., 2015; Souddi and Bouallala, 2023). Phanerophytes are rare and occur only sporadically, mainly in cleared areas, particularly along field margins and occasionally within fields under low mechanisation conditions (Taleb and Maillet, 1994; BenSellam et al., 1997; Kazi Tani et al., 2010; Souddi et al., 2022). This low representation of phanerophytes may be related to intensive agricultural practices and frequent disturbance in cultivated areas (Al-Sherif et al., 2018).

Anemochorous species are dominant across all the phytoecological groups studied. The high number of anemochorous species can be explained by the frequently strong winds in arid environments and their role in plant dispersal (Bradai et al., 2015; Bouallala et al., 2020; Hussein et al., 2022; Souddi and Bouallala, 2022). The presence of zoochorous species highlights the importance of animals in agricultural environments in maintaining seed dispersal. Animals can disperse seeds either by ingesting fruits or seeds (endozoochory) or by transporting them externally on their fur or feathers (epizoochory) (Calvino-Cancela, 2011). These animals transport and disperse diaspores during their movements between different sites, particularly while searching for water (Souddi and Bouallala, 2023). Plant dispersal by barochory is mainly related to the reproductive capacity of species (Abdourhamane et al., 2017).

Life cycle spectra reveal a dominance of annual species. This dominance is attributed to the short life cycle of annual plants, as well as to prevailing climatic conditions and water availability, which favour their frequent occurrence (Shaltout and El-Sheikh, 1991; Abd El-Hamid and Kamel, 2010). Annual plants exhibit high reproductive capacity and significant ecological, morphological, and genetic plasticity under high disturbance conditions such as agricultural practices (Grime, 1979; Abd El-Hamid and Kamel, 2010). The low number of perennial species may be attributed to intensive crop management practices, which negatively affect the vegetative growth of perennial weeds (Abd El-Ghani et al., 2013).

The distribution of plants according to photosynthetic metabolism shows high proportions of C_3 species across all phytoecological groups in the study area. This pattern may be explained by environmental conditions, including water and light availability, temperature, and evolutionary adaptations (Rauber et al., 2018). Morphotype spectra indicate a predominance of eudicot species. The dominance of eudicots, followed by monocots, has been reported throughout agrosystems and confirmed by several studies (Tanji and Ait Lhaj, 2010; Chafik et al., 2012; Zedam et al., 2021; Deghiche-Diab et al., 2022).

The phytogeographic spectrum based on species richness reveals a high proportion of Mediterranean species in groups 2 and 3, as well as in the overall study area. This reflects the geographical location of the study area and confers a Mediterranean character (Zedam et al., 2021). However, the real spectrum shows high proportions of cosmopolitan species across all groups. Cosmopolitan species are considered indicators of changes in phytocenoses driven by human activities (Shochat et al., 2006; El-Saied et al., 2015; Eddoud et al., 2018). Their dominance in some Saharan habitats has been reported (Al-Sherif et al., 2020; Souddi et al., 2022;

Souddi and Bouallala, 2023). The low representation of other phytogeographic elements may be explained by their gradual elimination due to cultivation practices, weed control, and poor adaptation to environmental conditions (Touré et al., 2008; Akedrin et al., 2020).

The weeds with the highest importance values (*S. oleraceus*, *A. arvensis*, and *E. spinosa*) are recognised as major weeds worldwide, although their invasive status varies depending on the region (Eddoud et al., 2018). *S. oleraceus* is widely distributed globally and is considered a difficult-to-control weed (Peerzada et al., 2019). It has been reported as a dominant species in crops such as wheat, millet, and alfalfa (Salama et al., 2016). Its high density and frequency are attributed to its strong adaptability to agricultural conditions, rapid reproduction, and ability to exploit soil disturbances associated with farming practices (Gomaa, 2012; Peerzada et al., 2019). Similarly, *A. arvensis* and *E. spinosa* showed high values of frequency, density, and Importance Value Index (IVI) in the studied crops. These patterns can be explained by the heterogeneity of soil properties and microclimatic conditions (Medjber-Teguig et al., 2018; Eddoud et al., 2018).

CONCLUSION

Weeds remain a major agronomic problem threatening cereal production. This study revealed the presence of 34 weed species belonging to 33 genera and 17 botanical families. The families Asteraceae, Amaranthaceae, Poaceae, and Brassicaceae were most represented, with a strong dominance of therophytes and hemicryptophytes, well adapted to the environmental conditions of cereal crops in arid areas. Cosmopolitan and Mediterranean species constituted key elements in the structure and floristic composition of the weed flora in the study area. The most problematic species, characterised by the highest importance values, pose a significant risk to cereal production, namely *S. oleraceus*, *A. arvensis*, and *E. spinosa*. Therefore, effective control of these weeds is essential for developing a rational management approach to cereal crops in drylands, within a framework of more productive, cleaner, and sustainable agricultural systems.

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CRediT AUTHORSHIP CONTRIBUTION STATEMENT

Mohammed Souddi: Conceptualisation, Data curation, Formal analysis, Investigation, Methodology, Software, Resources, Supervision, Validation, Visualisation, writing – original draft, Writing – review & editing. **M'hammed Bouallala:** Conceptualisation, Investigation, Methodology, Resources, Supervision, Validation, Visualisation, Writing – review & editing.

DECLARATION OF COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

ETHICS AND PERMIT APPROVALS

Not applicable.

DATA AVAILABILITY STATEMENT

Data will be made available on reasonable request from the corresponding author.

USE OF ARTIFICIAL INTELLIGENCE (AI) TOOLS

The authors declare that no AI tools were used.

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SAŽETAK

Raznolikost korovnih zajednica u usjevima žitarica tradicionalnih oaznih agroekosustava sušnih područja jugozapadnog Alžira (Sjeverna Afrika)

Žitarice su među najvažnijim kulturama u aridnim i semiaridnim područjima te imaju ključnu ulogu u tradicionalnoj poljoprivredi oaza jugozapadnog Alžira. Međutim, njihovu proizvodnju ograničavaju brojni biotički i abiotički čimbenici, pri čemu korovi predstavljaju jedan od najznačajnijih problema. Cilj ovog istraživanja bio je detaljno analizirati sastav i strukturu korovnih zajednica u usjevima žitarica unutar oaznih agroekosustava. Podaci su prikupljeni na temelju 30 fitoekoloških snimaka (relevéa) te analizirani primjenom pokazatelja bogatstva vrsta, gustoće, frekvencije, indeksa važnosti (IVI), Shannon–Weaverova indeksa raznolikosti, indeksa ujednačenosti, funkcionalnih svojstava biljaka i fitogeografskih spektara. Ukupno su zabilježene 34 vrste koje pripadaju 33 roda i 17 porodica. Najzastupljenije porodice bile su Asteraceae (17,6%), Amaranthaceae (14,7%), Poaceae (14,7%) i Brassicaceae (11,7%). U florističkom sastavu dominirale su eudikotske vrste (80,4%), dok su monokotiledone činile 19,5%. Terofiti su bili izrazito dominantan životni oblik (95%). Biogeografska analiza ukazala je na dominaciju kozmopolitskih (48,6%) i mediteranskih (22,8%) vrsta. Kao glavni način rasprostranjenja izdvojena je anemohorija (50,4%), dok su C3 biljke činile dominantnu fotosintetsku skupinu (92,9%). Najveću potencijalnu ekološku štetnost temeljem viskokih vrijednosti indeksa važnosti pokazale su vrste *Sonchus oleraceus*, *Anagallis arvensis* i *Emex spinosa*. Dobiveni rezultati pružaju znanstvenu osnovu za razvoj učinkovitih i ciljanih strategija suzbijanja korova, s ciljem povećanja prinosa i kvalitete žitarica u oaznim agroekosustavima.

Ključne riječi: bioraznolikost, proizvodnja žitarica, oaza, korovne zajednice, Alžir

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