SURVEY OF WEED BIODIVERSITY IN WADI AL-ARJE OF TAIF, SAUDI ARABIA

MAJRASHI, A. A.

Department of Biological Science, College of Science, Taif University, P.O. Box 11099, Taif 21944, Saudi Arabia
(e-mail: aa.majrashi@tu.edu.sa, majrashiaah@gmail.com; phone: +966-5363-49899)

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Abstract. Weeds represent the undesired plant biodiversity of an area. This study was aimed at the identification and assessment of weed species in the agricultural lands of Wadi AL-Arje (1500 m above sea level), Taif, Saudi Arabia. A total of 3581 plants were collected during this study belonging to 78 plant species under 40 different plant families. 1589 (44.37%) shrub plants were identified from 36 species belonging to 24 families. 1571 (43.87%) herb plants were recorded, which were classified under 22 species belonging to 18 plant families. The number of tree plants was 421 (11.76%) belonging to 20 species into 16 plant families. The numbers of wild plants and cultivated plants were observed as 2821 (78.78%) and 760 (21.22%), respectively. The most dominant plant families such as Papaveraceae, Lamiaceae, Brassicaceae, Asteraceae, and Fabaceae had plant densities of 476, 400, 329, 280, and 238, respectively. *Argemone ochroleuca, Dracaena cinnabari, Vachellia farnesiana, Cucumis pepo,* and *Eruca vesicaria* were found to be the most prominent weed species with a plant density of 476, 315, 168, 150, and 131, respectively. This study comprehensively presents the current weed biodiversity in Wadi AL-Arje, Taif to devise effective weed control measures.
Keywords: *weed biodiversity, agriculture, crops, weed species, weed survey*

Introduction

Humans have suffered from weed-related yield losses for thousands of years but their risk assessment is a comparatively recent phenomenon. Weeds pose a serious threat to global agro-ecosystems with considerable production losses. The hazards of weed expansion are ranked second to climate change (Haq et al., 2023). Weeds-related crop damage often exceeds fungal, insect, and bacteria-related losses. The biological stress of weeds along with indirect disease expansion by harboring crop insect pests contribute to low crop yield. They share considerable proportions of parks, lawns, orchards, and agricultural fields. Weed species spatially cluster in different crops and are capable of altering agricultural factors of an area such as natural plant diversity, vegetation, and insect fauna. Rapid reproduction with higher seed yield, regeneration, and wide phenotypic plasticity enable wide weed distribution. Soil composition, climate, weed management, and agricultural practices are considered key factors in determining weed diversity and variability in an area (Gafni et al., 2023). Cropping patterns, adopted management practices, microclimate, soil moisture, and farmers’ know-how also play a crucial part in establishing local weed diversity. Weeds’ complex heterogeneous nature complicates their assessments in diverse cropping patterns. Cropping patterns with differential canopy structures produce varying microclimates, which can affect the spatial density, emergence, population, and composition of weeds in agricultural fields. Weeds uptake more moisture than crops because of rapid root development and better climate tolerance and resource affinity. In this regard, the weeds' impact becomes more prominent in water-deficient regions. Weeds invade multiple types of ecological niches and habitats, however, their prevalence in horticulture and agricultural fields is more

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concerning where they compete with local plants for water and nutrients. Therefore, the identification and documentation of weeds in diverse agricultural fields of an area could provide detailed information regarding weed types of the area to follow appropriate management practices (Haq et al., 2021). During the last few decades, weed studies have generally investigated the spreading patterns of weeds in cropping fields (Blank et al., 2023). However, the literature regarding weed diversity is considerably scarce, particularly in developing Asian regions.

The weed competition ultimately increases agricultural costs and leads to reduced crop production. This situation presents a major hurdle in meeting the nutritional requirements of a rapidly growing global society. Approximately, 1800 weed species are linked to 31.5% of crop losses globally, which are important for human nutrition. Herbicide resistance has also been reported in 267 weed species including 113 monocots and 154 dicots (Heap, 2023). The undesirable invasive weeds globally threaten wildlands, croplands, and rangelands. Therefore, weed invasion should be investigated to understand their competitive interactions with local plants (Lucero et al., 2022). The competitiveness of a species depicts its capability to utilize scarce resources and hinder nutrient availability to other plants (Khattak et al., 2024). Saudi Arabia is a large country with diverse topographies, which could impact the occurrence of weed species. The variation in soil composition and topography favors differential plant and floral communities. The impact of landscape elevations and weed diversity has been established in previous studies considering it a crucial ecological element regarding weed distribution in a specific area. The cropping systems also determine the density and spatial distribution of weeds. Similarly, mechanized farming is a major recent phenomenon regarding the distribution of weed seeds in the field. For instance, the use of a combine harvester could result in elongated patches of weeds in the row’s direction. Therefore, the density and distribution of weeds could alter in different seasons. These factors highlight the importance of regular weed data collection in an area for better management measures. Keeping in view this background, this study was aimed at (a) weed documentation in Wadi Al-Arje Taif, Saudi Arabia (b) identification of the collected weed specimens, (c) assessment of weed diversity in the target area, and (d) assessment of weed density in Wadi Al-Arje. The results of this investigation will facilitate a better understanding of weed prevalence in the studied area. Moreover, the findings will help in devising and implementing sustainable weed management programs in Wadi Al-Arje for enhanced agricultural output.

Materials and methods

Location of study

The study was conducted in Wadi Al Arje of Taif, Kingdom of Saudi Arabia (*Figure 1*). Wadi Al Arje is located on the Eastern side of the Sarwat Mountains. The average altitude of Wadi Al Arje is 1400 m above sea level, however, the heights of 27 sampling locations ranged from 1374 m to 1495 m above sea level. The height of Wadi Al-Arje increases up to 1500 m towards the south and west. The coordinates of the study area are N 21-296 and E 40-496. Taif is a populous and fertile region. The area has almost 25500 agricultural farms having a total area of approximately 5,94,000 ha. Taif region is famous for agriculture and is characterized by the most fertile areas of the Kingdom of Saudi Arabia.

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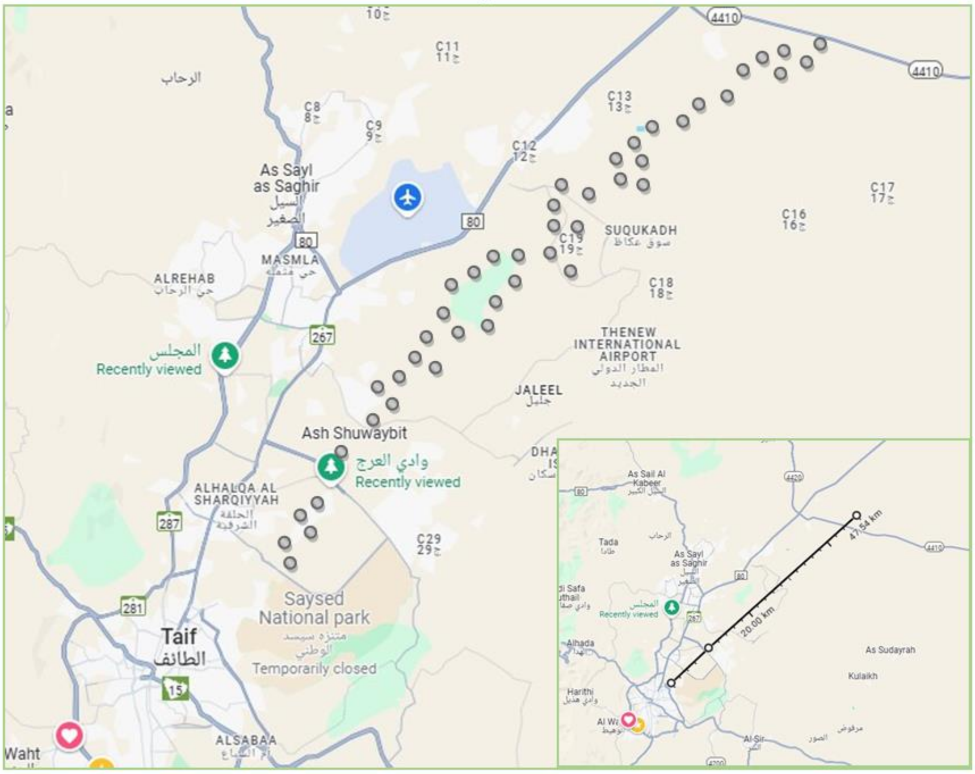

***Figure 1.** Map of Wadi Al-Arje, Taif Kingdom of Saudi Arabia. (http://www.athagafy.com/images/montada/ camelmap.jpg) (●)44 the study sites, where each site represents an area of 10 m^2*

Sample collection

Weed specimens were collected from August to October 2024. The weeds were collected from agricultural lands of several localities of the Wadi AL-Arje area of the Taif region, as presented in *Figures 1,2*.

Sample identification

The samples collected from 44 sites (10 m^2 / site) were prepared as herbarium samples. Weed density in crops was estimated according to arbitrary and visual observations. The studies of Sher H. and Al-Yemeny N. (2011) served as the reference point for the identification of weed species. *Figure 3* depicts the experimental design of weed collection from the agricultural farms of Wadi Al-Arje. The common weeds of Wadi Al-Arje were identified at the family and species level. Weed density was assessed in terms of number of plants in the studied area.

Data analysis

The weed density (number of plants) data were transformed using Log+1 or log before statistical analysis and subjected to one-way ANOVA. The means were significantly differentiated using the t-test and least significant difference (LSD) test. Similar statistical analyses have been applied in various previous studies (Juan et al., 2010; Levi et al., 2011).

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Figure 2. *Pictures of some sampling sites in the studied areas*

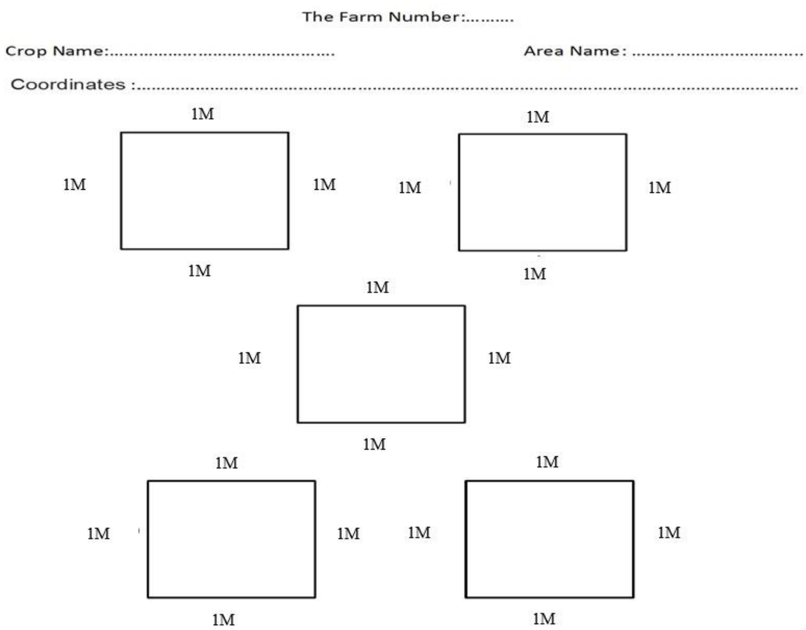

Figure 3. *Experimental design and quadrats arrangements of weeds in Wadi Al-Arje*

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Results

Vegetation analysis

A total of 3581 plants were collected during this study and taxonomically identified into families and relevant species. The collected plants belonged to 40 different plant families. These families contained 78 plant species with varying densities. The collected samples contained wild and cultivated plants, which were further differentiated into various environmental types including herbs, shrubs, and trees.

Density of plant families

The data revealed the presence of 40 plant families in the studied area, which included Lamiaceae, Fabaceae, Brassicaceae, Asteraceae, Solanaceae, Poaceae, Cucurbitaceae, Amaranthaceae, Typhaceae, Polygonaceae, Zygophyllaceae, Tamaricaceae, Rosaceae, Cupressaceae, Rutaceae, Anacardiaceae, Cactaceae, Papaveraceae, Apiaceae, Apoconaceae, Rhamnaceae, Aizoaceae, Euphorbiaceae, Nitrariaceae, Portulacaceae, Myrtaceae, Cyperaceae, Boraginaceae, Acanthaceae, Geraniaceae, Meliaceae, Oleaceae, Moraceae, Pandanaceae, Plantaginaceae, Malvaceae, Elaeagnaceae, Punicaceae, Soongaticacea, and Arecaceae. The number of species varied in each family. The highest number of plant species (7) were noted in the family Fabaceae. The number of species in other families were noted as Asteraceae (6), Solanaceae (6), Poaceae (5), Brassicaceae (4), Lamiaceae (3), Amaranthaceae (3), Rosaceae (3), Typhaceae (2), Polygonaceae (2), Zygophyllaceae (2), Tamaricaceae (2), Cupressaceae (2), Rutaceae (2), Cucurbitaceae (2), Anacardiaceae (2), Cactaceae (2), Papaveraceae (1), Apiaceae (1), Apoconaceae (1), Rhamnaceae (1), Aizoaceae (1), Euphorbiaceae (1), Nitrariaceae (1), Portulacaceae (1), Myrtaceae (1), Cyperaceae (1), Boraginaceae (1), Acanthaceae (1), Geraniaceae (1), Meliaceae (1), Oleaceae (1), Moraceae (1), Pandanaceae (1), Plantaginaceae (1), Malvaceae (1), Elaeagnaceae (1), Punicaceae (1), Soongaticacea (1), and Arecaceae (1). Collectively, all the identified families contained 78 plant species. The plant densities also significantly varied in different plant families of the study area. The highest plant density of 476 was noted in the family Papaveraceae whereas the lowest plant density of 1 was noted in the family Arecaceae. The plant densities in other families were noted as Lamiaceae (400), Brassicaceae (329), Asteraceae (280), Fabaceae (238), Cucurbitaceae (225), Typhaceae (196), Amaranthaceae (165), Tamaricaceae (158), Solanaceae (118), Apiaceae (115), Poaceae (112), Rosaceae (88), Zygophyllaceae (61), Apoconaceae (57), Polygonaceae (52), Cupressaceae (52), Rutaceae (50), Rhamnaceae (45), Aizoaceae (42), Euphorbiaceae (35), Nitrariaceae (35), Portulacaceae (33), Anacardiaceae (32), Cyperaceae (20), Myrtaceae (20), Boraginaceae (18), Acanthaceae (17), Geraniaceae (15), Cactaceae (14), Meliaceae (10), Oleaceae (9), Moraceae (9), Pandanaceae (8), Plantaginaceae (7), Malvaceae (6), Punicaceae (4), Elaeagnaceae (4), and Soongaticaceae (2) (*Figure 4*).

The plant densities resulted in varying relative densities of plant families, which remained 13.29% (Papaveraceae), 11.17% (Lamiaceae), 9.19% (Brassicaceae), 7.82% (Asteraceae), 6.65% (Fabaceae), 6.28% (Cucurbitaceae), 5.47% (Typhaceae), 4.61% (Amaranthaceae), 4.41% (Tamaricaceae), 3.30% (Solanaceae), 3.21% (Apiaceae), 3.13% (Poaceae), 2.46% (Rosaceae), 1.70% (Zygophyllaceae), 1.59% (Apoconaceae), 1.45% (Polygonaceae), 1.45% (Cupressaceae), 1.40% (Rutaceae), 1.26% (Rhamnaceae), 1.17% (Aizoaceae), 0.98% (Euphorbiaceae), 0.98% (Nitrariaceae),

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0.92% (Portulacaceae), 0.89% (Anacardiaceae), 0.56% (Cyperaceae), 0.56% (Myrtaceae), 0.50% (Boraginaceae), 0.47% (Acanthaceae), 0.42% (Geraniaceae), 0.39% (Cactaceae), 0.28% (Meliaceae), 0.25% (Oleaceae), 0.25% (Moraceae), 0.22% (Pandanaceae), 0.20% (Plantaginaceae), 0.17% (Malvaceae), 0.11% (Punicaceae), 0.11% (Elaeagnaceae), 0.06% (Soongaticaceae), and 0.03% (Arecaceae). Overall, the data demonstrated that families Fabaceae, Asteraceae, Solanaceae, Poaceae, Lamiaceae, Amaranthaceae, and Rosaceae were more prominent in terms of plants from diverse species. However, the families Papaveraceae, Lamiaceae, Brassicaceae, Asteraceae, Fabaceae, Cucurbitaceae, Typhaceae, Amaranthaceae, Tamaricaceae, Solanaceae, Apiaceae, and Poaceae appeared considerably prominent regarding density and relative density of different plant species (*Figure 4*). The statistical analysis presented a non-significant P-value of 0.791 between different families whereas the t-value of families was noted as 14.362. The test of homogeneity of variances revealed a mean-based significance value of 0.002 and Levene's test value of 3.437 among families.

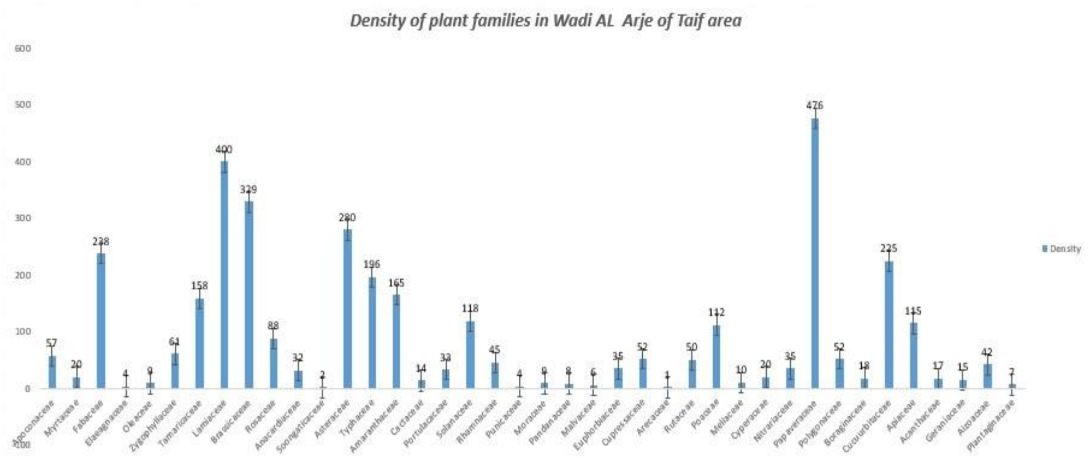

Figure 4. *The densities of plant families in Wadi AL-Arje, Taif, Saudi Arabia. Statistical analysis (ANOVA) presented a P-value of 0.791 and a t-value of 14.362 among families. The test of homogeneity of variances revealed a mean-based significance value of 0.002 and Levene's test value of 3.437 among families*

Density of plant species

The results presented the prevalence of 77 plant species belonging to different plant families in the studied area. The identified plant species included *Dracaena cinnabari*, *Thymus vulgaris*, *Mentha piperita* (Lamiaceae), *Vachellia farnesiana*, *Acacia Arabica*, *Albizia lebbeck*, *Acacia dealbata*, *Leucaena leucocephala*, *Ipomoea purpura*, *Melilotus albus* (Fabaceae), *Brassica juncea*, *Brassise acicularis*, *Eruca vesicaria*, *Sisymbium irio* (Brassicaceae), *Xanthium orientale*, *Bidens pilosa*, *Hazardia sauarrosa*, *Santolina chamaecyparissus*, *Lactuca sativa*, *Artemisia vulgaris* (Asteraceae), *Solanum incanum*, *Solanum muricatum*, *Urtica dioic*, *Nicotiana glauca*, *Datura stramonium*, *Isolanum lycopersicum* (Solanaceae), *Polypogon monspeliensis*, *Cenchrus clandestinus*, *Paspalum dilatatum*, *Agrostis stolonifera*, *Cenchrus ciliaris* (Poaceae), *Cucumis fistula*, *Cucumis pepo* (Cucurbitaceae), *Haloxylon ammodendron*, *Atriplex maximowiziana*, *Aerva javanica* (Amaranthaceae), *Typha domingensis*, *Dysphania ambrosioides* (Typhaceae), *Calligonum comosum*, *Rumex obtusifolius* (Polygonaceae), *Fagonia*

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laevis, *Tetraena simplex* (Zygophyllaceae), *Tamarix ramossima*, *Ocimum tenuiflorum* (Tamaricaceae), *Coleogyhe ramosissima*, *Prunus dulcis*, *Prunus armeniaca* (Rosaceae), *Cupressus semperviehs*, *Juniperus communis* (Cupressaceae), *Citrus limon*, *Citrus sinensis* (Rutaceae), *Rhus coriaria*, *Mangifera indica* (Anacardiaceae), *Aloe petricola*, *Opunia ficus* (Cactaceae), *Argemone ochroleuca* (Papaveraceae), *Petroselinum crispum* (Apiaceae), *Calotropis procera* (Apoconaceae), *Ziziphus spina* (Rhamnaceae), *Aizoon canariense* (Aizoaceae), *Ricinus communis* (Euphorbiaceae), *Peganum harmala* (Nitrariaceae), *Portulaca oleracea* (Portulacaceae), *Eucalyptus globulus* (Myrtaceae), *Cyperus rotundus* (Cyperaceae), *Justicia californica* (Acanthaceae), *Pelargonium graveolens* (Geraniaceae), *Azadirachta indica* (Meliaceae), *Menodora scabra* (Oleaceae), *Morus alba* (Moraceae), *Pandanus tectorius* (Pandanaceae), *Plantago major* (Plantaginaceae), *Alcea setosa* (Malvaceae), *Punica granat* (Punicaceae), *Hologcheas soongatica* (Soongaticacea), and *Phoenix dactylifera* (Arecacaeae) (*Figure 5*).

Figure 5. *The densities of plant species in Wadi AL-Arje, Taif, Saudi Arabia. Statistical analysis (ANOVA) presented a P-value of 0.281 and a t-value of 15.32 among species. The test of homogeneity of variances revealed a mean-based significance value of 0.05 and Levene's test value of 2.032 among species*

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The plant densities significantly varied in different plant species of the study area. The highest plant density of 476 was noted in the species *Argemone ochroleuca*. The plant densities of other species were noted as *Dracaena cinnabari* (315), *Vachellia farnesiana* (168), *Cucumis pepo* (150), *Eruca vesicaria* (131), *Brassise acicularis* (129), *Dysphania ambrosioides* (118), *Petroselinum crispum* (115), *Tamarix ramossima* (107), *Lactuca sativa* (100), *Polypogon monspeliensis* (88), *Haloxylon ammodendron* (83), *Typha domingensis* (78), *Cucumis fistula* (75), *Xanthium orientale* (70), *Coleogyhe ramosissima* (64), *Mentha piperita* (63), *Isolanum lycopersicum* (63), *Calotropis procera* (57), *Brassica juncea* (53), *Atriplex maximowiziana* (53), *Rumex obtusifolius* (52), *Ocimum tenuiflorum* (51), *Artemisia vulgaris* (50), *Ziziphus spina* (45), *Citrus limon* (42), *Juniperus communis* (42), *Aizoon canariense* (42), *Fagonia laevis* (40), *Hazardia sauarrosa* (36), *Ricinus communis* (35), *Peganum harmala* (35), *Portulaca oleracea* (33), *Acacia Arabica* (33), *Datura stramonium* (31), *Aerva javanica* (29), *Calligonum comosum* (23), *Thymus vulgaris* (22), *Tetraena simplex* (21), *Cyperus rotundus* (20), *Eucalyptus globulus* (20), *Rhus coriaria* (19), *Justicia californica* (17), *Prunus armeniaca* (17), *Sisymbium irio* (16), *Nicotiana glauca* (16), *Pelargonium graveolens* (15), *Leucaena leucocephala* (15), *Mangifera indica* (13), *Bidens pilosa* (13), *Cenchrus ciliaris* (13), *Acacia dealbata* (12), *Santolina chamaecyparissus* (11), *Cupressus semperviehs* (10), *Azadirachta indica* (10), *Menodora scabra* (9), *Morus alba* (9), *Pandanus tectorius* (8), *Citrus sinensis* (8), *Opunia ficus* (8), *Prunus dulcis* (7), *Plantago major* (7), *Alcea setosa* (6), *Aloe petricola* (6), *Paspalum dilatatum* (6), *Melilotus albus* (6), *Solanum incanum* (5), *Elaegnus angustifolia L* (4), *Agrostis stolonifera* (4), *Punica granat* (4), *Albizia lebbeck* (3), *Hologcheas soongatica* (2), *Urtica dioic* (2), *Solanum muricatum* (1), *Phoenix dactylifera* (1), *Cenchrus clandestinus* (1), and *Ipomoea purpura* (1). The results depicted that the densities of *Argemone ochroleuca*, *Dracaena cinnabari*, *Vachellia farnesiana*, *Cucumis pepo*, *Eruca vesicaria*, *Brassise acicularis*, *Dysphania ambrosioides*, *Petroselinum crispum*, *Tamarix ramossima*, *Lactuca sativa* were significantly higher than other species belonging to various plant families of the studied area (*Figure 5*).

The plant densities resulted in varying relative densities of plant species, which were noted as 13.29% (*Argemone ochroleuca*), 8.80% (*Dracaena cinnabari*), 4.69% (*Vachellia farnesiana*), 4.19% (*Cucumis pepo*), 3.66% (*Eruca vesicaria*), 3.60% (*Brassise acicularis*), 3.30% (*Dysphania ambrosioides*), 3.21% (*Petroselinum crispum*), 2.99% (*Tamarix ramossima*), 2.79% (*Lactuca sativa*), 2.46% (*Polypogon monspeliensis*), 2.32% (*Haloxylon ammodendron*), 2.18% (*Typha domingensis*), 2.09% (*Cucumis fistula*), 1.95% (*Xanthium orientale*), 1.79% (*Coleogyhe ramosissima*), 1.76% (*Mentha piperita*), 1.76% (*Isolanum lycopersicu*), 1.59% (*Calotropis procera*), 1.48% (*Brassica juncea*), 1.48% (*Atriplex maximowiziana*), 1.45% (*Rumex obtusifolius*), 1.42% (*Ocimum tenuiflorum*), 1.40% (*Artemisia vulgaris*), 1.26% (*Ziziphus spina*), 1.17% (*Citrus limon*), 1.17% (*Juniperus communis*), 1.17% (*Aizoon canariense*), 1.12% (*Fagonia laevis*), 1.01% (*Hazardia sauarrosa*), 0.98% (*Ricinus communis*), 0.98% (*Peganum harmala*), 0.92% (*Portulaca oleracea*), 0.92% (*Acacia Arabica*), 0.87% (*Datura stramonium*), 0.81% (*Aerva javanica*), 0.64% (*Calligonum comosum*), 0.61% (*Thymus vulgaris*), 0.59% (*Tetraena simplex*), 0.56% (*Cyperus rotundus*), 0.56% (*Eucalyptus globulus*), 0.53% (*Rhus coriaria*), 0.47% (*Justicia californica*), 0.47% (*Prunus armeniaca*), 0.45% (*Sisymbium irio*), 0.45% (*Nicotiana glauca*), 0.42% (*Pelargonium graveolens*), 0.42% (*Leucaena leucocephala*), 0.36% (*Mangifera indica*), 0.36% (*Bidens pilosa*), 0.36% (*Cenchrus ciliaris*), 0.34% (*Acacia dealbata*), 0.31%

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(*Santolina chamaecyparissus*), 0.28% (*Cupressus sempervienhs*), 0.28% (*Azadirachta indica*), 0.25% (*Menodora scabra*), 0.25% (*Morus alba*), 0.22% (*Pandanus tectorius*), 0.22% (*Citrus sinensis*), 0.22% (*Opunia ficus*), 0.20% (*Prunus dulcis*), 0.20% (*Plantago major*), 0.17% (*Alcea setosa*), 0.17% (*Aloe petricola*), 0.17% (*Paspalum dilatatum*), 0.17% (*Melilotus albus*), 0.14% (*Solanum incanum*), 0.11% (*Elaegnus angustifolia L*), 0.11% (*Agrostis stolonifera*), 0.11% (*Punica granat*), 0.08% (*Albizia lebbeck*), 0.06% (*Hologcheas soongatica*), 0.06% (*Urtica dioic*), 0.03% (*Solanum muricatum*), 0.03% (*Phoenix dactylifera*), 0.03% (*Cenchrus clandestinus*), and 0.03% (*Ipomoea purpura*). The relative densities of *Argemone ochroleuca, Dracaena cinnabari, Vachellia farnesiana, Cucumis pepo, Eruca vesicaria, Brassise acicularis, Dysphania ambrosioides, Petroselinum crispum, Tamarix ramossima,* and *Lactuca sativa* were significantly higher than other species of different families in the studied area (*Figure 4*). The statistical analysis demonstrated a non-significant P-value of 0.281 between species whereas the t-value of 15.32 was observed in the t-test of species. The test of homogeneity of variances revealed a mean-based significance value of 0.05 and Levene's test value of 2.032 among species.

Plant nature-based density in the studied area

The data demonstrated that the presence of wild plants was significantly higher (79%) among collected plants (*Figure 6*). The number of wild plants was noted as 2821 out of a total of 3581 plants. The wild plants belonged to the families Lamiaceae [*Dracaena cinnabari, Thymus vulgaris, Mentha piperita*], Fabaceae [*Vachellia farnesiana, Acacia Arabica, Albizia lebbeck, Acacia dealbata, Leucaena leucocephala, Ipomoea purpura, Melilotus albus*], Brassicaceae [*Brassica juncea, Brassise acicularis, Sisymbium irio*], Asteraceae [*Xanthium orientale, Bidens pilosa, Hazardia sauarrosa, Santolina chamaecyparissus*], Solanaceae [*Solanum incanum, Solanum muricatum, Urtica dioic, Nicotiana glauca, Datura stramonium*], Poaceae [*Polypogon monspeliensis, Cenchrus clandestinus, Paspalum dilatatum, Agrostis stolonifera, Cenchrus ciliaris*], Amaranthaceae [*Haloxylon ammodendron, Atriplex maximowiziana, Aerva javanica*], Typhaceae [*Typha domingensis, Dysphania ambrosioides*], Polygonaceae [*Calligonum comosum, Rumex obtusifolius*], Zygophyllaceae [*Fagonia laevis, Tetraena simplex*], Tamaricaceae [*Tamarix ramossima, Ocimum tenuiflorum*], Rosaceae [*Coleogyhe ramosissima, Prunus dulcis*], Cupressaceae [*Cupressus sempervienhs, Juniperus communis*], Anacardiaceae [*Rhus coriaria, Mangifera indica*], Cactaceae [*Aloe petricola, Opunia ficus*], Papaveraceae [*Argemone ochroleuca*], Apoconaceae [*Calotropis procera*], Rhamnaceae [*Ziziphus spina*], Aizoaceae [*Aizoon canariense*], Euphorbiaceae [*Ricinus communis*], Nitrariaceae [*Peganum harmala*], Portulacaceae [*Portulaca oleracea*], Myrtaceae

[*Eucalyptus globulus*], Cyperaceae [*Cyperus rotundus*], Boraginaceae [*Cenchrus ciliaris*], Acanthaceae [*Justicia californica*], Geraniaceae [*Pelargonium graveolens*], Meliaceae [*Azadirachta indica*], Oleaceae [*Menodora scabra*], Pandanaceae [*Pandanus tectorius*], Plantaginaceae [*Plantago major*], Malvaceae [*Alcea setosa*], Punicaceae [*Punica granat*], Soongaticacea [*Hologcheas soongatica*], and Arecacaeae [*Phoenix dactylifera*]. *Argemone ochroleuca* species belonging to the family Papaveraceae had the highest plant density among wild plants. The other prominent species among wild plants included *Dracaena cinnabari, Vachellia farnesiana, Brassise acicularis,* and *Dysphania ambrosioides*. Contrarily, *Phoenix dactylifera* belonging to the family Arecacaeae had the lowest prevalence in the studied area among wild plants.

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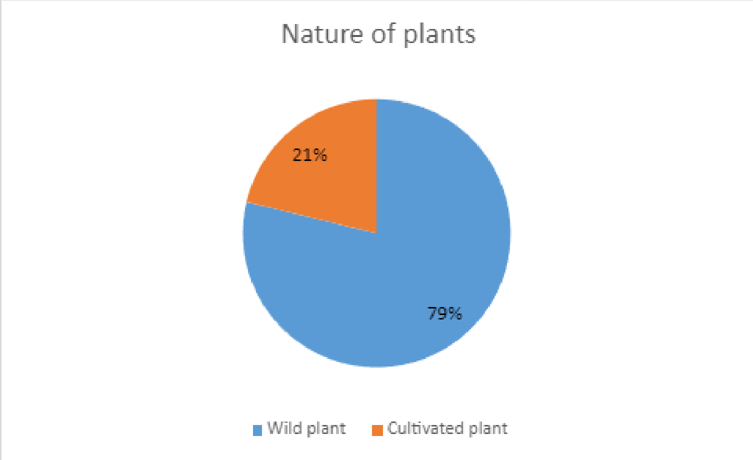

Figure 6. *The relative densities according to the nature of plants in Wadi AL-Arje, Taif, Saudi Arabia. Statistical analysis (ANOVA) presented a P-value of 0.321 and a t-value of 28.76 among species according to the nature of plants. The test of homogeneity of variances demonstrated a mean-based significance value of 0.000 and Levene's test value of 20.186 among species according to the nature of plants*

The results revealed that the prevalence of cultivated plants was significantly lower (21%) among collected plants (*Figure 6*). The number of cultivated plants was noted as 760 out of a total of 3581 plants. The cultivated plants belonged to different plant families including Brassicaceae [*Eruca vesicaria*], Asteraceae [*Lactuca sativa*, *Artemisia vulgar*], Solanaceae [*Isolanum lycopersicum*], Cucurbitaceae [*Cucumis fistula*, *Cucumis pepo*], Rosaceae [*Prunus armeniaca*], Rutaceae [*Citrus limon*, *Citrus sinensis*], Apiaceae [*Petroselinum crispum*], and Moraceae [*Morus alba*]. *Cucumis pepo* species belonging to the family Cucurbitaceae had the highest plant density among cultivated plants. The other dominant cultivated plants included *Eruca vesicaria*, *Petroselinum crispum*, *Lactuca sativa*, and *Cucumis fistula*. The lowest occurrence among cultivated plants in the studied area was noted for the species *Citrus sinensis* of the family Rutaceae. Plant nature-based sample data analysis revealed a non-significant P-value of 0.321 whereas the t-value of 28.76 was noted in the t-test of plant nature-based species analysis. The test of homogeneity of variances demonstrated a mean-based significance value of 0.000 and Levene's test value of 20.186 among species according to the nature of plants.

Environmental shape-based plant density in the studied area

The plant samples of Wadi Al-Arje depicted varying environmental shapes. The plants were categorized as herbs, shrubs, and trees. The occurrence of herbs and shrubs remained almost similar at 44.37% and 43.87%, which was significantly higher than the prevalence of trees at 11.76% (*Figure 7*). The number of shrub plants was noted as 1589 out of a total of 3581 plants. The shrub plants were observed in 36 species belonging to 24 families. 35 of these plant species had shrubs of wild nature whereas 1 species contained cultivated shrubs. The number of herb plants was noted as 1571 out of a total of 3581 plants. The herb plants were classified into 22 species belonging to 18 families. The nature of plants demonstrated that 16 out of 22 species had wild herbs whereas herbs in 6 species were cultivated plants. The number of tree plants was noted as 421

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out of a total of 3581 plants. The tree plants were categorized into 20 species belonging to 16 families. The nature of plants demonstrated that 16 out of 20 species had wild trees whereas trees in 4 species were cultivated plants. Environmental shape-based plant samples data analysis revealed a non-significant P-value of 0.962 whereas the t-value of 24.23 was noted in the t-test of environmental shape-based plant species analysis. The test of homogeneity of variances demonstrated a mean-based significance value of 0.022 and Levene's test value of 2.393 among species according to their nature.

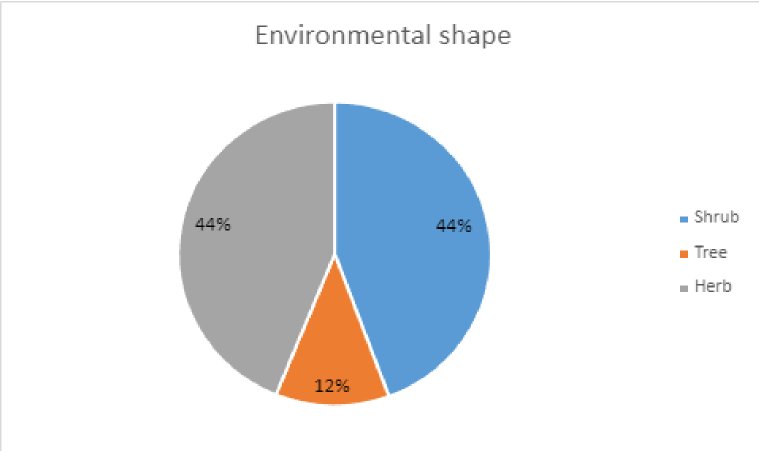

***Figure 7.** The relative densities according to the environmental shape of plants in Wadi AL-Arje, Taif, Saudi Arabia. Statistical analysis (ANOVA) presented a P-value of 0.962 and a t-value of 24.23 among species according to their environmental shape. The test of homogeneity of variances demonstrated a mean-based significance value of 0.022 and Levene's test value of 2.393 among species according to their environmental shapes*

Shrub density in different plant families

The plant samples from Wadi Al-Arje revealed the presence of shrub plants belonging to different families including Lamiaceae (*Dracaena cinnabari, Thymus vulgaris*), Fabaceae (*Vachellia farnesiana, Acacia Arabica, Albizia lebbeck, Melilotus albus*), Brassicaceae (*Brassica juncea*), Asteraceae (*Xanthium orientale, Bidens pilosa, Hazardia sauarrosa, Santolina chamaecyparissus*), Solanaceae (*Solanum incanum, Solanum muricatum, Nicotiana glauca, Isolanum lycopersicum*), Poaceae (*Cenchrus clandestinus, Agrostis stolonifera*), Amaranthaceae (*Haloxylon ammodendron, Aerva javanica*), Typhaceae (*Typha domingensis, Dysphania ambrosioides*), Polygonaceae (*Calligonum comosum*), Zygophyllaceae (*Fagonia laevis*), Tamaricaceae (*Tamarix ramossima, Ocimum tenuiflorum*), Rosaceae (*Coleogyhe ramosissima*), Anacardiaceae (*Rhus coriaria*), Cactaceae (*Aloe petricola, Opunia ficus*), Apoconaceae (*Calotropis procera*), Portulacaceae (*Portulaca oleracea*), Myrtaceae (*Eacalgptus globus*), Boraginaceae (*Cenchrus ciliaris*), Oleaceae (*Menodora scabra*), and Soongaticacea (*Hologcheas soongatica*) (*Figure 8*).

The family-wise highest to the lowest shrub plants density was noted as Lamiaceae (337), Fabaceae (210), Typhaceae (196), Tamaricaceae (158), Asteraceae (130), Amaranthaceae (112), Solanaceae (85), Rosaceae (64), Apoconaceae (57), Brassicaceae (53), Zygophyllaceae (40), Portulacaceae (33), Polygonaceae (23), Myrtaceae (20), Anacardiaceae (19), Boraginaceae (18), Cactaceae (14), Oleaceae (9), Poaceae (5),

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Elaeagnaceae (4), and Soongaticacea (2). The species wise highest to the lowest shrub plants density remained as *Dracaena cinnabari* (315), *Vachellia farnesiana* (168), *Dysphania ambrosioides* (118), *Tamarix ramossima* (107), *Haloxylon ammodendron* (83), *Typha domingensis* (78), *Xanthium orientale* (70), *Coleogyhe ramosissima* (64), *Isolanum lycopersicum* (63), *Calotropis procera* (57), *Brassica juncea* (53), *Ocimum tenuiflorum* (51), *Fagonia laevis* (40), *Hazardia sauarrosa* (36), *Portulaca oleracea* (33), *Acacia Arabica* (33), *Aerva javanica* (29), *Calligonum comosum* (23), *Thymus vulgaris* (22), *Eacalgptus globus* (20), *Rhus coriaria* (19), *Cenchrus ciliaris* (18), *Nicotiana glauca* (16), *Bidens pilosa* (13), *Santolina chamaecyparissus* (11), *Menodora scabra* (9), *Opunia ficus* (8), *Aloe petricola* (6), *Melilotus albus* (6), *Solanum incanum* (5), *Agrostis stolonifera* (4), *Elaegnus angustifolia* L (4), *Albizia lebbeck* (3), *Hologcheas soongatica* (2), *Solanum muricatum* (1), and *Cenchrus clandestinus* (1). The wild shrub plant species of Wadi Al-Arje included *Dracaena cinnabari*, *Thymus vulgaris*, *Vachellia farnesiana*, *Acacia Arabica*, *Albizia lebbeck*, *Melilotus albus*, *Brassica juncea*, *Xanthium orientale*, *Bidens pilosa*, *Hazardia sauarrosa*, *Santolina chamaecyparissus*, *Solanum incanum*, *Solanum muricatum*, *Nicotiana glauca*, *Cenchrus clandestinus*, *Agrostis stolonifera*, *Haloxylon ammodendron*, *Aerva javanica*, *Typha domingensis*, *Dysphania ambrosioides*, *Calligonum comosum*, *Fagonia laevis*, *Tamarix ramossima*, *Ocimum tenuiflorum*, *Coleogyhe ramosissima*, *Rhus coriaria*, *Aloe petricola*, *Opunia ficus*, *Calotropis procera*, *Portulaca oleracea*, *Eacalgptus globus*, *Cenchrus ciliaris*, *Menodora scabra*, and *Hologcheas soongatica*. *Isolanum lycopersicum* was the only cultivated shrub plant in the studied Wadi Al-Arje area.

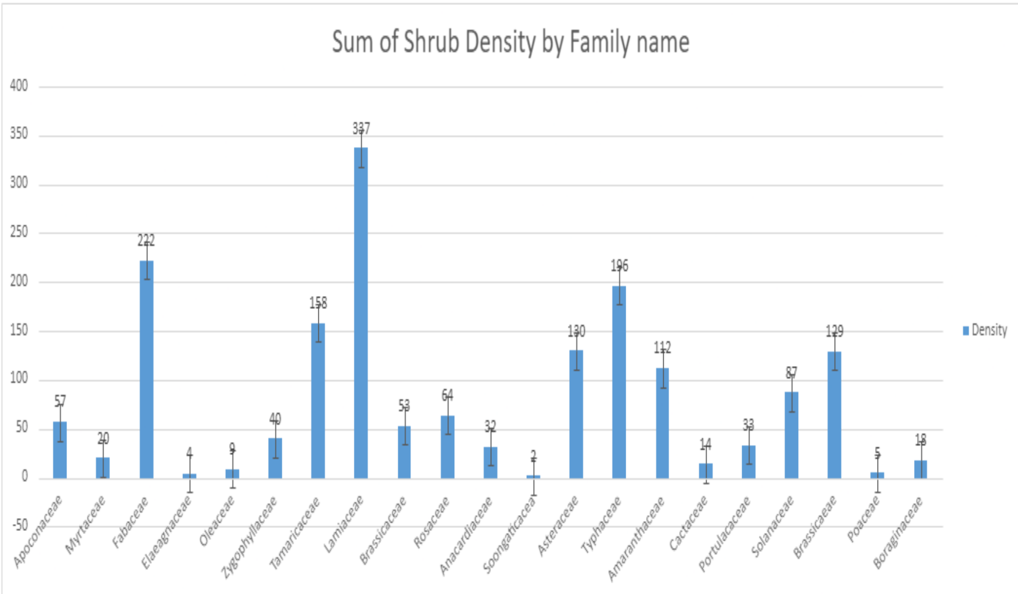

Figure 8. *The densities of shrub families in Wadi AL-Arje, Taif, Saudi Arabia*

Herb density in different plant families

The plant samples from Wadi Al-Arje demonstrated the presence of herb plants of different families including Lamiaceae (*Mentha piperita*), Fabaceae (*Ipomoea purpura*), Brassicaceae (*Eruca vesicaria*, *Sisymbium irio*), Asteraceae (*Lactuca sativa*, *Artemisia vulgaris*), Solanaceae (*Datura stramonium*), Poaceae (*Polypogon monspeliensis*,

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Cenchrus ciliaris), Cucurbitaceae (*Cucumis fistula*, *Cucumis pepo*), Amaranthaceae (*Atriplex maximowiziana*), Polygonaceae (*Rumex obtusifolius*), Zygophyllaceae (*Tetraena simplex*), Papaveraceae (*Argemone ochroleuca*), Apiaceae (*Petroselinum crispum*), Aizoaceae (*Aizoon canariense*), Nitrariaceae (*Peganum harmala*), Cyperaceae (*Cyperus rotundus*), Acanthaceae (*Justicia californica*), Geraniaceae (*Pelargonium graveolens*), and Plantaginaceae (*Plantago major*) (*Figure 9*).

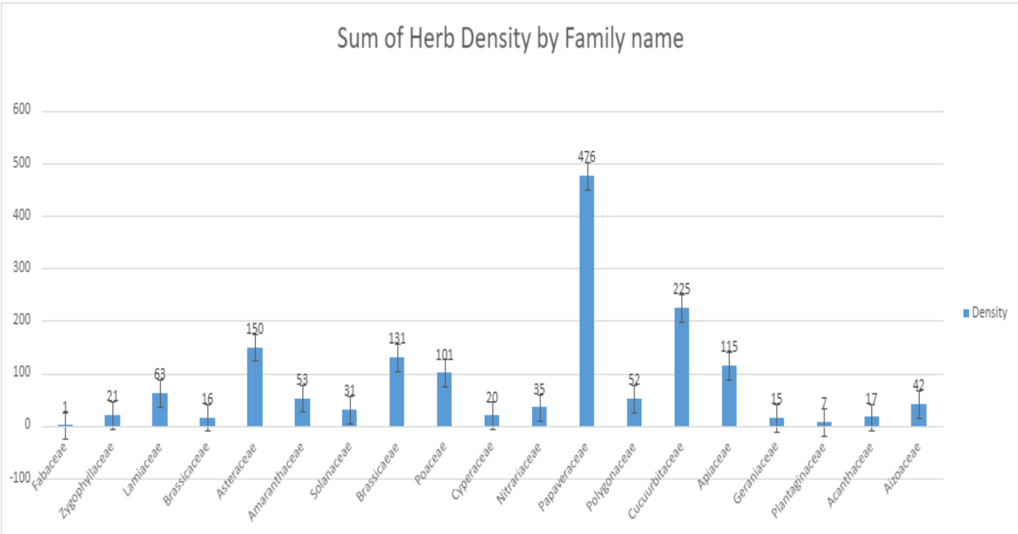

Figure 9. *The densities of herb families in Wadi AL-Arje, Taif, Saudi Arabia*

The data presented the family-wise highest to the lowest herb plants density as Papaveraceae (476), Cucurbitaceae (225), Asteraceae (150), Brassicaceae (147), Apiaceae (115), Poaceae (101), Lamiaceae (63), Amaranthaceae (53), Polygonaceae (52), Aizoaceae (42), Nitrariaceae (35), Solanaceae (31), Zygophyllaceae (21), Cyperaceae (20), Acanthaceae (17), Geraniaceae (15), Plantaginaceae (7), and Fabaceae (1). The species wise highest to the lowest herb plants density was noted as *Argemone ochroleuca* (476), *Cucumis pepo* (150), *Eruca vesicaria* (131), *Petroselinum crispum* (115), *Lactuca sativa* (100), *Polypogon monspeliensis* (88), *Cucumis fistula* (75), *Mentha piperita* (63), *Atriplex maximowiziana* (53), *Rumex obtusifolius* (52), *Artemisia vulgaris* (50), *Aizoon canariense* (42), *Peganum harmala* (35), *Datura stramonium* (31), *Tetraena simplex* (21), *Cyperus rotundus* (20), *Justicia californica* (17), *Sisymbium irio* (16), *Pelargonium graveolens* (15), *Cenchrus ciliaris* (13), *Plantago major* (7), and *Ipomoea purpura* (1).

The wild herb plant species of Wadi Al-Arje included *Mentha piperita*, *Ipomoea purpura*, *Sisymbium irio*, *Datura stramonium*, *Polypogon monspeliensis*, *Cenchrus ciliaris*, *Atriplex maximowiziana*, *Rumex obtusifolius*, *Tetraena simplex*, *Argemone ochroleuca*, *Aizoon canariense*, *Peganum harmala*, *Cyperus rotundus*, *Justicia californica*, *Pelargonium graveolens*, and *Plantago major*. The other species such as *Eruca vesicaria*, *Lactuca sativa*, *Artemisia vulgaris*, *Cucumis fistula*, *Cucumis pepo*, and *Petroselinum crispum* were the cultivated herb plants of Wadi Al-Arje samples.

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Tree density in different plant families

The plant samples from Wadi Al-Arje depicted the occurrence of tree plants of different families including Fabaceae (*Acacia dealbata*, *Leucaena leucocephala*), Brassicaceae (*Brassise acicularis*), Solanaceae (*Urtica dioic*), Poaceae (*Paspalum dilatatum*), Rosaceae (*Prunus dulcis*, *Prunus armeniaca*), Cupressaceae (*Cupressus sempervieh*s, *Juniperus communis*), Rutaceae (*Citrus limon*, *Citrus sinensis*), Anacardiaceae (*Mangifera indica*), Rhamnaceae (*Ziziphus spina*), Euphorbiaceae (*Ricinus communis*), Meliaceae (*Azadirachta indica*), Moraceae (*Morus alba*), Pandanaceae (*Pandanus tectorius*), Malvaceae (*Alcea setosa*), Punicaceae (*Punica granat*), and Arecacaeae (*Phoenix dactylifera*) (*Figure 10*).

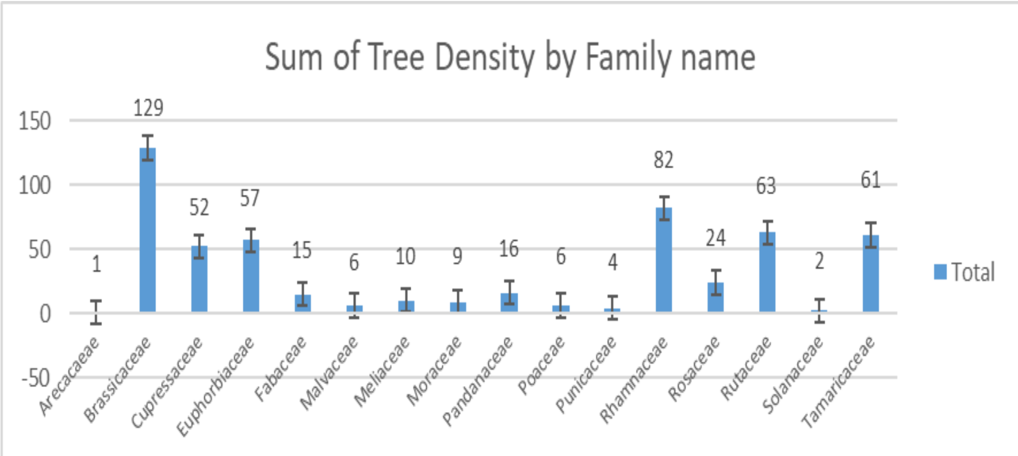

***Figure 10.** The densities of tree families in Wadi AL-Arje, Taif, Saudi Arabia*

The family-wise highest to the lowest tree plants density remained as Brassicaceae (129), Cupressaceae (52), Rutaceae (50), Rhamnaceae (45), Euphorbiaceae (35), Fabaceae (27), Rosaceae (24), Anacardiaceae (13), Meliaceae (10), Moraceae (9), Pandanaceae (8), Malvaceae (6), Poaceae (6), Punicaceae (4), Solanaceae (2), and Arecacaeae (1). The species wise highest to the lowest tree plants density was recorded as *Brassise acicularis* (129), *Ziziphus spina* (45), *Juniperus communis* (42), *Citrus limon* (42), *Ricinus communis* (35), *Prunus armeniaca* (17), *Leucaena leucocephala* (15), *Mangifera indica* (13), *Acacia dealbata* (12), *Cupressus sempervieh*s (10), *Azadirachta indica* (10), *Morus alba* (9), *Citrus sinensis* (8), *Pandanus tectorius* (8), *Prunus dulcis* (7), *Paspalum dilatatum* (6), *Alcea setosa* (6), *Punica granat* (4), *Urtica dioic* (2), and *Phoenix dactylifera* (1). The wild tree plant species of Wadi Al-Arje included *Brassise acicularis*, *Ziziphus spina*, *Juniperus communis*, *Ricinus communis*, *Leucaena leucocephala*, *Mangifera indica*, *Acacia dealbata*, *Cupressus sempervieh*s, *Azadirachta indica*, *Pandanus tectorius*, *Prunus dulcis*, *Paspalum dilatatum*, *Alcea setosa*, *Punica granat*, *Urtica dioic*, and *Phoenix dactylifera*. The other species such as *Prunus armeniaca*, *Citrus limon*, *Citrus sinensis*, and *Morus alba* were the cultivated tree plants of Wadi Al-Arje samples.

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Discussion

The effects of weeds on agricultural settings are considered multifaceted as they compete with crops in terms of light, space, and nutrients. This competition is manifold higher in desert regions with lower rainfalls and lesser water availability. Weeds are globally acknowledged to hinder agricultural outputs with their efficient nutrients and moisture-draining capabilities. They also limit sunlight availability to the crops at initial growth stages leading to significantly mitigated crop production. The lack of weed control measures could destroy the sown crops. Weeds also serve as a perfect habitat for the flourishing of pathogens and insect pests that also damage crops in addition to being detrimental to grazing animals. The weeds' growth patterns involving rapid growth and spreading, dormancy under unfavorable conditions, and seed production in large quantities make them better performers in the field environment than the crops. Moreover, other factors such as early flowering and fruiting as compared to the crops favor their rapid expansion and monopoly in the fields. These factors necessitate identification and detailed understanding of weed diversity, and density distribution in cropping areas for sustainable weed management and higher agricultural yields.

During this study, the Fabaceae family was found to have the highest weed species diversity (7) in the studied area with a plant density of 238. Fabaceae are also referred to as legumes of the bean family. This family is widely prevalent in various regions of the world and is considered the 3rd largest plant family comprising almost 765 genera and 20,000 species. Many species of this family grow as unwanted weed families in agricultural cropping areas worldwide. However, their presence as invasive plant species in South Asia, Europe, and China has been estimated at 15%, 7%, and 11%, respectively (Gulzar et al., 2024). The Asteraceae and Solanaceae families shared the second-highest weed species diversity of 6 with population densities of 280 and 118 in the studied area. Asteraceae is considered the largest global weed family of flowering species with diverse worldwide distribution in almost all continents. It is comprised of 1000 genera and 25,000 flowering weed species. This dominant weed family constitutes 43% global weed share in agricultural regions. The undesired plants of Asteraceae are well known for their allelopathy, secondary metabolites, and phytotoxicity, which hinder the growth of cultivated crops (Araújo et al., 2021). Solanaceae family mainly contains flowering plants that belong to 2500 species in almost 100 genera. They often contain glycoalkaloids, which are toxic to humans. The poisonous weeds of Solanaceae can be mistakenly harvested along with the crops, which could be seriously detrimental to human health. Therefore, these weeds must be eliminated from the fields before the harvesting season (Lauwers et al., 2022). The presence of the Poaceae family was quite significant as well with the species diversity of 5 and plant density of 112. The Poaceae weeds can tolerate various weather and environmental conditions, which facilitate their presence in diverse landscapes. These weeds have the distinct feature of reproducing from plant roots, nodes, seeds, rhizomes, and stems. The allelochemicals of Poaceae weeds help them in better exploitation of available resources and restrict other plants' growth. The presence of the Lamiaceae family in the study area had a species diversity of 3 and the second-highest plant density of 400. It is the 6th largest angiosperm family of annual or perennial plants. This cosmopolitan large family is comprised of 250 genera, which contain almost 7200 species whereas 175 species grow as weed plants worldwide. The prevalence of the Lamiaceae family is quite common in temperate areas, and these plants are also known for various types of pharmacological properties, allelochemicals, and toxicity (Islam et al., 2022). The Papaveraceae family was

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represented by only species but it had the highest weed plant density of 476 among the collected samples of Wadi Al-Arje. The cosmopolitan Papaveraceae family contains about 775 species in 42 genera. The prevalence of this family is common in subtropical and temperate regions. This family is characterized by colorful flowers with distinct sepals.

Argemone ochroleuca is a highly devastating invasive plant species that damages natural and agricultural ecosystems. Particularly, the allelochemicals of this weed are well known to restrict crop growth in the fields (Mlombo et al., 2024). Abd-ElGawad et al. (2020) investigated *Argemone ochroleuca* essential oils' composition and reported the presence of highly oxygenated components such as hydrocarbons, terpenoids (di, mono, and sesqui), and carotenoids. These ingredients have been established for their growth and germination-hindering properties in crops. *Dracaena cinnabari* is commonly known as dragon's blood. The resin of this plant is often used in conventional medicines as it contains secondary metabolites (Almaghrebi et al., 2024). *Vachellia farnesiana*, commonly known as mimosa bush, is a naturalized invasive woody type of weed species that is often reported in agricultural settings and grassland areas. The low densities of this weed are not considered problematic, however, its dense infestations threaten the agricultural lands and pasture grasses. *Dysphania ambrosioides* plant contains higher flavonoid and phenolic acid contents, which are known to prevent human ailments including hepatocellular cancer (Huang et al., 2023). Plant communities in the field are comprised of cultivated species (ornamentals and crops), and wild species. The plant density of both types can be influenced by various factors, which could include human intervention, biological invasions, pollution, climate, and land use (Swan et al., 2021). This study revealed a significantly high prevalence of wild-growing weed species as compared to the cultivated plants in the fields of Wadi Al-Arje. These findings are in contradiction with the findings of Seitz et al. (2022) who compared the occurrence of wild and cultivated plants in different urban gardens of Berlin, Germany. They noted a non-significantly higher presence of cultivated plant species (194) as compared to the wild plant species (184). This could be attributed to better human management in the garden environment than in the larger agricultural fields.

Shrubs are small-sized perennial woody plants (deciduous or evergreen) with their woody stems above the ground. The density of shrubs in an area mainly depends on the climatic and soil factors whereas the role of topography is considered minor (Moreno-Fernández et al., 2021). Shrub weeds serve as habitat for insect pests and compete with crops for moisture, light, and nutrients. The removal of shrubs from the fields is important to reduce their competition with other plants and expand agricultural and grassland areas. However, shrubs also have a role in reversing desertification in addition to serving as carbon storage and bioenergy sources (López-Marcos et al., 2020; Cruz-Alonso et al., 2020). Therefore, the identification of shrub plant species is necessary to understand their growth dynamics and response to the environmental parameters of an area. The shrub studies should involve the identification and investigation of their role in various ecosystems (Olthoff et al., 2021). Weeds are generally undesired plants of an area, however, sometimes weed herbs emerge as a rich source of medicine and food. Herbs are frequently used in traditional medicines, but agriculturists categorize these herbs as weeds. Mimosa, Argemone, Cynodon, Parthenium, Oxalis, Cyprus, and Amaranthus genera are known for high medicinal values and these are commonly found in gardens, fields, and roadside. The global market of medicinal weed herbs is rapidly growing, which could be an alternate income source for farmers. However, they

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alleviate the nutritional value of grown crops, vegetables, and fruits in the field. Therefore, their elimination enhances the crop yield. Contrarily, a more recent approach to tackling weed herbs is to utilize them for therapeutic applications, which could yield extra income to cover the herb weed-associated losses (Devi et al., 2023). The invasive trees/plants result in the loss of biodiversity in an ecosystem (Khapugin et al., 2020). For example, *Acacia dealbata* is one of the identified weed tree species during this study that is well known for its invasive nature. Factors like higher seed yield, more than 70% germination rate, the release of allelochemicals, and rapid growth favor its invasive expansion in the ecosystem. Other weed trees could also exert similar properties in the agricultural and forest areas. Therefore, the investigation of the invasive potential of such species could help in devising effective preventive strategies.

Conclusions

Weeds are a key global factor that hinders the productivity of agricultural areas. The detailed knowledge of area-specific weed distribution and density can help in developing efficient weed management approaches. This study thoroughly surveyed the weed biodiversity of Wadi AL-Arje of Taif, Saudi Arabia, which is a highly fertile agricultural area. Several types of weed families and related species were identified during the study, which had varying plant densities. The findings of this study could help in developing more effective area-specific weed countermeasures for enhanced agricultural output. To conclude, the study strongly recommends regular surveying of weed populations in targeted agricultural areas and the application of an integrated weed management approach to avoid production losses.

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