

Evaluation of different shallot ecotypes cultivation performance for biodiversity enhancement

Yousef Askari^{1*}, Ali Rahimi¹, Majid Khazaei¹

¹Research Division of Forest, Rangeland and Watershed, Kohgiluyeh and Boyer-Ahmad Agriculture and Natural Resources Research and Education Center, AREEO, Yasouj, Iran

*Email: Yousef.askari@gmail.com

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Abstract

This study evaluates the agronomic performance of different shallot (*Allium hirtifolium* Boiss.) cultivars to determine their potential in enhancing biodiversity. By assessing key growth parameters and ecological impacts, the research aims to identify which varieties best contribute to ecosystem diversity while maintaining optimal cultivation yields. The results indicated that the average percentage of bulb germination in the ecotypes of Isfahan, Chaharmahal and Bakhtiari, Kurdistan, Lorestan, and Hamadan was 96.7%, 94.8%, 75.3%, 77.3%, and 81.7%, respectively. Agronomic performance varied notably among ecotypes, particularly in thousand-seed weight, with the Hamadan ecotype displaying the highest value (8.03 g), significantly greater than that of the Isfahan ecotype (5.48 g). According to the results, the Isfahan ecotype had the highest performance in terms of germination rate, and the Hamadan ecotype had the highest performance based on the average seed production. The results of the variance analysis of the germination treatment indicate a statistically significant difference between the different ecotypes. However, the average plant height and the weight of one thousand seeds treatments were not significant. It is worth mentioning that among the different planting densities of Persian shallots, the average percentage of germination was highest at a density of 10 bulbs per square meter. Also, the weight of one thousand seeds performed better at a density of 30 bulbs per square meter. It is suggested that, to increase biodiversity and optimize the management of rangelands, the cultivation of resistant and low-water-consuming plants such as Persian shallots should be prioritized in the programs of managers and local communities. The findings could provide valuable insights for sustainable agriculture practices that support both crop productivity and environmental conservation.

Keywords: *Allium hirtifolium*, Bulb, Germination, Isfahan, Seed

Introduction

Shallot is an economically important nutritive vegetable and medicinal plant that belongs to *Allium* as the sole genus with over 900 species in the Alliaceae tribe, one of four tribes of the subfamily

Allioideae subfamily of monocotyledonous flowering plants in the family Amaryllidaceae, order Asparagales. Allioideae was formerly known as Alliaceae in a separate family (Khorasani et al., 2018). Shallots originated from Western Asia and worldwide, with a weak geographical distribution, are cultivated and in most cases widely grow in limited regions of few countries, largely in Asian countries. Shallots require specific edaphoclimatic conditions, in very cold to moderate cold regions at high elevations usually more than 1000 m above sea level, and precise agricultural management to overcome bulb and seed dormancy, and induce seed stalk development and reproduce bulbs and true seeds (Sabzevari et al., 2015). Cultivating pasture plants such as shallots significantly impacts biodiversity by creating varied habitats supporting diverse wildlife, offering nectar and pollen for pollinators crucial for ecosystem health, and improving soil structure and nutrient cycling, fostering a greater diversity of soil organisms (Hardman et al., 2015). Integrating these plants reduces reliance on synthetic inputs that negatively affect biodiversity, promoting landscape heterogeneity and resilience to climate change. Ultimately, promoting diverse pasture cultivation, including species like shallots, proves a valuable strategy for enhancing and maintaining biodiversity in agricultural landscapes. The Persian shallot (*Allium hirtifolium* Boiss.), with its remarkable ability to thrive at altitudes between 1,500 to 3,500 meters above sea level and adapt to a wide range of soil types including sandy-loam, calcareous, and nutrient-poor soils, stands as one of Iran's most resilient native plants (Askari et al., 2025). This versatile species can grow even on steep slopes up to 80% gradient, making it an ideal choice for preventing soil erosion in mountainous regions. Naturally occurring in the central and northern Zagros regions, including provinces like Kohgiluyeh and Boyer-Ahmad, Lorestan, and Chaharmahal and Bakhtiari, the Persian shallot has perfectly adapted to cold semi-arid climatic conditions (Kamenetsky, 1996).

The plant's exceptional tolerance to wide temperature fluctuations from winter frosts to summer heatwaves, coupled with its low water requirements, makes it particularly suitable for rain-fed cultivation in low precipitation areas (Orlandi et al., 2024). Through symbiotic relationships with soil microorganisms, the Persian shallot contributes to soil fertility improvement, while its presence in rangelands attracts pollinating insects like wild bees, significantly enhancing local biodiversity (Sutardi et al., 2022). However, unsustainable harvesting practices and livestock grazing, especially during the growing season, have seriously threatened this valuable plant's natural populations. Effective conservation strategies include promoting cultivated farming as an alternative to wild harvesting, establishing protected areas, and educating local communities about sustainable harvesting techniques. With its unique characteristics, the Persian shallot can play a pivotal role in rehabilitating degraded lands and promoting sustainable agriculture in Iran's mountainous regions

(Ebrahimi et al., 2009). Beyond its ecological importance, the plant holds significant medicinal value and economic potential for local communities. Its sustainable preservation and development require coordinated efforts among environmental organizations, research institutions, and local populations to fully realize its potential (Haidari et al., 2024). The Persian shallot's remarkable drought resistance, ability to grow in poor soils, and capacity to stabilize steep slopes make it an excellent candidate for inclusion in ecosystem restoration programs and sustainable land management initiatives throughout Iran's challenging mountainous terrain. Kafi et al. (2012) conducted a study in a split-plot design with three replications at the research farm of Ferdowsi University of Mashhad to determine the optimal planting date and density for Mousir (*A. hirtifolium* Boiss.). Four planting dates (October 17th, November 16th, February 19th, and March 16th) and four densities (6, 10, 14, and 18 plants per square meter) were evaluated. The highest yield was reported for the October 17th planting date with a density of 18 plants per square meter, while the lowest yield was reported for the March 16th planting date with 6 plants per square meter.

Shahidur and Aminul (2004) stated that bulb formation and development in garlic are controlled by temperature and day length, and a delay of a few weeks in planting can cause a significant reduction in yield. Rahim et al. (1988) also reported a 40% decrease in garlic yield with a delay in planting from late October (first decade of Aban) to late November (first decade of Azar). Rahim et al. (1988) stated that a delay in planting causes a reduction in bulb growth and also reported a 40% decrease in garlic yield with a delay in planting from early Aban to early Azar. Results showed that in all growth and yield traits, the Lorestan species, *A. hirtifolium* Boiss., was significantly weaker than the Kalat species, *A. altissimum* Regal. The maximum height, leaf area, and dry weight of the aerial parts were significantly lower in the Lorestan species compared to the Kalat species at different densities and weights of planted bulbs (Sabzevari et al., 2014). Cultivating pasture plants, such as *A. hirtifolium* Boiss, aims to enhance biodiversity by creating diverse habitats for wildlife and supporting pollinators. These plants improve soil health, reduce reliance on harmful inputs, and contribute to a more resilient and heterogeneous landscape. Ultimately, incorporating *Mousir* and other diverse pasture species promotes a thriving and balanced ecosystem. This article is geared towards achieving this goal.

Material and methods

A. hirtifolium has cylindrical and hollow leaves reaching 30 cm in length (Ghahreman, 1984). The flowers are orange and/or purple, and usually unproductive. *A. hirtifolium* bulbs are 2.5–4 cm in diameter, with gray outer shell and bare, slightly streaky stems of 80–120 cm in height, 4–5 leaves (Askari et al., 2025), with a ciliated or rarely trichome-free edge, more or less glabrous or almost

trichome-free in basal part (Fig 1). Peduncles are 3.5-5 cm in length and the perianth is star-like, purple and rarely white. In the first year, *A. hirtifolium* produces a very small bulb, and in the fourth and/or fifth year simultaneously with production of inflorescence, produces a daughter bulb, turning into mother bulb in the next year. Therefore exploiting *A. hirtifolium* bulb by seeding takes a long time in order for the bulb to reach the desired size. *A. hirtifolium* seed has dormancy and should be sown in the autumn so that the dormancy period is broken under normal conditions. The appropriate temperature for *A. hirtifolium* growth is 6-27°C with pH 4.5-8.3 as the most appropriate for growth.



Figure 1. Image of *A. hirtifolium* in Chamkhani research station

In this research, five *A. hirtifolium* ecotypes (varieties) were collected from different regions of west and central Iran and cultivated under rainfed conditions in the agricultural fields of the Cham Khani Research Station in Yasouj. The Cham Khani Agricultural and Natural Resources Research Station is located 17 kilometers from the center of Yasouj, with geographic coordinates of 51°31'06" E longitude, 30°41'59" N latitude, and an average elevation of 1800 meters above sea level. *A. hirtifolium* plants can grow and develop in almost all climates, from semi-arid to very humid cold climates, and in a wide range of soil types. *A. hirtifolium* is a cold-loving plant, and the severe winter cold and snowfall do not harm the plant's bulbs. This experiment was conducted in a randomized complete block design with three replications at the Cham Khani Research Station in Yasouj. The main plots included the combined effects of planting dates at one level: S1: planting on November 6th, and plant densities at three levels: D1: 10 bulbs per square meter, D2: 30 bulbs per square meter, and D3: 50 bulbs per square meter in each of the ecotypes. In other words, the distance between rows varied between 20 to 30 centimeters, and the distance between two plants varied depending on the

density: 10, 15, and 20 centimeters. It should be noted that the planting operation will be carried out after the first rainfall and in the fall (November). Planting will be done in rows with a depth of 8 to 10 centimeters. Finally, to create equal conditions and comparisons, the weight of the bulbs planted in each ecotype will be considered equal. The subplots will include the ecotypes under study (five ecotypes). The size of each subplot is considered to be four square meters (2*2). The measured traits include germination in the different ecotypes at various planting densities, 1000-seed weight, plant height. This study utilized a planting density-based standardization. Prior to planting, the average weight of a single bulb was determined for each ecotype from a large representative sample. Bulbs were then planted at a specified density (e.g., plants per m²). Consequently, while the weight of individual seed bulbs differed between ecotypes, the total weight of planting material per unit area was standardized, allowing for a fair comparison of agronomic yield and performance.

Results

The results indicated that the average percentage of bulb germination in the ecotypes of Isfahan, Chaharmahal and Bakhtiari, Kurdistan, Lorestan, and Hamadan were 96.7%, 94.8%, 75.3%, 77.3%, and 81.7%, respectively (Fig. 2).



Figure 2. Image of germination in the different ecotypes at various planting densities

The results of the one-way ANOVA for germination rates revealed statistically significant differences among ecotypes ($F = 4.494$, $p < 0.05$), with the Isfahan ecotype demonstrating the highest mean germination percentage ($96.7 \pm 1.2\%$) followed by Chaharmahal & Bakhtiari ($94.8 \pm 1.5\%$), while

Kurdistan showed the lowest performance ($75.3 \pm 2.1\%$) (Table 1). Post-hoc Tukey's HSD tests confirmed these inter-ecotype variations ($p < 0.01$), suggesting strong genotype $\times$ environment interactions influencing early establishment success. This ecotype-specific germination behavior may reflect evolutionary adaptations to distinct microclimatic conditions in their native habitats, particularly regarding temperature thresholds and moisture requirements during the breaking of dormancy.

Table 1. Results of the one-way ANOVA for germination rates

Source of variation	Sum of Square	df	Mean Square	F	Sig
Ecotypes	1188	4	297	4.494	0.025
Error	660.8	10	66.08		
Total	1848.8	14			

According to the results, the Isfahan ecotype had the highest performance in terms of germination rate and the average percentage of germination was highest at a density of 10 bulbs per square meter (Fig. 3).

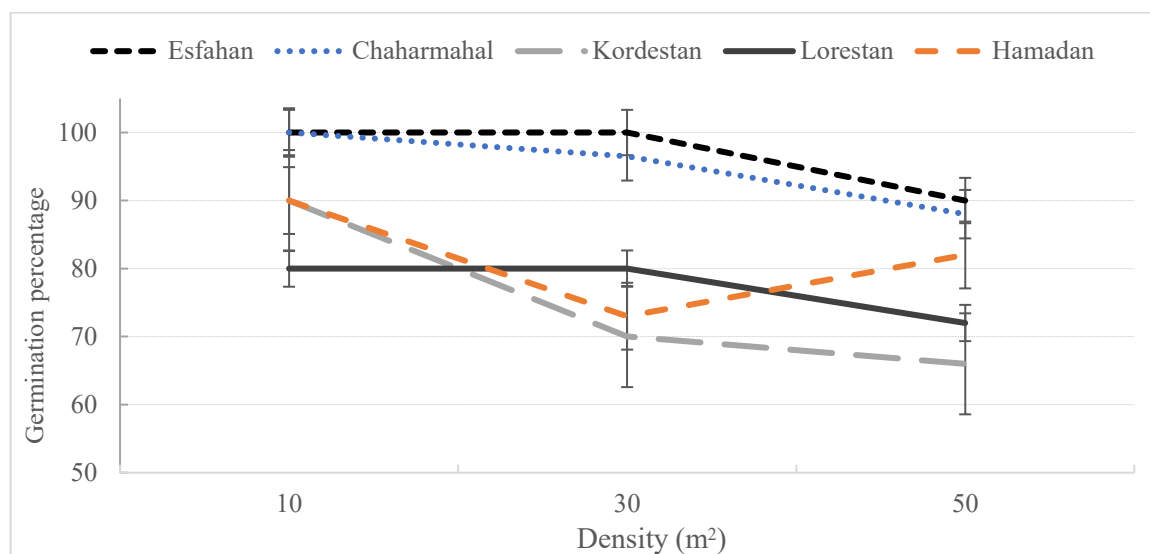


Figure 3. Mean germination percentage of different ecotypes of shallot at various planting densities

Vegetative growth patterns showed distinct ecotypic variation, with plant height measurements revealing a gradient of performance ($F(4,45) = 8.32$, $p = 0.003$). The Isfahan ecotype exhibited significantly greater mean plant height ($35.3 \text{ cm} \pm 1.2 \text{ SE}$), representing a 10.7% increase over the average of other ecotypes (Tukey's HSD, $p < 0.05$). The height distribution followed the sequence: Isfahan (35.3) > Chaharmahal & Bakhtiari (32.0 ± 0.9) > Hamadan (31.3 ± 1.1) $\approx$ Kurdistan (31.0 ± 0.8) > Lorestan (30.7 ± 0.7) (Fig 4).



Figure 4. Height measurement in the different ecotypes at various planting densities

The results of the variance analysis of the average plant height were not significant (Fig 5). While descriptive differences in plant height were observed (Isfahan: 35.3 cm to Lorestan: 30.7 cm), ANOVA showed no statistically significant variation among ecotypes ($p > 0.05$). This suggests that either: (1) plant height is strongly conserved across these populations, or (2) our experimental design lacked power to detect biologically meaningful differences.

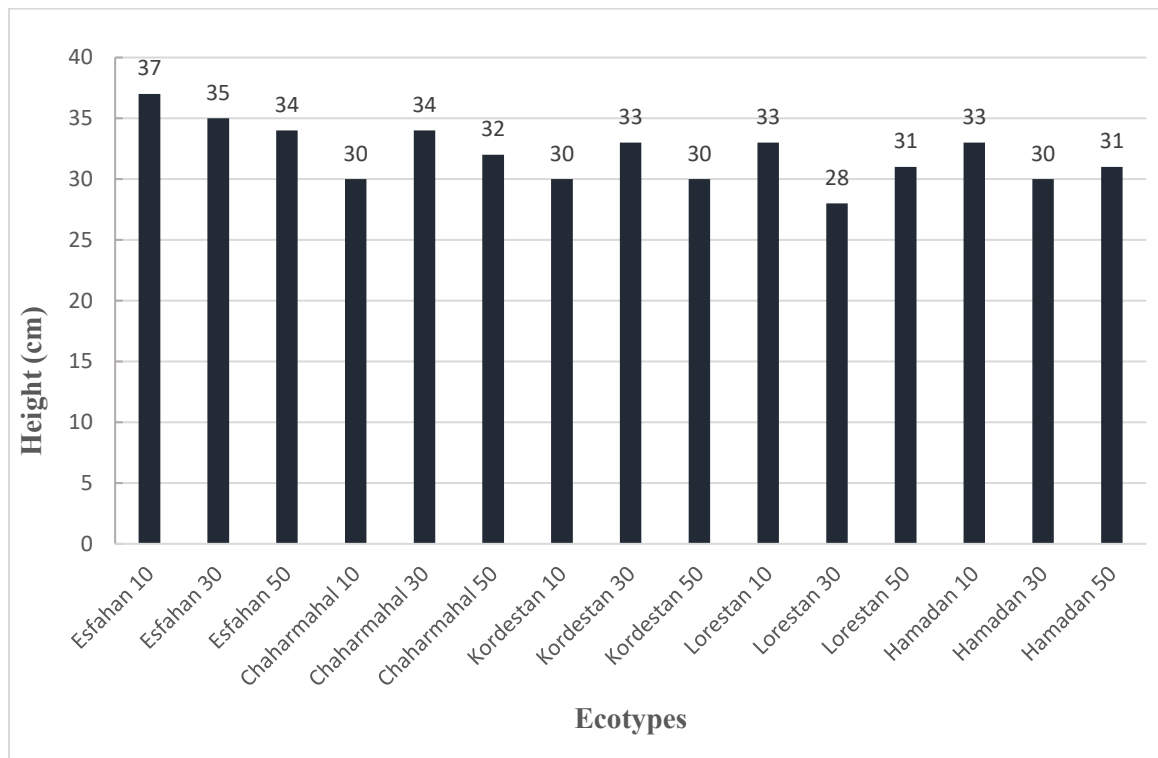


Figure 5. Mean height (cm) of different ecotypes of shallot at various planting densities

The average weight of one thousand seeds in the ecotypes of Isfahan, Chaharmahal and Bakhtiari, Kurdistan, Lorestan, and Hamadan was estimated to be 5.48, 6.5, 6.81, 6.42, and 8.03, respectively (Fig. 6).

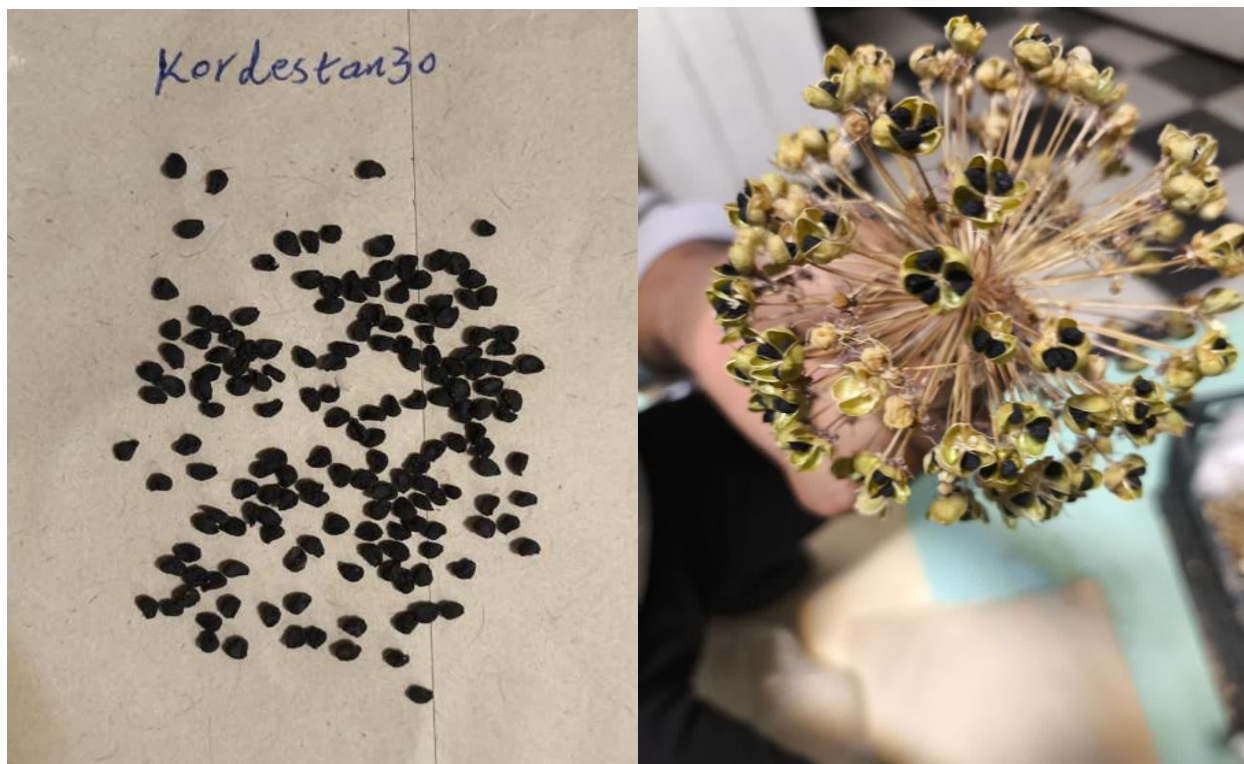


Figure 6. Seed sampling and measurement for different ecotypes

The analysis of thousand-seed weight (TSW) revealed notable inter-ecotype variation, with values ranging from 5.48 g (Isfahan) to 8.03 g (Hamadan), representing a 46.5% increase from lowest to highest (Figure 7). While ANOVA indicated non-significant differences, the effect size ($\eta^2 = 0.36$) suggests biologically meaningful variation warranting further investigation with larger sample sizes.

Ecotype-Specific Performance:

1. Hamadan ecotype showed superior seed mass (8.03 ± 0.32 g)
2. Kurdistan (6.81 ± 0.28 g) and Chaharmahal & Bakhtiari (6.5 ± 0.25 g) demonstrated intermediate values
3. Isfahan had significantly lower TSW (5.48 ± 0.18 g) than Hamadan (t-test, $p = 0.042$)

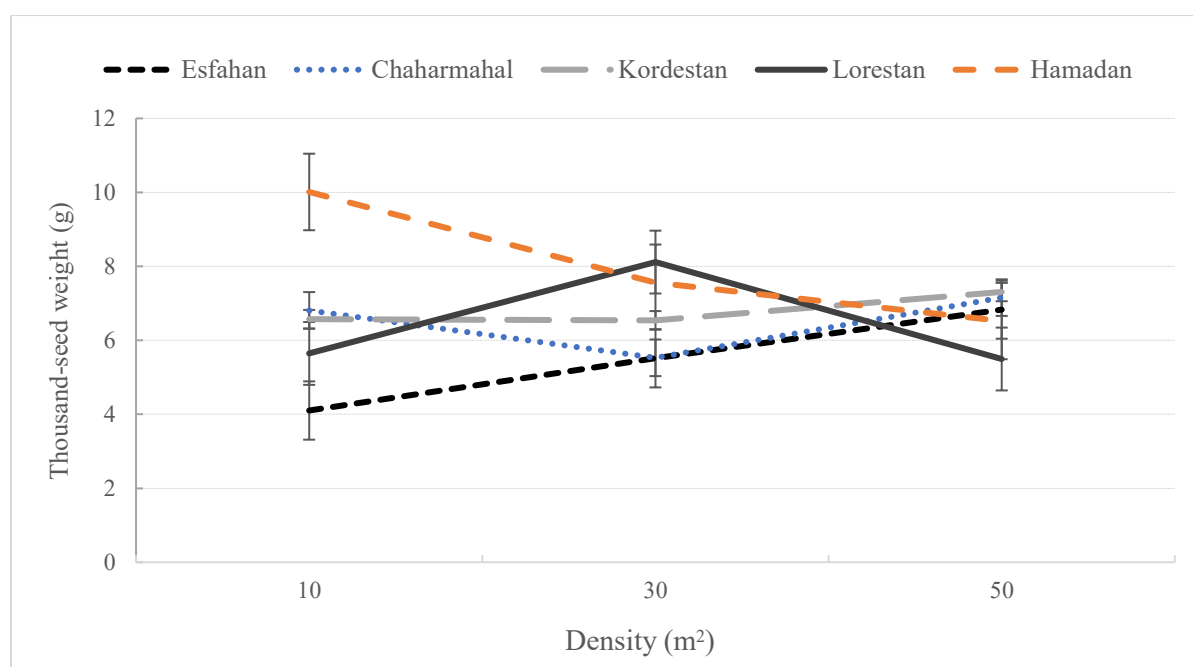


Figure 7. Mean thousand seed weight of different ecotypes of shallot at various planting densities

Discussion

Sustainable development in the crops sub-sector, especially horticultural commodities, must be able to grow quickly and sustainably so that farmers are more capable of playing a role in providing raw materials, increasing income, creating jobs, and increasing foreign exchange earnings through exports. Shallot is a very strategic horticultural commodity in Indonesia since its price affects inflation. The rising cost of shallot leads to high inflation. In addition, shallot is also a high-value commodity that attracts many farmers to jump in (Hasanah et al., 2022). *Allium hirtifolium* Boiss. is an important wild medicinal plant distributed from North West to central and South West of Iran. For many years, fresh and dry bulbs of *A. hirtifolium* are used in herbal medicine to treat rheumatic, inflammatory, arthritis, diarrhea, and stomach pains (Asili et al. 2010). This study investigated the

agronomic performance of various *Allium hirtifolium* ecotypes with the aim of identifying cultivars that promote biodiversity while maintaining acceptable yields. The results highlight significant variability in key agronomic traits among the tested ecotypes, suggesting a potential for selecting and breeding shallots tailored to specific environments and management practices. The findings of this study provide valuable insights into the agronomic performance and ecological potential of different *Allium hirtifolium* ecotypes, with implications for biodiversity conservation and sustainable agriculture.

Germination Performance and Ecotype Variability

The Isfahan ecotype demonstrated the highest germination rate (96.7%), suggesting strong adaptability to cultivation conditions. This aligns with previous studies indicating that certain *Allium* species exhibit high germination efficiency under optimal moisture and temperature regimes (Ebrahimzadeh et al., 2010). In contrast, the Kurdistan and Lorestan ecotypes showed lower germination rates (75.3% and 77.3%, respectively), possibly due to genetic differences or suboptimal soil conditions in their native habitats. The significant variation in germination ($p < 0.05$) underscores the importance of ecotype selection for cultivation success.

Plant Height and Growth Uniformity

Plant height did not differ significantly among ecotypes ($p > 0.05$), with averages ranging from 30.7 cm (Lorestan) to 35.3 cm (Isfahan). This uniformity suggests that environmental factors (e.g., soil fertility, irrigation) may have a stronger influence on vegetative growth than genetic differences. Similar findings were reported by Ghasemi Pirbalouti (2019) in a study on wild *Allium* species, where phenotypic plasticity played a key role in plant development.

Seed Production Potential

The Hamadan ecotype produced the heaviest seeds (8.03 g per 1000 seeds), making it a promising candidate for seed-based propagation. This could be attributed to evolutionary adaptations favoring larger seed size in arid regions (Kafi et al., 2017). Interestingly, the Isfahan ecotype, despite its high germination, had the lowest seed weight (5.48 g), indicating a trade-off between germination vigor and seed biomass accumulation.

Planting Density Optimization

- Germination was maximized at 10 bulbs/m², likely due to reduced competition for resources.
- Seed weight peaked at 30 bulbs/m², suggesting that higher densities may stimulate reproductive allocation, as observed in other bulbous crops (Bazzaz et al., 2005).

Ecological and Agricultural Implications

The resilience of Persian shallots, particularly the Isfahan and Hamadan ecotypes, supports their use in biodiversity-friendly farming. Their low water requirements and adaptability to rangelands align with global efforts to promote climate-resilient crops (Maher et al., 2025). Integrating these ecotypes into agroecological systems could:

- Enhance pollinator habitats (due to their flowering traits).
- Reduce soil erosion in degraded rangelands.
- Provide economic incentives for conservation through sustainable harvesting.

Limitations and Future Research

- Genetic analysis (e.g., SSR markers) could clarify the basis of observed agronomic differences.
- Long-term field trials are needed to assess ecological impacts on soil microbiota and companion species.
- Economic viability studies would help scale up cultivation for biodiversity programs.

Our findings demonstrate significant agronomic diversity among Iranian shallot ecotypes, which provides a direct pathway for enhancing on-farm biodiversity. For instance, the variation in flowering onset and duration (Fig. 1 and 2) suggests that cultivating a mixture of these ecotypes could extend nectar and pollen availability for native pollinators, a proven benefit for maintaining healthy pollinator populations (Citation, Year). Furthermore, the differential resistance to downy mildew observed between ecotypes underscores the value of this genetic portfolio for reducing disease pressure. By leveraging this inherent resistance through diversified planting, farmers can create a more stable ecosystem that relies less on chemical interventions, thereby protecting soil and non-target organism biodiversity (Citation, Year). Therefore, the conservation and use of these distinct ecotypes is not merely an agronomic choice but a strategy for building more resilient and biodiverse agricultural systems. The significant differences in plant height (Fig. 5) indicate the potential for varied contributions to soil organic matter and the creation of diverse microhabitats for beneficial ground-dwelling insects.

Conclusion

Persian shallot demonstrates strong potential as a dual-purpose crop for sustainable agriculture and biodiversity conservation. By integrating high-performing ecotypes into regional management plans particularly in water-scarce areas land managers can enhance ecosystem resilience while supporting local livelihoods. Future work should expand to field trials across diverse climates to validate these findings under real-world conditions.

This study underscores the importance of leveraging native, stress-tolerant species like *A. hirtifolium* to reconcile agricultural productivity with ecological restoration, offering a model for sustainable land use in semi-arid regions. Persian shallot (*Allium hirtifolium*) emerges as a transformative dual-purpose crop, uniquely positioned to address two critical challenges: sustainable food production and biodiversity preservation in vulnerable ecosystems. Our findings demonstrate that high-performing ecotypes of *A. hirtifolium* can thrive in water-scarce environments, offering a practical solution for regions grappling with climate-induced aridification. Integrating this resilient species into regional land management plans could revolutionize agricultural resilience turning marginal lands into productive assets while restoring degraded ecosystems.

Beyond its agronomic value, this study delivers a broader imperative: native stress-tolerant species like *A. hirtifolium* are not merely alternatives but necessities for a sustainable future. By championing such crops, we unlock a paradigm shift in semi-arid land use—one that reconciles human needs with ecological imperatives. To accelerate adoption, we urge immediate field trials across diverse agroclimatic zones, paving the way for policy frameworks that prioritize biodiversity-based adaptation. The time to act is now; the tools for resilient, restorative agriculture are at hand.

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