WEED BIODIVERSITY AND DENSITY ASSESSMENT OF WADI LIYAH OF TAIF, SAUDI ARABIA

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Abstract. The presence of unwanted weed plants exerts multifaceted impacts on the ecosystem and particularly influences landscape and agricultural operations. This investigation was performed to identify and assess the density and diversity of weed plants in Wadi Liyah, Taif, Saudi Arabia. A total of 3626 plants (herbs, shrubs, trees) were collected representing 60 plant species in 27 plant families. The plant density of herbs was significantly higher than that of trees and shrubs. A total of 2300 (63%) herb plants belonged to 33 species in 16 different plant families. The density of trees was assessed as 1054 (29%) plants, which belonged to 16 species in 12 families. The density of shrub plants remained at 271 (7%) belonging to 11 species of 9 families. The dominant plant families included Amaranthaceae (641), Poaceae (637), Fabaceae (488), Tetradiclidaceae (350), and Asteraceae (244) whereas *Aerva javanica* (471), *Vachellia farnesiana* (365), *Peganum harmala* (350), *Cynodon dactylon* (246), *Menodora scabra* (237), and *Eragrostis pilosa* (237) were the most prevalent weed plant species in the area. The study thoroughly investigates the weed biodiversity and density in Wadi Liyah in the Taif region. The findings could help in better weed control measures without disturbing the balance of the ecosystem.
Keywords: *agriculture, crops, herbs, shrubs, trees*

Introduction

Weed plants are a key influential element of the agriculture sector. The detrimental aspects of weed plants are mainly associated with their yield-limiting impacts, and they have developed as efficient competitors of crops. Weed management becomes particularly complicated in vegetable farms, organic farms, and small farms with fewer input resources, which could ultimately result in low profitability (Madden et al., 2021). Resource competition analysis could reveal the dynamics of the weed community’s chances of successful invasion in new areas. Weeds are considered a key biotic limitation factor in the agriculture sector causing significant annual losses to quantity and quality of crop production. Weed plants can more quickly utilize natural resources (space, water, nutrients, and light) than planted crops because of their more efficient biological features and frost and drought resistance (Khattak et al., 2024). Root length, photosynthetic pathway, and plant structure of weeds contribute to their better water uptake capability and growth. The spatial pattern of weed seeds is another important factor in weed distribution along with the management practices of a particular area. Therefore, the detailed knowledge of weeds’ biological characteristics is important for effective management outputs. However, weed investigations significantly differ in developed and underdeveloped countries. The availability of limited weed information in an area could restrict the designing of efficient countermeasures.

The role of weed biodiversity is important in supporting agroecosystems and food webs. A thorough understanding of weed communities’ response to human-induced and environmental factors is mandatory to develop ecologically sound and efficient control

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strategies (Hatzigiannakis et al., 2024). Agricultural systems face a significant impact of human-induced activities where weed biodiversity exerts both positive and negative effects. The management practices could result in selective weed infestation. The extent of weed tolerance and susceptibility differs in various crops and thus might require different remedial measures. A study in western France, involving 150 experimental fields, identified 108 weed species in winter wheat plots with an average of 9.46 species per plot (Gaba et al., 2016). Contrarily, Hofmeijer et al. (2021) reported much higher weed diversity (197 species) in the wheat fields of Sweden, Denmark, Latvia, Germany, and Finland. The slow growth, broader row spacing, and low plant density of maize during its early stages also make it susceptible to weed infestation. Therefore, the process of weed invasion in various land use classes and crops should be properly studied to achieve satisfactory results of weed management measures. The types of various weed management strategies of an area could be impacted by farmers' differential capability of acquiring management inputs. Weeds can also release allelochemicals in the soil and facilitate pathogen and pest development, which aggregate into economic loss of 33 billion USD/Year in the USA (Pimentel et al., 2005). Herbicides are commonly applied to deal with weed infestations. However, frequent applications of herbicides trigger segetal immune pathways in plants that have led to resistance in 380 weed biotypes globally. Moreover, strict regulations and the negative impacts of herbicides on the ecosystem discourage their usage in the current era. Therefore, bioherbicides are gaining popularity as a safe and effective alternative with a global market value of 1.6 billion EUR and an annual growth of 15%. High selectivity and specificity, non-toxic nature, and low cost favor the expansion of bio-products. However, despite several studies, only 25 mold-based bioherbicides are commercially available, which remain unable to counter the negative effects of weeds on agricultural productivity and cereal losses (Kubiak et al., 2022).

The rising food demand in proportion to the global human population necessitates weed management practices to assure food security. The current intensive tillage and herbicide-based weed management practices pose considerable environmental risks such as soil erosion, compromised soil quality, loss of organic matter, soil compaction, and nutrient depletion (Orzech et al., 2021). These factors also affect the global pastures and croplands. The yield reductions and high carbon footprint are major drawbacks of tillage-based management systems. On the other hand, despite all hazards weeds are an integral part of the agroecosystems. Recently, the idea of neutral weed communities has also surfaced where certain weeds coexist with cropping systems without harming the quality and yield of the produce rather than weed-free situations. Neutral weeds' promoting management practices can alleviate soil tillage and herbicide applications to improve biodiversity and ecosystems. This novel approach suggests that the removal of all weeds from the fields is not desirable. Multiple studies have suggested that weeds' competitive impacts depend on various factors including crop traits, field environment, and weed community in the field. Weed communities could benefit agroecosystems under certain conditions without negatively affecting the crops. Adeux et al. (2019) investigated winter crop biomass of cereal, weed biomass, and weed density for three years and screened six weed communities. Two of these communities did not significantly alleviate grain yield as compared to weed-free treatments. These weed communities mainly contained *Stellaria media* (L.) Vill (common chickweed), *Veronica persica* Poir. (Persian speedwell), *Geranium dissectum* L. (cut-leaf geranium), *Galium aparine* L. (catchweed bedstraw), and *Veronica hederifolia* L. (ivy leaf speedwell).

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Thus, weeds are also a key element of agroecosystem biodiversity from the conservation angle. The unjudicial herbicidal applications could quickly reduce the weed diversity and abundance in the fields. However, the removal of too many weeds from the fields could result in species decline at higher trophic levels. The low weed biodiversity in the field encourages the domination of fewer more competitive weed species, which ultimately become more difficult to control. The presence of neutral weed communities in the field, which do not affect the quality and crop production, could reduce management practices for their better conservation and sustained biodiversity (MacLaren et al., 2019). These weeds could promote the long-term production and sustainability of crops. Ecological weed management can be achieved either by promoting weed biodiversity or selecting specific species for elimination or conservation.

Heap (2023) has reported herbicide resistance in 267 monocot (113) and dicot (154) weed species. In this scenario, a site-specific weed management approach (SSWM) can help in avoiding herbicides' negative impacts. The technique encourages the herbicide applications according to the weed density and discourages the herbicide spraying in weed-free patches of the field (Esposito et al., 2021). However, precise information on weed infestations in the target area must be available, which can be obtained through remote sensing and field scouting. SSWM can reduce the usage of herbicides by 40%–60% to reduce contaminations and input costs. However, heterogeneous weed dispersal is the main restriction of SSWM. Weed heterogeneity (spatial and temporal) in agricultural fields causes variations in phenology, dispersal, and growing time. Therefore, in-depth elaboration of the spatiotemporal dynamics of weeds can help in avoiding the limitations of the SSWM technique. The invasive species are capable of expanding across large geographical areas and infesting new productive areas. Invasive and arable weeds combined with ecological adaptability and environmental disturbance are crucial for weed-weed and crop-weed interactions (Lucero et al., 2022). Elevation is an important parameter of topography that affects the composition, spatial distribution, and density of weeds in an area. Certain other factors can help in restricting weed species expansion as well. For example, crops having dense canopies and tall plant lengths restrict weed growth better than short crops with open canopies. The competitive crops can effectively suppress the weeds' field growth and density as well. The influence of management practices is generally significant on the diversity and composition of weed species in an area. For example, chemical herbicides rapidly alleviate weed population in agricultural fields and orchards whereas mowing enhances richer communities with diverse types of species. Mowing could help the grass species in forming new crown tillers and potentially facilitate seed spread. It is also considered to enhance perennial weeds' growth more than short-lived weeds in comparison to tillage operations and herbicide applications. Moreover, different variables such as slope angle of an area, and soil characteristics could also considerably affect species-environment relationships. The literature reveals contradictory findings regarding the effect of environmental factors and human management factors on weed diversity. Some studies report that environmental factors (soil texture, pH, and the soil's properties) primarily drive weed biodiversity whereas other studies prioritize the impacts of human activities. Livestock activities also significantly influence the weed flora diversity of an area. Particularly, livestock grazing helps in better growth and richness of weed biodiversity. Hatzigiannakis et al. (2024) have reported that animal grazing promoted the growth of annual and perennial weeds. Therefore, balanced weed

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management measures are necessary for sustainable agricultural activities. The current study carried out the collection of weed plant samples from Wadi Liyah of Taif, Saudi Arabia followed by their identification, analysis of weed diversity, and estimation of weed density. The findings of this study present a clear picture of weed prevalence in the studied area. It could help in adopting sustainable weed management programs in Wadi Liyah for enhanced agricultural yields without affecting the balance of the agroecosystem of the area.

Materials and methods

Location of study

The study involved the investigation of plant diversity in Wadi Liyah of Taif region, Kingdom of Saudi Arabia (*Fig. 1*). The study area is situated on the Sarwat Mountains (Eastern Slopes) at an altitude of 1593 m above sea level, however, the heights of 22 sampling locations ranged from 1399 m to 1605 m above sea level. The height of this area increases towards the south and west sides and reaches up to a maximum level of 1660 m. The coordinates of this area are N 21-296 and E 40-496. Taif is a densely populated area, which is famous for its agricultural fields. Agricultural farms (25,500) cover an area of approximately 594,000 ha. Taif region is the most fertile area of the Kingdom of Saudi Arabia, which produces diverse types of agricultural products.

Plant specimen collection

Plant specimens were collected during vegetation-rich season (August to October) of 2024 from various agricultural areas of Wadi Liyah of Taif, Saudi Arabia (*Fig. 1*).

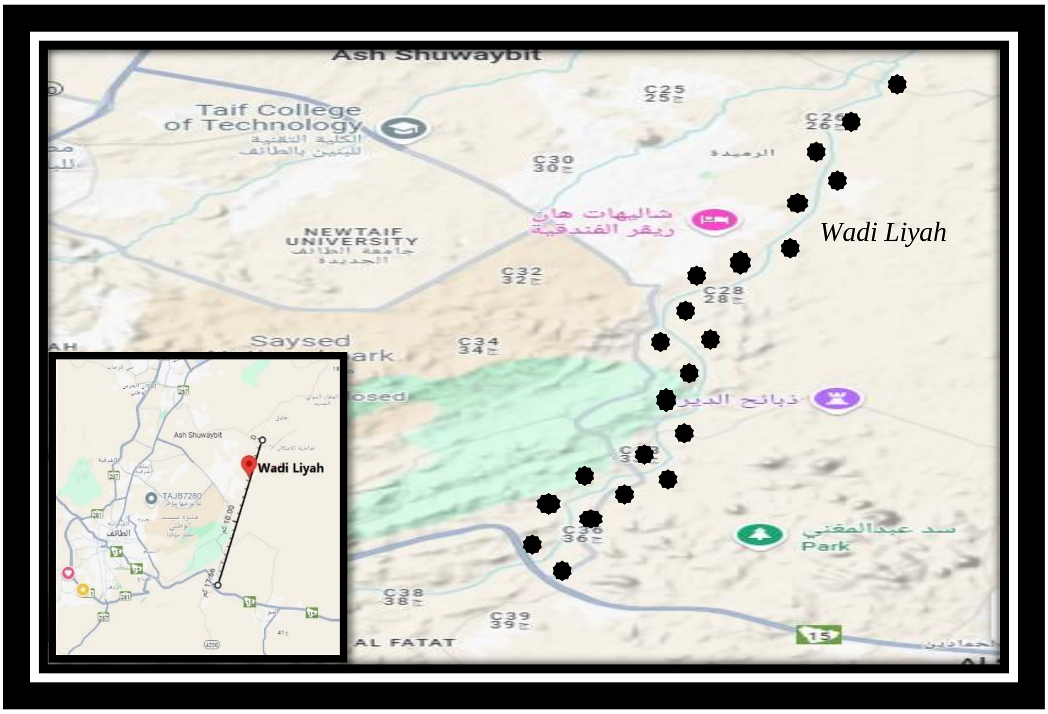

Figure 1. *Map of Wadi Liyah, Taif, Kingdom of Saudi Arabia. (http://www.athagafy.com/images/montada/camelmap.jpg) (⬤) The 22 study sites, where each site represents an area of 10 m2*

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Sample identification

Herbarium specimens were prepared from the collected plant samples for identification. Weeds' invasion of crops was assessed according to visual or arbitrary observations. The methodology of Sher and Al-Yemeny (2011) served as the reference point for the identification of weed species. *Figure 2* demonstrates the experimental design that was followed to collect weed samples from agricultural farms. The collected weed plants were identified and categorized into relevant species and families.

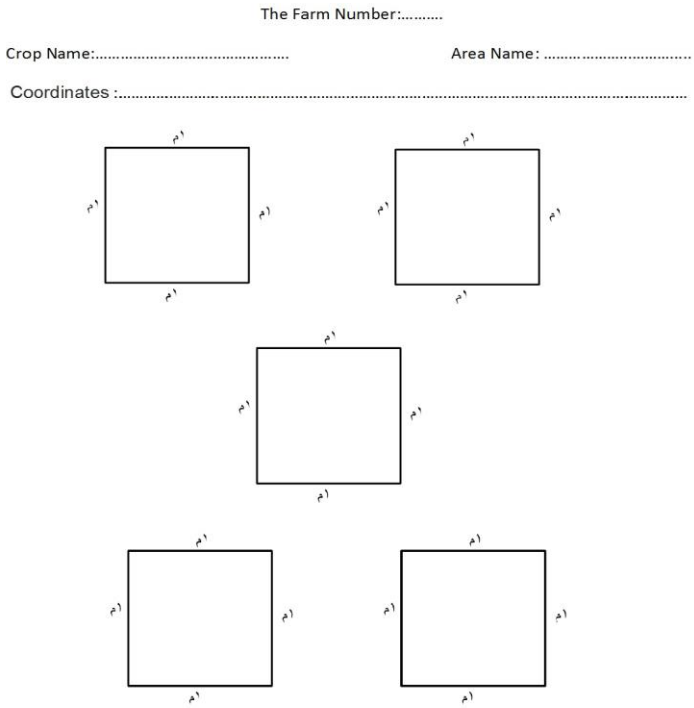

Figure 2. *Experimental design and quadrats arrangements of weeds in the study area*

Data analysis

SPSS (v26) was employed for the data analysis. The data was transformed using Log + 1 or log and subjected to statistical analysis (one-way ANOVA). Levene's test, T-test, and LSD (least significant difference) test differentiated the means. These statistical analyses have been previously reported in similar studies (Juan et al., 2010; Levi et al., 2011).

Results

Weed vegetation analysis

The survey involved the collection and examination of a total of 3626 plants from the study area. Plants were taxonomically identified and classified into respective families and related species. Weed samples belonged to 27 plant families, which were comprised of 60 plant species with differential densities. The collected samples mostly contained wild plants with only a few exceptions of cultivated plants. The plants were further categorized into different environmental types of plants including herbs, shrubs, and trees.

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Density of plant families

The examination identified 27 plant families in the studied area, which included Zygophyllaceae, Fabaceae, Brassicaceae, Asteraceae, Solanaceae, Poaceae, Amaranthaceae, Cucurbitaceae, Euphorbiaceae, Arecaceae, Apocyaceae, Tetradiclidaceae, Tamaricaceae, Rhamnaceae, Oleaceae, Typhaceae, Nyctaginaceae, Aizoaceae, Aspargaceae, Heliotropiaceae, Portulacaceae, Polemoniaceae, Polygonaceae, Cupressaceae, Cleomaceae, Brickellia, and Malvaceae. Plant families were represented by different numbers of species. The Asteraceae family had the highest number of plant species (8). The species count varied in other families and were noted as Poaceae (6), Amaranthaceae (5), Solanaceae (5), Fabaceae (5), Zygophyllaceae (3), Apocyaceae (3), Euphorbiaceae (3), Cucurbitaceae (2), Arecaceae (2), Rhamnaceae (2), Tetradiclidaceae (1), Tamaricaceae (1), Brassicaceae (1), Oleaceae (1), Typhaceae (1), Nyctaginaceae (1), Aizoaceae (1), Aspargaceae (1), Heliotropiaceae (1), Portulacaceae (1), Polemoniaceae (1), Polygonaceae (1), Cupressaceae (1), Cleomaceae (1), Brickellia (1), and Malvaceae (1).

The identified plant families collectively contained 60 plant species. The weed densities considerably differed in various plant families of the Wadi Liyah area of Taif Saudi Arabia. The highest plant density of 651 was noted in the family Amaranthaceae whereas the lowest plant density of 2 was noted in Malvaceae and Brickellia families. The plant densities in other families were noted as Poaceae (541), Fabaceae (488), Nitrariaceae (350), Asteraceae (244), Oleaceae (237), Euphorbiaceae (146), Apocyaceae (139), Typhaceae (134), Tamaricaceae (123), Zygophyllaceae (100), Brassicaceae (100), Solanaceae (93), Nyctaginaceae (46), Aizoaceae (44), Arecaceae (42), Aspargaceae (33), Rhamnaceae (28), Heliotropiaceae (25), Portulacaceae (22), Cucurbitaceae (13), Polemoniaceae (12), Polygonaceae (5), Cupressaceae (3), Cleomaceae (3) and Malvaceae (2) (*Fig. 3*). Overall, Amaranthaceae, Poaceae, Fabaceae, Tetradiclidaceae, and Asteraceae families were more prominent regarding plant density whereas families Asteraceae, Poaceae, Amaranthaceae, Solanaceae, and Fabaceae appeared more dominant regarding species diversity (*Fig. 3*). The statistical analysis presented the t-value of 12.27 revealing a strong statistical significance between tested families. A mean-based significance value of 0.003 was observed in the test of homogeneity of variances whereas Levene’s test value remained 4.11 among families denoting significantly different variances between groups.

Density of plant species

The examination of samples identified 60 plant species from different plant families in the Wadi Liyah area of Taif. The identified plant species included *Catharanthus roseus, Calotropis procera, Ceropegia gigantean* (Apocyaceae), *Aerva javanica, Chenopodiastrum murale, Atrieiex mjxiawicziana, Dysphania ambrosioides, Axyris amaranthoides* (Amaranthaceae), *Santolina chamaecyparissus, Baccharis halimifolia, Centaurea solstiti, Chrysothamnus viscidifblus, Xanthisma spinulosum, Dittrichia viscosa, Xanthium orientale, Helianthus annuus* (Asteraceae), *Fagonia laevis, Tetraena alba, Balanites aegyptiaca* (Zygophyllaceae), *Pithecellobium dulce, Calicotome villosa, Vachellia farnesiana, Bituminaria bituminosa, Vachellia tortills* (Fabaceae), *Cenchrus cilliais, Cortaderia selloana, Eleusine indica, Cynodon dactylon, Sisymbium irio, Eragrostis pilosa* (Poaceae), *Citrullus colocynthis, Cucumis anguria* (Cucurbitaceae),

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Phoenix dactylifera, *Cynara cardunculus* (Arecaceae), *Lycium ferocissimum*, *Datura innoxia*, *Solanum incanum*, *Nicotiana glauca*, *Solanum lycopersicum* (Solanaceae), *Euphorbia resinifera*, *Ricinus communis*, *Ocimum tanuiflorum* (Euphorbiaceae), *Sarcomphalus obtusifolius*, *Ziziphus mucronata* (Rhamnaceae), *Peganum harmala* (Tetradiclidaceae), *Menodora scabra* (Oleaceae), *Tamarix ramosissima* (Tamaricaceae), *Typha domingensis* (Typhaceae), *Bocrhavia coccinea* (Nyctaginaceae), *Aizoon canariense* (Aizoaceae), *Asparagus albus* (Aspargaceae), *Heliotropium supinum* (Heliotropiaceae), *Portulaca oleracea* (Portulacaceae), *Eriastrum eremicum* (Polemoniaceae), *Rumex crispus* (Polygonaceae), *Carrichtera annua* (Brassicaceae), *Cupressus arizonica* (Cupressaceae), *Polanisia dodecandra* (Cleomaceae), *Brickellia californica* (Brickellia), and *Malva parviflora* (Malvaceae) (*Fig. 4*).

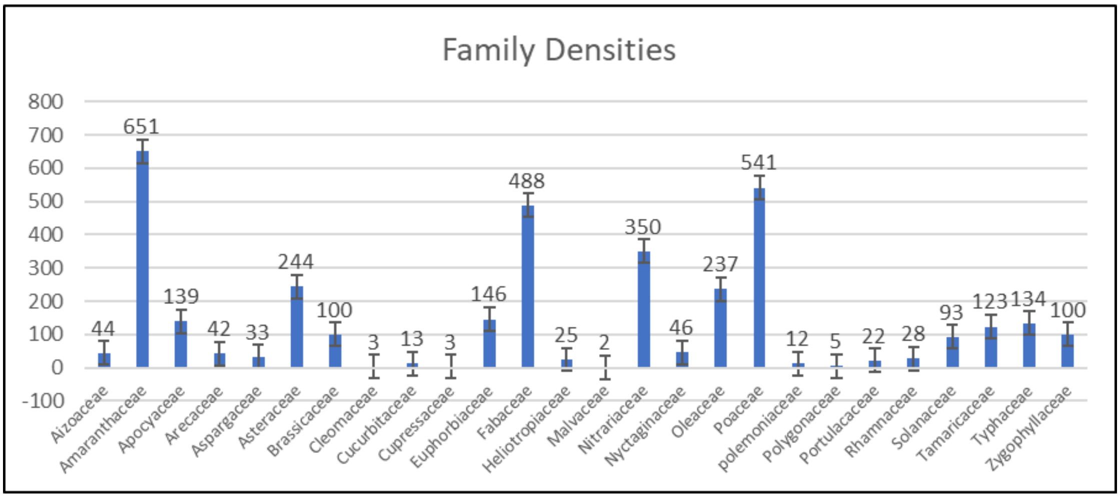

Figure 3. *Densities of weed plant families (mean ± SE) in agricultural crops of Wadi Liyah, Taif, Saudi Arabia. Statistical analysis (ANOVA) presented a P-value of 0.361 and a t-value of 12.27 among families. The test of homogeneity of variances revealed a mean-based significance value of 0.003 and Levene's test value of 4.11 among families.*

The data demonstrated significantly different plant densities among identified plant species of the study area. *Aerva javanica* had the highest plant density of 471 among all the species. The plant densities of other species were found as *Vachellia farnesiana* (365), *Peganum harmala* (350), *Cynodon dactylon* (246), *Menodora scabra* (237), *Eragrostis pilosa* (237), *Dysphania ambrosioides* (146), *Typha domingensis* (134), *Tamarix ramosissima* (123), *Calotropis procera* (111), *Helianthus annuus* (109), *Vachellia tortills* (101), *Sisymbium irio* (96), *Ricinus communis* (87), *Fagonia laevis* (69), *Solanum incanum* (63), *Ocimum tanuiflorum* (58), *Xanthium orientale* (51), *Centaurea solstiti* (51), *Bocrhavia coccinea* (46), *Aizoon canariense* (44), *Phoenix dactylifera* (38), *Cortaderia selloana* (35), *Asparagus albus* (33), *Tetraena alba* (29), *Ziziphus mucronata* (27), *Heliotropium supinum* (25), *Atrieiex mjxiawicziana* (23), *Catharanthus roseus* (22), *Portulaca oleracea* (22), *Pithecellobium dulce* (19), *Datura innoxia* (17), *Eleusine indica* (16), *Dittrichia viscosa* (13), *Eriastrum eremicum* (12), *Citrullus colocynthis* (11), *Solanum lycopersicum* (10), *Chenopodiastrum murale* (10), *Xanthisma spinulosum* (8), *Cenchrus cilliais* (7), *Ceropegia gigantean* (6), *Rumex crispus* (5), *Chrysothamnus viscidifblus* (5), *Santolina chamaecyparissus* (5), *Carrichtera annua* (4), *Cynara cardunculus* (4), *Cupressus arizonica* (3), *Polanisia*

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dodecandra (3), *Calicotome villosa* (2), *Brickellia californica* (2), *Malva parviflora* (2), *Baccharis halimifolia* (2), *Lycium ferocissimum* (2), *Cucumis anguria* (2), *Balanites aegyptiaca* (2), *Nicotiana glauca* (1), *Euphorbia resinifera* (1), *Axyris amaranthoides* (1), *Bituminaria bituminosa* (1), and *Sarcomphalus obtusifolius* (1). The densities of *Aerva javanica*, *Vachellia farnesiana*, *Peganum harmala*, *Cynodon dactylon*, *Menodora scabra*, and *Eragrostis pilosa* were noted to be significantly higher than other species of various plant families of the Wadi Liyah area in Taif (*Fig. 4*). The statistical analysis demonstrated a t-value of 10.28 representing significant differences among the densities of tested species. A mean-based significance value of 0.003 was noted in the test of homogeneity of variances whereas analysis revealed a Levene's test value of 4.14 among species suggesting significantly dfferent variances between groups.

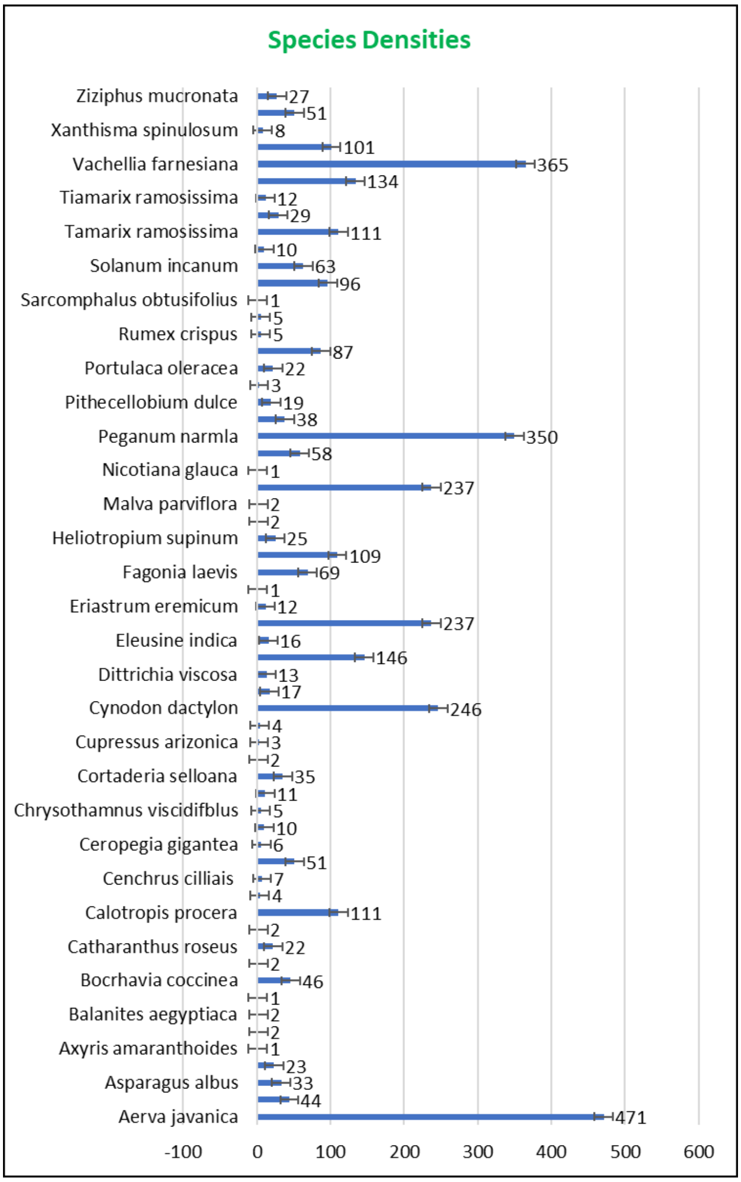

Figure 4. *Densities of weed plant species (mean ± SE) in agricultural crops of Wadi Liyah, Taif, Saudi Arabia. Statistical analysis (ANOVA) presented a P-value of 0.527 and a t-value of 10.28 among species. The test of homogeneity of variances revealed a mean-based significance value of 0.003 and Levene's test value of 4.14 among species*

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Plant density according to growth patterns

The plant samples of the Wadi Liyah area mainly had three types of growth patterns and were categorized as herbs, shrubs, and trees. The occurrence of herbs was significantly higher than trees and shrubs. The occurrence of these plant types was noted as 63% herb plants, 29% trees, and 7% shrub plants (*Fig. 5*). The number of herb plants was observed as 2300 out of a total of 3626 plants. The herb plants of 33 species were noted among the collected samples, which belonged to 17 families. All the herb plants were identified as wild natural plants. The data of this study demonstrated the presence of 1054 tree plants out of a total of 3626 plants. The tree plants of 16 species were found among the collected samples, which belonged to 12 families. All the tree plants were identified as wild trees except the species *Phoenix dactylifera*, which were cultivated plants of the studied area. Among the collected samples, 271 shrub plants were identified out of a total of 3626 plants. The shrub plants were found in 11 species among collected samples, which belonged to 8 families. All the shrub plants were identified as wild natural plants (*Fig. 5*). Growth pattern-based plant samples data analysis revealed a significant P-value of 0.03 whereas the t-value of 22.11 was noted in the t-test of growth pattern-based plant species analysis, which also confirmed strong statistical significance among tested groups. The test of homogeneity of variances depicted a mean-based significance value of 0.245 whereas Levene's test value was noted as 1.398 among species according to the growth patterns of plants demonstrating similar variances between tested groups.

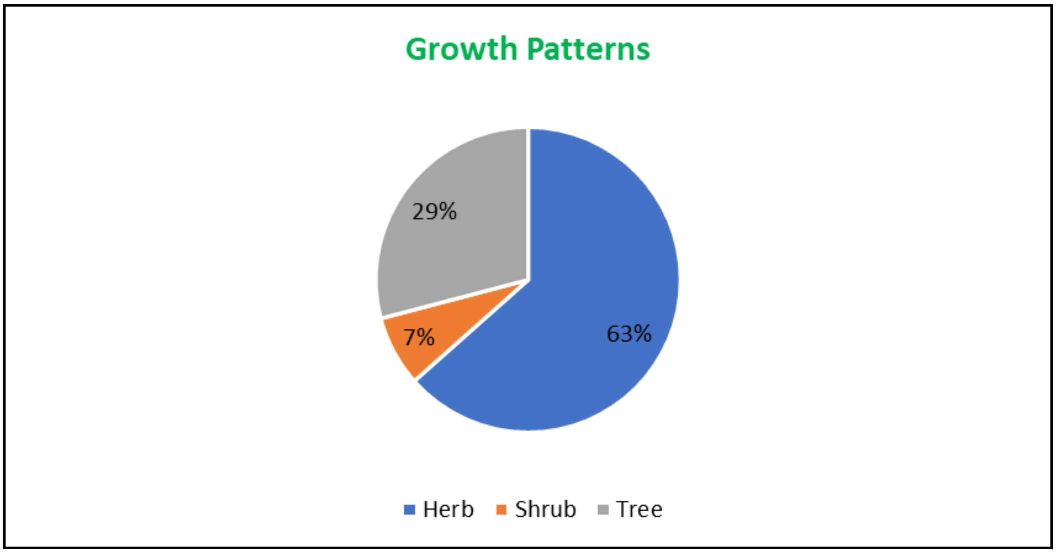

Figure 5. *Growth pattern-based densities of weed plants in agricultural crops of Wadi Liyah, Taif, Saudi Arabia. Statistical analysis (ANOVA) presented a P-value of 0.03 and a t-value of 22.11 among species according to the nature of plants. The test of homogeneity of variances demonstrated a mean-based significance value of 0.245 and Levene's test value of 1.398 among species according to the growth patterns of plants*

Herb plant density among collected plants

The plant samples from Wadi Liyah demonstrated the highest occurrence of herb plants, which belonged to different families including Apocyaceae (*Catharanthus roseus*), Amaranthaceae (*Aerva javanica, Chenopodiastrum murale, Atrieiex*

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mjxiawiczciana, *Dysphania ambrosioides*, *Axyris amaranthoides*), Asteraceae (*Centaurea solstiti*, *Helianthus annuus*, *Chrysothamnus viscidifblus*, *Xanthisma spinulosum*, *Dittrichia viscosa*, *Xanthium orientale*), Fabaceae (*Bituminaria bituminosa*), Poaceae (*Cenchrus cilliais*, *Cortaderia selloana*, *Eleusine indica*, *Cynodon dactylon*, *Eragrostis pilosa*), Cucurbitaceae (*Citrullus colocynthis*, *Cucumis anguria*), Solanaceae (*Datura innoxia*, *Solanum incanum*, *Nicotiana glauca*), Euphorbiaceae (*Ricinus communis*, *Ocimum tanuiflorum*), Tetradiclidaceae (*Peganum harmala*), Typhaceae (*Typha domingensis*), Nyctaginaceae (*Bocrhavia coccinea*), Aizoaceae (*Aizoon canariense*), Portulacaceae (*Portulaca oleracea*), Polemoniaceae (*Eriastrum eremicum*), Polygonaceae (*Rumex crispus*), and Malvaceae (*Malva parviflora*) (*Fig. 6*).

The results of this study revealed that family-wise highest to the lowest herb plant density remained Amaranthaceae (651), Poaceae (541), Nitrariaceae (350), Asteraceae (237), Euphorbiaceae (145), Typhaceae (134), Brassicaceae, (96), Nyctaginaceae (46), Aizoaceae (44), Solanaceae (81), Apocyaceae (22), Portulacaceae (22), Cucurbitaceae (13), Polemoniaceae (12), Polygonaceae (5), Malvaceae (2), and Fabaceae (1). The species-wise highest to the lowest herb plants density was observed as *Aerva javanica* (471), *Peganum harmala* (350), *Cynodon dactylon* (246), *Eragrostis pilosa* (237), *Dysphania ambrosioides* (146), *Typha domingensis* (134), *Helianthus annuus* (109), *Ricinus communis* (87), *Solanum incanum* (63), *Ocimum tanuiflorum* (58), *Centaurea solstiti* (51), *Xanthium orientale* (51), *Bocrhavia coccinea* (46), *Aizoon canariense* (44), *Cortaderia selloana* (35), *Atrieiex mjxiawiczciana* (23), *Portulaca oleracea* (22), *Catharanthus roseus* (22), *Datura innoxia* (17), *Eleusine indica* (16), *Dittrichia viscosa* (13), *Eriastrum eremicum* (12), *Citrullus colocynthis* (11), *Chenopodiastrum murale* (10), *Xanthisma spinulosum* (8), *Cenchrus cilliais* (7), *Chrysothamnus viscidifblus* (5), *Rumex crispus* (5), *Malva parviflora* (2), *Cucumis anguria* (2), *Bituminaria bituminosa* (1), *Nicotiana glauca* (1), and *Axyris amaranthoides* (1) (*Fig. 6*).

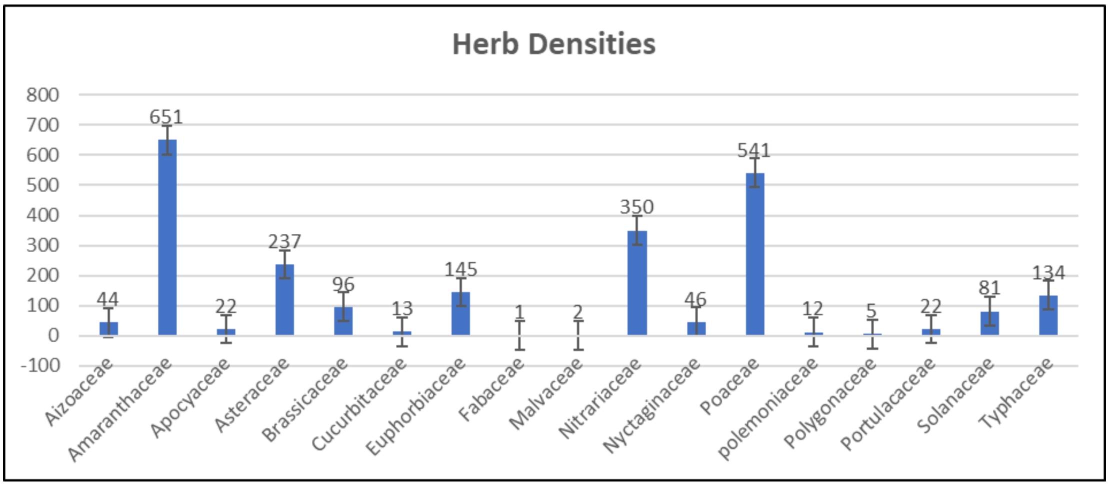

Figure 6. *Densities of weed herb families (mean ± SE) in agricultural crops of Wadi Liyah, Taif, Saudi Arabia*

Tree plant density among collected plants

The densities of tree plants were second to herb plant density among samples from Wadi Liyah. Tree plants belonged to different families including Apocyaceae (*Calotropis procera*, *Ceropegia gigantean*), Zygophyllaceae (*Balanites aegyptiaca*), Fabaceae

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(*Pithecellobium dulce, Vachellia farnesiana, Vachellia tortills*), Arecaceae (*Phoenix dactylifera, Cynara cardunculus*), Solanaceae (*Solanum lycopersicum*), Euphorbiaceae (*Euphorbia resinifera*), Rhamnaceae (*Ziziphus mucronata*), Oleaceae (*Menodora scabra*), Tamaricaceae (*Tamarix ramosissima*), Brassicaceae (*Carrichtera annua*), Cupressaceae (*Cupressus arizonica*), and Cleomaceae (*Polanisia dodecandra*) (*Fig. 7*).

During this study, family-wise highest to the lowest tree plants density was observed as Fabaceae (485), Oleaceae (237), Tamaricaceae (123), Apocyaceae (117), Arecaceae (42), Rhamnaceae (27), Solanaceae (10), Brassicaceae (4), Cupressaceae (3), Cleomaceae (3), Zygophyllaceae (2), and Euphorbiaceae (1). The species wise highest to the lowest herb plants density was found as *Vachellia farnesiana* (365), *Menodora scabra* (237), *Tamarix ramosissima* (123), *Calotropis procera* (111), *Vachellia tortills* (101), *Phoenix dactylifera* (38), *Ziziphus mucronata* (27), *Pithecellobium dulce* (19), *Solanum lycopersicum* (10), *Ceropegia gigantean* (6), *Carrichtera annua* (4), *Cynara cardunculus* (4), *Cupressus arizonica* (3), *Polanisia dodecandra* (3), *Balanites aegyptiaca* (2), and *Euphorbia resinifera* (1) (*Fig. 7*).

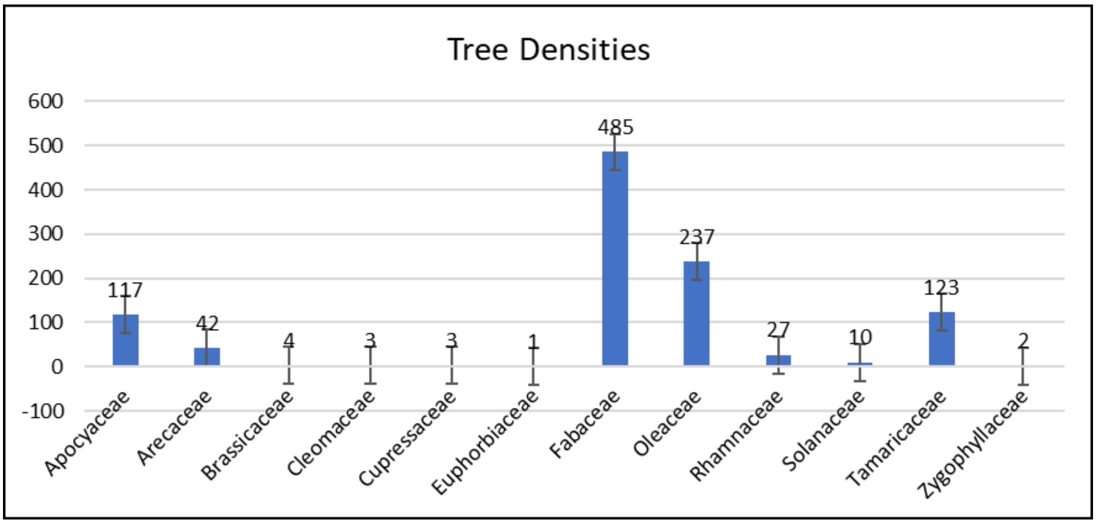

Figure 7. *Densities of tree plant families (mean ± SE) in agricultural crops of Wadi Liyah, Taif, Saudi Arabia*

Shrub plant density among collected plants

Wadi Liyah plant samples illustrated the lowest prevalence of shrub plants, which belonged to different families such as Asteraceae (*Santolina chamaecyparissus, Baccharis halimifolia*), Zygophyllaceae (*Fagonia laevis, Tetraena alba*), Fabaceae (*Calicotome villosa*), Poaceae (*Sisymbium irio*), Solanaceae (*Lycium ferocissimum*), Rhamnaceae (*Sarcomphalus obtusifolius*), Aspargaceae (*Asparagus albus*), Heliotropiaceae (*Heliotropium supinum*), and Brickellia (*Brickellia californica*) (*Fig. 8*). Family-wise highest to the lowest shrub plant density among collected plant samples remained as Zygophyllaceae (98), Aspargaceae (33), Heliotropiaceae (25), Asteraceae (7), Fabaceae (2), Solanaceae (2), and Rhamnaceae (1). The species-wise highest to the lowest herb plants density was found as *Sisymbium irio* (96), *Fagonia laevis* (69), *Asparagus albus* (33), *Tetraena alba* (29), *Heliotropium supinum* (25), *Santolina chamaecyparissus* (5), *Baccharis halimifolia* (2), *Calicotome villosa* (2), *Lycium ferocissimum* (2), *Brickellia californica* (2), and *Sarcomphalus obtusifolius* (1) (*Fig. 8*).

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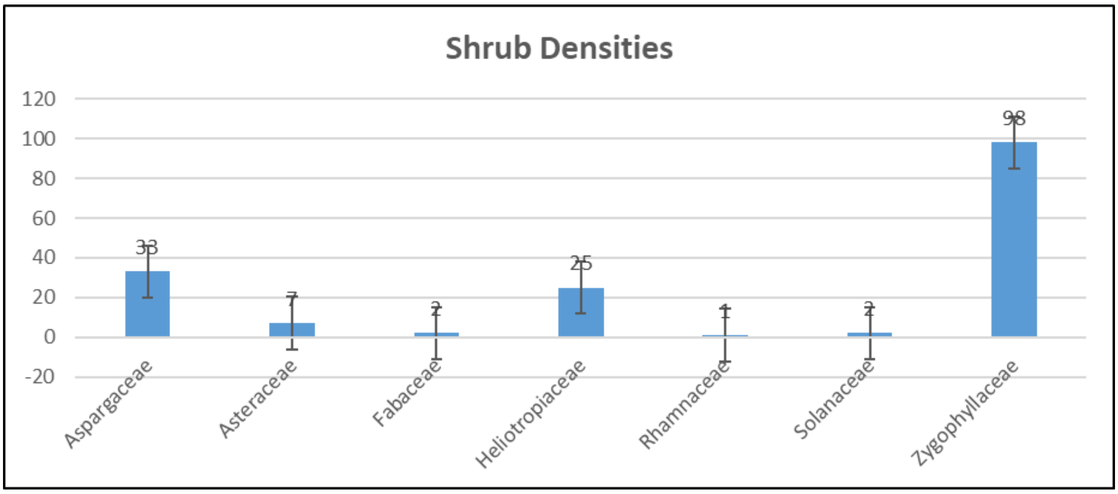

Figure 8. *Densities of shrub plant families (mean ± SE) in agricultural crops of Wadi Liyah, Taif, Saudi Arabia*

Discussion

The identification and documentation of the weed population and density of an area is a preliminary step toward efficient management practices. Different weed families and species, grown crops, and weed density contribute to varying weed hazards in agricultural fields. The financial burden of global weed management practices is quite high. They are reported to damage huge grain quantities in addition to the expenses of weed management practices. Australian farmers face an annual grain loss of 2.7 million tons and weed management expenditures of 3.3 billion AUD/year (Llewellyn et al., 2016). Weed management practices cost over 33 billion USD in the USA whereas Indian farmers suffer from a loss of 11 billion USD/year because of weeds in various crops including maize, wheat, soybean, and peanut (Gharde et al., 2018). Therefore, a precise understanding of weed parameters and related environmental elements can be helpful in appropriate management practices at the proper time of the cropping season. The undesired weed herbs could also be a rich source of herbal medicines and food nutrients. The herb plants are major contributors to the traditional medicines, however, agriculturists classify them as unwanted weeds. Farmers often do not know the medicinal value of the weed herbs. However, chemical analysis has established the presence of medicinal compounds that can be used to cure various diseases. Different commonly found plant genera (Mimosa, Argemone, Cynodon, Parthenium, Oxalis, Cyprus, and Amaranthus) have been well studied and documented for their high medicinal values. The global market of medicinal weed herbs is rapidly growing, which could be an alternate income source for farmers. Weed herb investigations should mainly focus on detecting the presence of flavonoids and alkaloids. Other main classes of bioactive compounds include tannins, phenols, mucilage, saponins, glucosinolates, anthocyanins, volatile oils, minerals, vitamins, and cardiac glycosides. These compounds help in plant protection against, insect pests, diseases, and environmental severities (drought and cold) (Singh and Singh, 2020). Plants synthesize these medicinal compounds through metabolic pathways, which can help in treating various ailments including sore, ulcerated mouth, and ulcer diseases (Devi et al., 2023). However, the loss caused by weeds to cultivated crops exceeds insects and disease-linked losses. Therefore, maintaining a balance is of key importance for optimal agricultural yield in an area.

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The data of this study depicted a dominant prevalence of plants belonging to Amaranthaceae, Poaceae, Fabaceae, Tetradiclidaceae, and Asteraceae families in the studied Wadi Liyah of Taif, Saudi Arabia. The Amaranthaceae family had the highest plant density of 651, which belonged to five species. The Amaranthaceae family consists of about 2052 species in 178 genera. These plants often grow in deserts, salt habitats, and coastal and arid regions. Plants of this family are widespread in South and North America, Africa, Europe, and Asia. Amaranthaceae plants (perennials, biennials, and annuals) are mostly herbaceous. However, perennial and annual shrubs and a few trees and vines are also included in this family. It is a large and diverse plant family as some plants possess significant nutritional value whereas other plants are considered detrimental/toxic weeds. Both types of plants of this family are used in traditional medicine preparations. Different species of this family produce bioactive compounds with diverse applicability. These bioactive compounds are known to possess anti-inflammatory, antifungal, anticancer, and antibacterial properties (Todorović et al., 2022). Some plants of this family have also developed resistance to various herbicides and thus their management becomes a challenging task in the agricultural fields (Wang et al., 2017).

The plant density (637) of the Poaceae family was almost similar to the Amaranthaceae family. The plants of this family mainly belonged to six species in the studied area. Poaceae is a large family of 10,000 species, which mainly include grasses and other economically important members (Liu et al., 2023). Selective breeding and environmental selection have led to the rapid genome evolution of this family. They can sustain diverse types of environments in various landscapes. Their capability to reproduce from different plant parts (roots, nodes, seeds, rhizomes, and stems) is a distinct characteristic. These plants are well-known for the production of monoterpenes and sesquiterpenes-rich essential oils. The presence of allelochemicals facilitates their better growth and nutrient utilization in the fields by suppressing the growth of other plants. It helps their overgrowth as weeds in agricultural fields, which necessitates novel remedial measures to counter Poaceae family weeds. The grasses of this family are considered highly irritating weeds in the agricultural fields. Different grass species of Poaceae have emerged as dominant invasive weed species in cereal crops (wheat, corn, and rice) globally. Chen et al. (2024) have reported a high proportion of grass weeds in a studied area in Eastern China. The widespread presence of Poaceae grass-weeds globally poses a higher risk to agricultural areas. Fabaceae (legumes, beans, and peas) family was presented by five weed species, which had a collective plant density of 488. This large family mainly contains annual and perennial flowering plants, trees, and shrubs, which are recognized based on their legume fruits and stipulate leaves. The plant roots of this family contain nitrogen-fixing nodules, which help in enhancing soil fertility. Plants contain compound leaves with stipules modified into spines/glands. Some species of this family are rich in protein and thus are an important part of the human diet, which include soybeans, beans, chickpeas, fava beans, peas, and lentils. Different species of this family are used as highly nutritious livestock fodder such as clovers, vetches, alfalfa, and sweet-clover. Fabaceae is the 3rd largest family with 20,000 species belonging to 765 genera. It is widely found across the globe and serves as a dietary and medicinal source in various regions (Maroyi, 2023). Several species of this family grow as competing weed plants in agricultural fields, and their higher invasive prevalence has been documented in Europe, China, and South Asia (Gulzar et al., 2024). The data revealed significant plant density (350) of the Tetradiclidaceae family

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that was presented by only one weed species. The presence of only one species of this family represents its rare occurrence in the studied area. The plants of this family are mostly suffrutescent shrubs (perennial and annual) of 100 cm in length, which ascend with alternate branching. The simple leaves of this family of plants either contain deeply divided linear segments or minute pseudostipules. The bisexual yellow or white colored flowers of this family of plants can be leaf-opposed or terminal. Flowers either grow solitary or in cymes (spike-like) with 4-5 sepals and petals, 4 stamens, and 15 dilated filaments, which are attached to an angular or annular disk. The fruits of this plant family appear as berries or locular capsules and contain albuminous seeds.

The families Asteraceae and Oleaceae shared almost similar plant densities of 244 and 237, respectively. However, the species diversity of the Asteraceae family was significantly higher (8) than the Oleaceae family (1). Asteraceae is a major weed family of flowering species with its presence across almost all continents. It is comprised of 1600 genera and 32,000-34,000 flowering weed species. It is considered to contribute 10% of all flowering species whereas its global weed share in agricultural areas is considered to be 43% (Govaerts et al., 2021). The plants of this family are commonly found in deserts, mountains, semi-arid, and arid areas, which contain clustered inflorescences appearing like a single compound flower. These plants grow as perennial woody shrubs, annual herbs, trees, lianas, and succulents. The Asteraceae family also includes economically important crops such as lettuce, chrysanthemum, sunflower, and herbs. Several Asteraceae species synthesize compounds (sesquiterpene lactones, flavonoids, polyacetylenes, terpenes, saponins, and phenolic acids) of pharmacological properties. These compounds help in their dominant growth in various habitats (Araújo et al., 2021). Asteraceae members have been utilized for medicinal and dietary purposes since ancient times. The members of this family largely have the same chemical composition as most of the plants contain a natural polysaccharide (inulin), which possesses strong prebiotic characteristics. The secondary metabolites of Asteraceae plants are well-known to exhibit wound healing, antioxidant, antimicrobial, anti-inflammatory, and diuretic properties (Rolnik and Olas, 2021). However, their undesired growth in agricultural fields coupled with phytotoxicity and allelochemicals hinder the growth of crops. Oleaceae or the olive family is comprised of 700 plant species in 28 genera, which grow in tropical and temperate conditions. The plants often produce numerous odoriferous flowers. Several plants of this family are considered ecologically important mainly including olives, forsythias, jasmines, ash trees, lilacs, privets, and osmanthuses. Most of the species of this family grow as trees and small shrubs except a few lianas and one herb plant. Many plants of this family are economically important as they produce fruits and oil (olive), fragrances and ornaments (lilacs, jasmines, and osmanthuses), and timber (ash tree). Several species also produce palatable leaves and drupes, which are consumed by humans and animals (Dupin et al., 2020). The plants of its different species produce evergreen and deciduous leaves. The evergreen species are mostly prevalent in tropical and warm temperate areas whereas deciduous species inhabit the colder areas.

The plant densities considerably varied among plant species of the study area. The highest plant density of 471 was noted in the species *Aerva javanica*, which belongs to the Amaranthaceae family. This plant inhabits various regions of South Asia, Africa, and Australia. This herbaceous and softwood plant can grow up to 1.6 m in length with broad leaves. Different parts of this plant (seeds and roots) are used in traditional medicine and are believed to cure kidney disease, toothache, and headache. The multi-

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stems of this plant are used as animal fodder and fuel. The male and female flowers grow on different plants, which were traditionally picked and used for the stuffing of saddle pads and cushions in the Arabian region (Chabane and Mouhoub, 2017). The species *Vachellia farnesiana* also had a significant occurrence in the study area with a plant density of 365. This shrub/small tree belonging to the family Fabaceae grows as an evergreen plant in most areas. The flowers of this plant are utilized in the perfume industry. It bears a dark brown fruit as a seedpod. *Vachellia farnesiana* causes bush encroachment on rangelands and pastures. This plant is also cultivated in certain areas as a fodder crop to feed animals. The plant density of species *Peganum harmala* in the study area was noted as 350. This herbaceous perennial plant often grows in saline soils, Mediterranean regions, and temperate desert areas. It has long been used in herbal medicines to treat hypertension, cough, diabetes, and asthma. It is common cattle feed (camels, sheep, and livestock) in various areas during the winter season. Phytochemical investigations have reported the presence of beneficial secondary metabolites (trace elements, alkaloids, volatile oils, and flavonoids) in this plant. These compounds collectively contribute to its antibacterial, leukemia-resisting, anti-inflammatory, psoriasis-resisting, and antibacterial properties (Zhu et al., 2022). *Cynodon dactylon* belonging to the family Poaceae presented a plant density of 246 in the studied area. It is commonly known as Bermuda grass and is a quite prevalent weed in warmer regions worldwide. Its deep root system of up to 2 meters of depth helps in its survival in drought conditions and thus is often used as lawn grass. The juice of this grass is considered to exhibit diuretic properties in humans. The anti-inflammatory effects of these plants help in effectively curing chronic inflammation (Ramteke et al., 2024). *Menodora scabra* family Oleaceae and *Eragrostis pilosa* of family Poaceae shared the same plant density of 237 in the studied area. *Menodora scabra* is a broom-shaped shrub that is often found among desert plantations. It grows in plateaus, mountains, and desert habitats. The multiple branches of this plant can grow up to a length of 30 cm and produce yellow-colored flower clusters at the tip of capsule-shaped fruits. *Eragrostis pilosa* is a common weed in many regions of the world. This is a narrow-leaf annual grass that also serves as fodder for animals.

During this study, the collected and identified plants were categorized based on their growth patterns as herbs, trees, and shrubs. Herb plants had the highest plant density of 2300 out of a total of 3626 plants, which were represented by 33 species of 16 families. Weed herbs though compete with the crops, however, these plants often have beneficial medicinal properties. Farmers often consider these plants as weeds but recent chemical analyses have confirmed their medicinal compounds, which can effectively cure various diseases. These recent reports have led to rapid market growth of medicinal herbs providing additional income to the farmers. Therefore, weed herb studies should also focus on detecting medicinal compounds for treatment purposes (Devi et al., 2023). The occurrence of tree plants was noted as 1054, which were represented by 16 species in 12 families. All the tree samples were of wild nature except *Phoenix dactylifera* plants. The trees generally positively contribute to the environment except for invasive plants, which could disturb the ecosystem of an area (Khapugin et al., 2020). Shrub occurrence was found to be significantly lower and only 271 shrubs were identified among collected samples, which were represented by 11 species of 9 families. All the shrubs were of wild natural type. The survivability of shrubs is generally considered high as they can tolerate drought conditions and are being recently focused to tackle global warming. Shrubs are promoted in water-scarce areas where they serve as barriers to avoid soil erosion and desertification. They can also help in environmental restoration and run-off reduction (López-Marcos et al., 2020). Shrub berries are consumed by humans and they can also protect new crop plant seedlings from animal browsing.

Conclusions

The understanding of weed plant distribution and diversity-affecting elements could facilitate the development of effective remedial measures without impacting the local ecosystem of an area. Though the plantation is important for an ecosystem, however, extensive weed growth is a major limiting factor regarding agricultural production. This study comprehensively investigated the weed biodiversity of Wadi Liyah of Taif, Saudi Arabia. The investigation identified various plant species and relevant families. A total of 3626 plants were collected during the study, which belonged to 60 plant species within 27 plant families. All of the collected samples were of wild types except only one species of *Phoenix dactylifera*. Regarding the nature of the plants, the prevalence of herbs was significantly higher followed by tree plants. The occurrence of shrubs in the study area appeared significantly low. According to the plant density, the presence of Amaranthaceae, Poaceae, Fabaceae, Tetradiclidaceae, and Asteraceae families was dominant in the area. Similarly, the plant densities of *Aerva javanica, Vachellia farnesiana, Peganum harmala, Cynodon dactylon, Menodora scabra,* and *Eragrostis pilosa* species appeared more prominent than other identified species. To conclude, this study thoroughly elaborates on the weed plant biodiversity of the study area, which could help in designing better management approaches in this area and other areas of the world with similar distribution of weed plants.

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