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The Interaction of Artemisia persica Allelopathy, Drought and Arbuscular Mycorrhizal Fungi on Growth and Physiological Indices of Ferula haussknechtii H. Wolff ex Rech.f.

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ABSTRACT

Aims Ferula L. is one of the largest genera from Apiaceae family with about 180 species, which grow in semi-arid rangelands. One of the challenges associated with this genus in their natural habitats is drought and additionally in case of Ferula haussknechtii H. Wolff ex Rech.f. species is allelopathy caused by companion with Artemisia persica Boiss.

Materials & Methods The present study aimed to investigate the roles of Arbuscular Mycorrhizal (AM) fungi in the growth, physiological characteristics, nutrient uptake, and survival of Ferula haussknechtii H. Wolff ex Rech. F. grown under the interactive influences of drought and allelopathy stress conditions. Four levels of allelopathy stress, three levels of drought stress, and two mycorrhizal treatments (AM and Non-AM) were applied to the pots in a completely randomized design with a factorial arrangement.

Findings Based on ANOVA results (p≤5%), the survival capacities of the Non-AM inoculated plants were significantly less than those of the AM inoculated plants for all allelopathic and drought stress levels. The maximum values of survival capacity were seen in AM×FC×A1 treatment as 75% and the lowest survival capacity was observed in Non-AM×30%FC×A4 as 29%. In general, AM fungi inoculation significantly increase the root:shoot ratios and mycorrhizal dependency values (p≤5%). Based on ANOVA results, the highest and lowest values for root:shoot ratios were observed as 0.71 and 0.27 for Non-AM×30%FC×A4 and AM×FC×A1 treatments, respectively. Drought stress and allelopathic conditions have a destructive effect on total chlorophyll content. The maximum and minimum proline content (0.21 and 0.04) was observed in treatment of AM incubated with highest level of drought and allelopathic and in Non-AM incubated with lowest level of drought and allelopathic, respectively.

Conclusions AM fungi inoculation had a significant positive effect on total nitrogen and phosphorus content in plant tissues but a significant negative effect on total nitrogen and phosphorus content was observed in drought and allelopathic stress treatments.

Keywords Mycorrhizalinoculation; Allelopathy; Drought; Ferula haussknechtii

CITATION LINKS

[1] Effects of vegetation canopy and climate ... [2] Wheat LEA genes, PMA80 and PMA1959, enhance ... [3] Differential antioxidative responses ... [4] Evaluation of salt tolerance ... [5] Mechanisms of tolerance of ... [6] Chemistry and mechanisms ... [7] Investigation and compare ... [8] Allelopathy: State of ... [9] Allelopathic characteristics ... [10] Factors affecting weeping ... [11] Rhizosphere communication of plants ... [12] Interaction between arbuscular mycorrhizal ... [13] Synergistic effect of dual inoculation ... [14] Identification of arbuscular mycorrhizal ... [15] Improved growth and essential oil yield ... [16] Induction of defense responses in ... [17] Ferula. In: Unknown ... [18] Growth, biochemical modifications ... [19] Chemical polymorphism ... [20] Field response of wheat to ... [21] The levels of GA3 and GA20 may ... [22] Alfalfa (Medicago sativa L.) clones ... [23] Growth responses of several ... [24] The relation of expectation and ... [25] Rapid determination of free proline ... [26] Neue method zur bestimmung ... [27] Soil chemical analysis: Advanced ... [28] Allelopathic effects of foliage ... [29] Relating foliar dehydration ... [30] Inhibitory effects of Artemisia ... [31] The ecological impact of ... [32] Allelopathy and VA mycorrhizae ... [33] Effect of foliar spray of aqueous ... [34] A study of the mechanism of ... [35] Caffeic acid induced changes ... [36] Comparative effect of natural growth ... [37] Allelopathy of yellow fieldcress ... [38] The effects of clipping and soil ... [39] Preinoculation of lettuce and ... [40] Influence of arbuscular mycorrhizal ... [41] Antioxidant systems and plant response ... [42] AM fungi effects on the growth ... [43] Arbuscular mycorrhizal fungi ... [44] Role of arbuscular mycorrhizae ... [45] Glycinebetaine applied under ... [46] Effects of different drought and ... [47] The rate of protein biosynthesis ... [48] Effect of extract of fast ...

Introduction

It is well known that drought stress is one of the most influential abiotic factors on the vegetation survival in arid and semi-arid areas. In these areas, the only native and tolerant plant species can grow [1]. This stress affects the growth and production of plants and causes several biochemical and physiological changes [2, 3]. Drought stress reduces the nutrient uptake of the roots and finally leads to the plant's death [4]. Hence, soil aridity stress could diminish the potential of rangeland production [5]. Under drought stress, nutrient uptake and plant growth can be highly influenced by using biofertilizers.

Allelopathy may have direct or indirect impacts on the germination, growth, and evolution of the same species or other species [6]. Allelopathic materials inhibit plant growth [7], affect the activity of microorganisms, limit processes such as nitrogen fixation by symbiotic bacteria, and reduce nitrification [8]. The allelopathic effects of Artemisia species on various plants have been studied in other research [9]. This biotic stress is one of the reasons for the lack of growth and establishment of plants in arid and semiarid regions [10].

As a result of fungi activities, the application of arbuscular mycorrhiza fungus (AM fungi) can increase the quantitative and qualitative properties of plants. As fungi grow, nutrients are transferred from the tissues of fungi to the soil and plant. Thus, the inoculation of AM fungi could certainly effect some changes in the soil and plant systems. AM fungi can spur the root system of the plant, making the plant use a larger volume of soil and gain access to soil micropores [11]. The acquisition of nutrients in AM fungi inoculation can increase nutrition uptake, which in turn increases the dry weights and plant growth [12, 13] and increase the symbiotic efficiency [14]. The enhancement of total nutrients content of plant tissues after the inoculation of AM fungi has demonstrated by the majority of researches [15, 16].

Ferula as a genus of perennial herbs belongs to the family Apiaceae, includes many species (about 180 species) that is typical of dry areas of the Old World. In Iran, there are around 30 species, 15 of them are endemic [17]. The large genus Ferula commonly used in traditional medicine and it is a promising source of biologically active ingredients. Plants from this genus are a source of perfumes (*F. gummosa* Boiss.), spices (*F. assa-foetida* L.) resins (*F. sumbul* Willd.) and food (*F. communis* L.), but this rich ethnopharmacology also includes poisoning, as exemplified by ferulosis [18]. Up to now, no scientific studies have been done on the ecological properties of *F. haussknechtii*. *Ferula haussknechtii* H. Wolff ex Rech. F. is native in semi-arid rangelands of Iran. *Artemisia persica* Boiss which grows in mountainous rangelands may have allelopathic effects on *F. haussknechtii*.

Objective: In order to optimize the use of arid and semi-arid lands, the objectives of this study was to assess the effects of AM fungi on the survival, physiological traits, nutrient uptake, and growth of *F. haussknechtii* grown under the interactive effects of allelopathy and drought stress conditions.

Materials and Methods

Measurement procedures: This experimental study was conducted based on a factorial arrangement in a completely randomized design (with 4 replications) in the greenhouse of Malayer University. The soil was provided as a mixture of sand, loam, and clay, in 2:1:1 (V:V:V) ratio. Then the mixture was air-dried, sieved through a 2mm screen, and steam-sterilized (on two successive days) before inoculation and planting.

As allelopathy is often a root to root interaction [9], the root of *A. persica* was obtained from a natural rangeland, and then was washed, air-dried, and grinded to produce a uniform powder. The ratio of 0 (as control), 1, 5, and 10% w/w of this powder was mixed with the soil (respectively defined as A1, A2, A3, and A4). The soil moisture was maintained in Field Capacity (FC) for two months to complete the powder decomposition. After that, two mycorrhizal treatments (inoculated with AM fungi; AM and without AM fungi inoculation; Non-AM) and three drought stress treatments (FC; as control, 60% FC, and 30% FC) were applied to the pots. By the use of a Clevenger type apparatus, the root dry material of *A. persica* (200g) was distilled for 3 hours. The essential oil constituents of *A. persica* roots were identified based on the method described by Rustaiee *et al*. [19].

Mycorrhizal inoculation was prepared according to the method described by Al-Karaki *et al*. [20]. The seeds of the *F. haussknechtii* were obtained from the natural rangelands (33° 52' 41" N, 48° 28' 9" E) of Aleshtar city, Lorestan Province, Iran. The gathered seeds were homogenized and their dormancy was evaluated by the germination test. After seed dormancy had detected, the seeds were

put in 30ml of GA_3 solution based on the doses and immersion times described by Fernandez *et al*. [21].The treated seeds of *F. haussknechtii* were planted in 5kg plastic pots. As *F. haussknechtii* is a slow-growing plant, to obtain enough volume of plant biomass, 200 plants per pot were planted at a temperature ranging from 12 to 28°C and a 12h photoperiod during the study.

Thirty days after plant transplantation, seedlings of each pot were thinned down to 100 seedlings and the soil was saturated with water to full FC. Then, the plants were either maintained under well-watered (control) conditions or put to water deficit stress by inhibiting water until the soil reached a water content of 60% of FC, and 30% FC. At the end of the study, the plant survival capacity (%) was determined by using Equation 1 [22]. A plant was considered dead if it showed the necrosis of all leaves, stems, and roots.

$$\text{Survival capacity (\%)} = \frac{\text{The number of survived plants}}{\text{Number of total plants}} \times 100 \quad (1)$$

The root to shoot ratio was calculated to measure the growth of plants. Hence, at the end of the study, the soils were washed with water and plant shoots and roots were separated. Afterward, shoot and root dry weights were determined in gr after they were oven-dried at 70°C for 48 hours.

Response to mycorrhizal colonization or mycorrhizal dependency (MD) percentage for each treatment was determined by Equation 2 [23].

$$\text{MD (\%)} = \frac{\text{Dry weight of mycorrhizal plant} - \text{average dry weight of noninculated plant}}{\text{Dry weight of mycorrhizal plant}} \times 100 \quad (2)$$

A spectrophotometer was used to determine the chlorophyll contents of the plants [24] while the method proposed by Bates *et al*. [25] was chosen to determine the proline contents. Total nitrogen contents (TNC) were determined using Kjeldahl's method [26], and Total Phosphorus (TP) contents of plant tissues were estimated by vanadomolybdate method [27].

Statistical analysis: The survival capacity, shoot height, root length, Root: shoot ratio, Mycorrhizal dependency, total chlorophyll, proline, nitrogen, and phosphorus contents are the studied parameters in this research. The statistical analyses were performed by ANOVA using SAS 10 software. The differences between means were tested for significance by Duncan's multiple range test at $p \leq 0.05$.

Findings

The essential oil constituents of *A. persica* roots: The major constituents of the essential oil of *A. persica* were α-pinene (7.66%), 1,8-cineole (6.2%), trans-pinocarveol (10.1%), pinocarvone (8.3%), artedouglasia oxide (C, D, and B; 21.3%), and laciniata furanone (E, F, G, H; 16.3%).

The survival capacity: Survival capacity significantly differed across various interactive treatments of AM fungi, drought stress, and allelopathic conditions in *F. haussknechtii*. Based on ANOVA results, the maximum values of survival capacity were seen in AM×FC×A1 treatment as 75% and the lowest survival capacity was observed in Non-AM×30%FC×A4 as 29% (Figure 1). Generally, the survival capacity percentage reduced under drought stress and allelopathic conditions, but the AM fungi additions increased the survival capacity values. The Non-AM inoculated plants had remarkably lower survival capacities than AM inoculated plants at all drought and allelopathic stress levels (Diagram 1).

The growth rate: The shoot length of *F. haussknechtii* was seen at its maximum (21.1cm) and its minimum (5.5cm) at AM×FC×A1 and Non-AM×30%FC×A4 treatments, respectively. There were not any remarkable differences between shoot height values at AM×FC×A1, AM×FC×A2, and AM×FC×A3 treatments. In addition, no significant differences were observed in the shoot height under Non-AM×FC×A2, Non-AM×FC×A3, and Non-AM×FC×A4 treatments (Table 1).

However, the root lengths of plants differed across the various treatments. As demonstrated in Table 1, the maximum and minimum root length values were seen in AM×60%FC×A1 (15.3cm) and Non-AM×30%FC×A4 (7cm) treatments, respectively. The root length values demonstrated no significant differences in Non-AM×FC×A2, Non-AM×FC×A3, and Non-AM×FC×A4 treatments. Based on ANOVA results, the maximum and minimum values for root: shoot ratios were observed as 0.71 and 0.27 for Non-AM×30%FC×A4 and AM×FC×A1 treatments, respectively. In general, the results showed that root:shoot ratios and MD values significantly increased under drought stress and allelopathic conditions.

The total chlorophyll, proline, nitrogen, and phosphorus contents: The total chlorophyll content of *F. haussknechtii* differed significantly in different studied treatments. The highest

content of total chlorophyll was seen as 9.4mg g^{-1}in AM×FC×A1 treatment and the lowest was recorded as 3.6mg g^{-1} in Non-AM×30%FC×A4 treatment (Table 2). In general, the results showed that drought stress and allelopathic conditions have a destructive effect on total chlorophyll content of *F. haussknechtii*. Compared with the control, the total chlorophyll content of *F. haussknechtii* significantly increased in AM fungi inoculated treatments.

Generally, the interactive effects of AM fungi application, drought, and allelopathic stress had a significant effect on increasing the proline content. It was observed that in AM×30%FC×A4 treatment, the presence of proline content rose to its highest level (0.21µmol gFW^{-1}) while the lowest level was observed in Non-AM×FC×A1(0.04µmol gFW^{-1}) treatments.

Compared with the control, a significant negative effect on TNC was seen in drought and allelopathic stress treatments. Moreover, a significant positive effect of the AM fungi inoculation was observed on the total nitrogen content (TNC) in plant tissues of *F. haussknechtii*. The maximum values of TNC in *F. haussknechtii* were seen in AM×FC×A1 (4.1%) and the lowest value was reported as 1.1% in Non-AM×30%FC×A4 treatment (Table 2). A similar trend was seen in the change of total Phosphorus Content (TP). The highest level of TP was recorded as 3.7g kg^{-1} in AM×FC×A1 treatment and the minimum content of TP was reported as 0.8g kg^{-1} in Non-AM×30%FC×A4 treatment (Table 2).

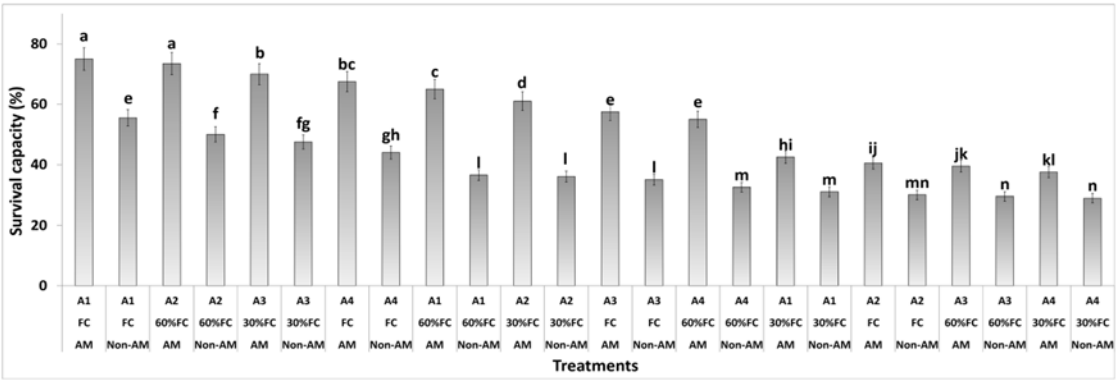

Diagram 1) The effect of Arbuscular Mycorrhizal fungi on the survival capacity of *F. haussknechtii* grown under the interactive effects of allelopathy and drought stress conditions. Different letters on the bar graphs represent a significant difference at $p<0.05$

Table 1) The effect of Arbuscular Mycorrhizal fungi on root length, shoot height, mycorrhizal dependency, and root:shoot ratio of *F. haussknechtii* grown under the interactive effects of allelopathy and drought stress conditions

Treatments	**Shoot height** (cm)	**Root length** (cm)	**Root: shoot ratio**	**Mycorrhizal dependency** (MD)
AM×FC×A1	21.1±0.90 a*	10.5±0.41 gh	0.27±0.02 f	21.07±1.13 e
Non-AM×FC×A1	16.6±0.72 cd	8.7±0.26 ij	0.27±0.02 f	
AM×60%FC×A2	15.5±0.11 de	14.2±0.19 b	0.34±0.03 def	31.73±2.01 cd
Non-AM×60%FC×A2	9.9±0.09 ij	11±0.17 ef	0.43±0.02 bcd	
AM×30%FC×A3	11.1±0.10 hi	11.9±0.13 de	0.41±0.02 cde	40.13±2.07 a
Non-AM×30%FC×A3	5.5±0.02 l	7.2±0.13 k	0.71±0.04 a	
AM×FC×A4	17.7±0.62 bc	9±0.11 ij	0.28±0.02 f	23.79±1.09 e
Non-AM×FC×A4	13.3±0.41 fg	8.4±0.08 ij	0.30±0.01 ef	
AM×60%FC×A1	17.7±0.17 bc	15.3±0.12 a	0.32±0.03 ef	28.33±1.06 cd
Non-AM×60%FC×A1	12.2±0.11 gh	11.6±0.19 ef	0.37±0.01 def	
AM×30%FC×A2	11.1±0.06 hi	12.5±0.17 de	0.41±0.02 cde	39.49±1.12 a
Non-AM×30%FC×A2	5.5±0.03 l	7.2±0.13 k	0.70±0.06 a	
AM×FC×A3	19.9±0.12 ab	9.3±0.18 hi	0.27±0.02 f	30.52±2.03 cd
Non-AM×FC×A3	13.3±0.08 fg	8.4±0.14 ij	0.30±0.01 ef	
AM×60%FC×A4	14.4±0.09 ef	13.1±0.10 cd	0.35±0.03 def	33.51±1.09 bc
Non-AM×60%FC×A4	8.8±0.03 jk	10.7±0.17 fg	0.47±0.01 bc	
AM×30%FC×A1	14.4±0.13 ef	12.8±0.18 cd	0.33±0.02 def	39.06±0.92 a
Non-AM×30%FC×A1	7.7±0.03 k	8.3±0.16 j	0.52±0.03 b	
AM×FC×A2	19.9±0.11 ab	10±0.14 gh	0.27±0.02 f	26.10±1.08 de
Non-AM×FC×A2	14.4±0.01 ef	8.5±0.16 ij	0.28±0.01 f	
AM×60%FC×A3	15.5±0.12 de	13.7±0.18 bc	0.34±0.03 def	37.20±2.01 ab
Non-AM×60%FC×A3	8.8±0.03 jk	10.8±0.11 f	0.48±0.04 bc	
AM×30%FC×A4	10.3±0.05 i	11.8±0.17 de	0.44±0.02 bcd	37.16±1.03 ab
Non-AM×30%FC×A4	5.5±0.02 l	7±0.16 k	0.73±0.08 a	

*Different letters on the same column show a significant difference at $p<0.05$.

Table 2) The effect of Arbuscular Mycorrhizal fungi on chlorophyll, proline, total nitrogen, and total phosphorus contents of *F. haussknechtii* grown under the interactive effects of allelopathy and drought stress conditions

Treatments	**Chlorophyll content** (mg g^{-1})	**Proline** (µmol gFW^{-1})	**TNC** (%)	**TP** (g kg^{-1})
AM×FC×A1	9.4±0.34 a*	0.11±0.02 def	4.1±0.12 a	3.7±0.11 a
Non-AM×FC×A1	6.9±0.12 e	0.04±0.01 g	2.8±0.08 cd	2.4±0.09 cd
AM×60%FC×A2	9.2±0.23 a	0.14±0.03 bcde	3.8±0.07 ab	3.6±0.12 a
Non-AM×60%FC×A2	6.3±0.13 f	0.16±0.03 abcd	2.6±0.08 de	2.1±0.12 cde
AM×30%FC×A3	8.8±0.15 b	0.20±0.04 a	3.7±0.06 abc	3.4±0.21 ab
Non-AM×30%FC×A3	5.9±0.09 fg	0.19±0.03 ab	2.5±0.03 def	1.9±0.12 def
AM×FC×A4	8.4±0.11 bc	0.13±0.02 cde	3.5±0.04 bc	3.2±0.18 abc
Non-AM×FC×A4	5.5±0.08 gh	0.11±0.02 def	2.2±0.11 efg	1.7±0.07 ef
AM×60%FC×A1	8.1±0.11 c	0.13±0.02 cde	3.4±0.10 bc	3±0.60 abc
Non-AM×60%FC×A1	4.6±0.07 l	0.16±0.03 abcd	1.7±0.08 gh	1.3±0.81 fg
AM×30%FC×A2	7.6±0.08 d	0.19±0.02 ab	3.2±0.12 c	2.8±0.21 bc
Non-AM×30%FC×A2	4.5±0.04 l	0.18± 0.03abc	1.7±0.06 gh	1.2±0.03 fg
AM×FC×A3	7.2±0.09 e	0.13±0.01 cde	3±0.09 cd	2.6±0.06 bcd
Non-AM×FC×A3	4.4±0.02 l	0.09±0.01 efg	1.5±0.03 hi	1.2±0.03 fg
AM×60%FC×A4	6.9±0.12 e	0.15±0.02 bcd	2.9±0.12 cd	2.4±0.04 cd
Non-AM×60%FC×A4	4.1±0.06 m	0.17±0.03 abcd	1.3±0.06 i	1±0.02 fg
AM×30%FC×A1	5.3±0.09 hi	0.19±0.02 ab	2.1±0.03 efg	1.6±0.03 ef
Non-AM×30%FC×A1	3.9±0.04 m	0.17±0.01 abcd	1.3±0.09 i	0.9±0.01 fg
AM×FC×A2	5.1±0.05 ij	0.12±0.01 de	1.9±0.04 fgh	1.5±0.02 ef
Non-AM×FC×A2	3.8±0.03 mn	0.06±0.01 fg	1.3±0.02 i	0.9±0.01 g
AM×60%FC×A3	4.9±0.02 jk	0.15±0.02 bcd	1.9±0.09 fgh	1.4±0.03 fg
Non-AM×60%FC×A3	3.7±0.03 n	0.16±0.03 abcd	1.2±0.06 i	0.8±0.01 g
AM×30%FC×A4	4.7±0.07 kl	0.21±0.02 a	1.8±0.11 gh	1.3±0.02 fg
Non-AM×30%FC×A4	3.6±0.06 n	0.19±0.03 ab	1.1±0.04 i	0.8±0.01 g

*Different letters on the same column indicate a significant difference at $p<0.05$.

Discussion

Biotic and abiotic stresses like drought and allelopathy have negative impacts on the plants' survival capacity. In drought stress conditions, the secretion of secondary metabolites of plants with allelochemical materials for chemical protection increases and the role of allelopathy interference becomes more evident [28]. Based on the results of this study, AM fungi inoculation enhanced drought and allelopathic stress tolerance in *F. haussknechtii*. The survival capacities of Non-AM inoculated plants were significantly less than those of AM inoculated plants at all drought and allelopathic stress levels. The development of hyphae in the soil can modify and enhance the water relations of host plants [29]. Compared with 60%FC, the alleviation effect of AM fungi reduced under 30%FC drought treatments (Diagram 1). The allelopathic properties of *A. persica* became more evident under dry conditions. These results are in agreement with the study of Escudero *et al*. who found allelopathic properties of *A. persica* as biotic interference became more evident under drought stress [30].

The shoot height of *F. haussknechtii* decreased significantly with an increase in the root ratio of *A. persica* (Table 1). There are similar reports about the suppuration of plants height under allelopathic conditions [31]. Root length of *F. haussknechtii* was significantly decreased as the root ratio of *A. persica* increased. These findings are in accord with the report of Afzal et al. who stated that the root growth of *Vigna radiata* and *Phaseolus vulgaris* were decreased remarkably under allelopathic conditions [32]. Shoot height reduction under allelopathic conditions may be caused by root length reduction [33]. In this regard, the root growth reduction under allelopathic stress may be caused by mitotic activity reduction of root cells [34]. On the other hand, photosynthesis performance [35], growth hormones activity [36], protein synthesis, and water relations [37] may alter negatively under allelopathic stress.

Based on ANOVA results, root:shoot ratios of *F. haussknechtii* enhanced under drought and allelopathy stress. It seems that under biotic and abiotic stresses, plants allocated more photosynthate to the roots and the root:shoot ratios were enhanced [38].

Under drought and allelopathy stress, mycorrhizal dependency increased in the AM-inoculated plants. It is well known that plants with AM fungi symbiosis tolerate stress better than Non-AM plants [39]. In general, the MD values had a significant increase under drought stress and allelopathic conditions. Kumar et al. have reported similar results and have stated that MD values significantly increased under

stressful conditions [40].

The various drought stress and allelopathic conditions have a destructive effect on the total chlorophyll content of *F. haussknechtii* (Table 2). Earlier, a significant decrease in chlorophyll content had been reported by drought stress in sunflower varieties [18]. The decrease of chlorophyll content under drought stress may be due to damage to chloroplasts done by active oxygen species [41]. On the other hand, the reduction in the total chlorophyll content at different allelopathic levels might be due to the presence of allele chemicals. Compared with the control, the total chlorophyll content of *F. haussknechtii* significantly increased in AM fungi inoculated treatments. An increase in the chlorophyll synthesis and, in turn, an increase in the photosynthesis rate under mycorrhiza treatment has been reported [42]. The use of biofertilizers such as AM fungi increases the amount of nutritional materials available to the plant such as nitrogen and as a result increases the overall chlorophyll content.

According to the results, in AM×30%FC×A4 treatment, the presence of proline content rose to its highest level (0.21µmol gFW^{-1}) while the lowest level was observed in Non-AM×FC×A1 (0.04µmol gFW^{-1}) treatments. In biotic and abiotic stress conditions, plants accumulate osmolytes. As a protein amino acid osmolyte, proline can protect plants in stressful conditions. Plants inoculated with AM fungi can produce and accumulate proline in their tissues [43]. Thus, the better growth of AM fungi inoculated plants (AM) compared to that of Non-AM fungi plants in a drought and allelopathic stresses may be due to the increase of some osmolytes as proline. In agreement with the present investigation, Garg and Manchanda reported the accumulation of proline in mycorrhiza-stressed plants [44].

The TNC (%) and TP (g kg^{-1}) reduced significantly under the interactive effects of drought and allelopathic stresses. In agreement with this investigation, there are reports that the uptake of nutrients [45] and plant growth [46] reduced under drought stress and allelopathic stress due to the exertion of allelochemicals [47] prevents the minerals uptake by roots [48]. On the other hand, as a biological strategy, AM fungi inoculation helped plants to alleviate the adverse interactive effects of drought and allelopathic stresses and enhanced the uptake capacity of plants absorbing more essential nutrients such as N and P.

The limitations of this research include plant species identification and seed collection of *Ferula haussknechtii* H.

Conclusion

In conclusion, the damage caused by allelopathy and drought stress was obviously alleviated by the use of AM fungi. The application of AM fungi increased plant root symbiosis and, in turn, plant nutrient and water uptake, and finally improved plant growth. All the quantitative and qualitative properties of *F. haussknechtii* grown under the interactive effects of allelopathy and drought stress conditions were increased after using AM fungi. Therefore, the negative effects of allelopathy as a biotic stress, and drought as an abiotic stress, were alleviated by AM fungi addition. The growth and spread of plants in arid and semi-arid rangelands follow a patch and inter-patch pattern. The required amounts of biofertilizers such as AM fungi for the alleviation of drought and allelopathic stresses are much less than those of agricultural lands because they are only used in the patch areas. Hence, AM fungi addition may be an economical method for alleviating abiotic and biotic stresses in arid and semi-arid rangelands. However, further field studies must be conducted in natural rangelands.

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