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Exploring the allelopathic impact of leaf extracts from three desert flora on roman chamomile (*Chamaemelum nobile* L. (All.)) under three experimental conditions

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Original Research

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Abstract:

This study aimed to assess the allelopathic effects of leaf extracts from *Prosopis juliflora* (an invasive species), *Acacia nilotica*, and *Ziziphus spina-christi* (native species) on seed germination and seedling growth of *Chamaemelum nobile* (L) All. (Roman chamomile) under three vegetative conditions (laboratory, greenhouse, and field). The germination percentage, germination rate, and seedling growth of Roman chamomile were evaluated under both laboratory and greenhouse conditions. In the laboratory, the effects of various concentrations of leaf powder (30%, 50%, and 100%) were assessed, with distilled water used as the control. During the greenhouse stage, different litter-to-sand ratios (1:15, 1:10, and 1:5) were utilized for evaluation. The study was conducted using a completely randomized design with four replications. Field experiment was performed utilizing a randomized systematic design, in which 10 randomly selected seedlings of each species were planted at distances of 0, 1, and 2 m from selected trees. The results indicated that leaf extracts of *P. juliflora*, *A. nilotica*, and *Z. spina-christi* reduced the germination percentage, radicle length, and plumule length of Roman chamomile across all concentrations compared to the control. Moreover, an increase in leaf extract concentrations led to a decrease in germination percentage, germinationrate, radicle length, and plumule length. *P. juliflora*'s leaf extract exhibited a more pronounced impact on all variables compared to the other species. In this context, the treatment with 100% leaf extract of *P. juliflora* yielded the lowest percentage of germination (24%), the lowest germination rate (3 seeds per day), the shortest plumule length (0 mm), and the shortest radicle length (3.5 mm) for Roman chamomile. In the greenhouse treatment, the litter-to-sand ratio significantly influenced the germination and radicle length of Roman chamomile, with all variables showing an increase with higher sand proportions relative to leaves. The highest allelopathic effects were observed in the *P. juliflora* leaf extract mixed with sand. These findings were supported by the results of field treatments. The field study confirmed the results of the experiments conducted in both laboratory and greenhouse. Additionally, the frequency of Roman chamomile was found to increase as the distance from *A. nilotica* and *P. juliflora* increased, suggesting an influence over the plant's spread. Conversely, *Z. spina-christi* exhibited a different behavior, indicating its supportive role in enhancing the presence of Roman chamomile in natural settings. Regarding the significant medicinal value of Roman chamomile in Iran, along with the allelopathic impact of *A. nilotica* and *P. juliflora* on other plants, it is advisable to prioritize the cultivation of species like *Z. spina-christi* which are better adapted to local soil and climate conditions.

Keywords: Allelopathy; Germination rate; Seedling growth; Field conditions; Greenhouse conditions

Introduction

The term "allelopathy" is derived from the Greek words "allelo," meaning "mutual," and "pathos," meaning "harm." This phenomenon can influence various aspects of plant physiology, including their occurrence, development, transitions, community structure, dominance, diversity, and biomass production (Hanna and Goran, 2023).

Allelopathy refers to the interaction of plants with their metabolites, where plants produce chemical compounds that can inhibit or stimulate the growth of other species (Jabran, 2017; Mushtaq et al., 2020). This phenomenon involves the release of some organic compounds into the rhizosphere, affecting neighboring plants (Cheng et al., 2022; Wang et al., 2023). The allelopathic potential has been observed in both living plants and decaying plant residues (Bonanomi et al., 2021). Understanding the allelopathic effects of plants is crucial for ecosystem restoration projects and natural resource management, as it can impact seed germination and seedling growth significantly (Alshahrani and Suansa, 2020; Wang et al., 2022). Particularly in regions facing water scarcity, drought, and salinity, the effects of allelopathy can be exacerbated (Wu et al., 2020; Motalebnejad et al., 2023).

The invasive *Prosopis juliflora* (Sw.) DC. is a xerophytic species that has adapted to grow in arid regions with alkaline soils. While it can be effective in combating desertification, it has significant negative effects on native biodiversity due to its allelopathic properties. This plant releases water-soluble allelochemicals from its leaves, which can inhibit the physiological and biochemical processes of neighboring plants. The dry leaves are rich in flavonoids (containing as much as 3.6%) and alkaloids (2.2%), which can suppress the growth of native species (Bibi et al., 2023; Almoshadak et al., 2024). The widespread introduction of *P. juliflora* in arid and semi-arid regions has led to the decline of native forests, resulting in reduced species diversity and endangerment of local flora. Consequently, the allelopathic effects of *P. juliflora* not only alter the composition of native plant communities but also threaten the ecosystem services provided by these forests (Bibi et al., 2023; Almoshadak et al., 2024).

Acacia nilotica (L.) Delile, like other *Acacia* species, exhibits a range of allelopathic effects on seedling growth of various crops, with its leachates demonstrating activity that can either stimulate or inhibit growth depending on the concentration of allelochemicals and the sensitivity of the target species. In particular, *A. nilotica* has been shown to suppress seedling establishment for many agricultural plants, with bark extracts proving to be more inhibitory than leaf extracts (Al-Wakeel et al., 2007; Alshareef and Alaib, 2019). Some studies have further shown that lower concentrations of foliar extracts of *A. nilotica* can stimulate seedling growth, while higher concentrations result in suppressive effects. Various parts of *Acacia* species contain allelopathic compounds-primarily phenolic acids and flavonoids-which exhibit strong allelopathic potential, particularly affecting plants growing beneath their canopy. Despite the recognition of these phytotoxic compounds, the physiological and metabolic actions of these natural products on higher plants have received limited attention in the literature (Al-Wakeel et al., 2007; Alshareef and Alaib, 2019).

Ziziphus spina-christi (L.) Desf. (commonly known as sidr) is a multipurpose tree belonging to the Rhamnaceae family, and it is recognized for its notable allelopathic effects, particularly in tropical and subtropical regions with high altitudes that experience elevated temperatures and drought conditions. The leaves of sidr contain a variety of medicinal compounds traditionally used by local residents to address various health issues. In addition to their medicinal uses, sidr leaves have served as cleaning agents and nutritious fodder for animals. The presence of bioactive compounds-such as flavonoids, alkaloids, saponins, and other allelopathic substances-in the leaves plays a significant role in plant interactions. Therefore, investigating these properties is critical for developing effective management strategies for both the species and its surrounding environment. Furthermore, the allelopathic interactions of sidr have been employed to protect crops and serve as environmentally friendly alternatives to harmful fungicides, herbicides, and insecticides. Extracts from sidr leaves have demonstrated inhibitory effects on the growth and development of other plants and microorganisms, highlighting the potential of this medicinal plant in treating various ailments, including ulcers, diabetes, and wounds (Elaloui et al., 2016; Hanna and Goran, 2023).

Chamaemelum nobile (L.) All. (Roman chamomile) is one of the oldest medicinal plants discovered by humans and today, it is among the most widely used plants from which hundreds of medicinal and cosmetic products are made worldwide. This indigenous species is naturally distributed in many parts of Iran, including the southern and western regions and its flowers are widely used in pharmaceutical, cosmetic, and food industries (Rashidi and Najafzadeh, 2018).

While there have been numerous studies on plant allelopathy, few have focused on the allelopathic effects of other species on Roman chamomile. Therefore, exploring the allelopathic properties of the three tree species on Roman chamomile is essential for understanding its ecological role and potential applications in sustainable agriculture and medicine. However, Astaraei (2008) evaluated the allelopathic impact of *Peganum harmala* on Roman chamomile and found negative effects on seed germination and survival. Given that Roman chamomile naturally grows near *P. juliflora*, *A. nilotica*, and *Z. spina-christi* in southern parts of Iran, this study investigates the allelopathic effects of these three species on Roman chamomile under laboratory, greenhouse, and field conditions.

Materials and methods

The allelopathic effects of *P. juliflora*, *A. nilotica*, and *Z. spina-christi* on seed germination and seedling growth of Roman chamomile were investigated in this study. Leaf samples of the three aforementioned species were collected from Chahkotah forest park, situated in the central district of Bushehr city at 51°08′ E longitude and 29°03′ N latitude in 2015. Bushehr exhibits a hot semi-arid climate, classified according to the Köppen climate classification system, characterized by a precipitation pattern that is similar to that of Mediterranean climates. The region experiences an average annual precipitation of 268 mm, an average annual temperature of 28.8 °C, and an average relative humidity of 65%. The dominant woody species in the area was *P. juliflora*, while the herbaceous layer was characterized by *Pennisetum divisum* (J.F.Gmel.) Henrard, *Cenchrus ciliaris* L., and Roman chamomile. Concurrently, seeds of Roman chamomile were also gathered from the same location. The study encompassed both laboratory experiments and field observations, with designated plots established to assess allelopathic effects under natural conditions. The field plots were spaced approximately 5 m apart, with 10 randomly selected trees per species. Sampling was conducted using a randomized-systematic design under each tree, with three plots established at intervals of zero, one, and two meters from each tree. Figure 1 illustrates the geographical location of the study area on the map.

Fresh leaves of *P. juliflora*, *A. nilotica*, and *Z. spina-christi* were collected to prepare the extracts. Leaf samples were randomly obtained from five trees of each species, aged between 8 and 12 years. Mature seeds of Roman chamomile, which were uniform in size and shape, were selected and dried in an oven at 30 °C for 72 hours before experimentation.

Subsequently, 100 seeds were randomly chosen for each treatment from the seed mass, following a Completely Randomized Design (CRD) with four replicates per treatment. Four levels of leaf extraction were employed in each treatment.

The seeds were disinfected with 1% sodium hypochlorite for 5 minutes and rinsed thoroughly with distilled water before experimentation. Germination properties were studied using 100 seeds per species with 4 replications in the control group treated with distilled water.

The leaves of the three studied species were washed, dried at 40 °C for 48 hours, and ground into powder for extraction. Leaf powder from *P. juliflora*, *Z. spina-christi*, and *A. nilotica* were separately mixed with distilled water at a ratio of 1:10 (leaf to distilled water). The mixture was agitated for one hour at 160 rpm, refrigerated for 24 hours, agitated again for an hour, refrigerated once more for 24 hours, and then centrifuged at 3000 rpm for 5 minutes to remove excess material. The resulting extract was considered as the base extract (100%), with concentrations of 30% and 50% prepared by dilution with distilled water and stored in the refrigerator until use. Petri dishes were sterilized, and 25 seeds were placed on each dish, with 5 mL of each extract added to the samples. The Petri dishes were incubated at a constant temperature of 25 °C and a relative humidity of 65%, under a photoperiod of 16 hours of light and 8 hours of darkness, illuminated by 1000 lux fluorescent light (Bahmani et al., 2016; Rahimi et al., 2016).

Germination percentage was calculated using the formula $\mathrm{Gp} = n/N \times 100$, where Gp represents germination percentage, n is the number of germinated seeds, and N is the total number of seeds.

The Germination Rate (GR) was calculated according to the following equation:

GR $=$ (number of germinated seedlings/day) $+\ldots+$ (number of germinated seedlings/day of final count)

Radicle and plumule lengths were measured using calipers over 5 days (ISTA, 2010).

In greenhouse experiments, sand collected from the study area was washed, sieved through a 2 mm sieve, and mixed with freshly fallen leaves on the ground in ratios of 1:15, 1:10, and 1:5 (litter-to-sand by volume). A control group consisting of sand only was also included. Small plastic pots filled with the prepared mixtures were used for seed sowing at a depth of 1 cm (Kartoolinejad and Sahebalam,

Figure 1. Geographic location of the experiment site.

2024). The pots were placed under fluorescent light, irrigated daily, and measurements of radicle and plumule lengths were taken after 5 days.

Data analysis was conducted using SPSS software. The normality of the data was assessed using the Kolmogorov-Smirnov test, while data homogeneity was evaluated using the Levene test. General Linear Models (GLM) were employed to assess the effects of species, concentration, and their interaction on germination percentage, germination rate, radicle length, and plumule length in the laboratory and greenhouse phases. Mean comparisons were performed using Tukey HSD test.

Results

Laboratory experiment

The analysis of variance revealed significant differences ($p < 0.01$) for the effects of species, concentration, and their interaction on the germination traits of Roman chamomile, including percentage and rate of germination, radicle length, and plumule length (Table 1).

The investigation into the interaction effect of different leaf extractions from the three species revealed significant variations among treatments concerning the germination percentage, germination rate, radicle length, and plumule length of Roman chamomile (figures 2-5). The highest values for germination percentage, germination rate, radicle length, and plumule length were observed in the leaf extract of *Z. spina-christi*, while the lowest values were recorded in the leaf extract of *A. nilotica*. The mean results for germination percentage, germination rate, radicle length, and plumule length indicated a decreasing trend with an increase in leaf extract concentration (30%, 50%, and 100%) compared to the control group. Particularly, the extract with a concentration of 100% exhibited the lowest values for all traits. Notably, the plumule length was not observed in the extracts with a concentration of 100% for *A. nilotica* and *P. juliflora* (figure 4).

Greenhouse experiment

The results of the analysis of variance conducted in greenhouse conditions indicated that the litter-to-sand ratio of the three studied species had a significant impact on the germination characteristics of Roman chamomile ($p < 0.01$) (Table 2).

Given the significance of these differences, a Tukey's test was performed, revealing significant variations among all treatments across all studied factors (figures 6-9).

The results revealed that there was no plumule length observed in the ratio of 1:10 litter-to-sand for *A. nilotica*, and similarly, no plumule length was observed in the ratio of 1:15 litter-to-sand for both *A. nilotica* and *P. juliflora* (figure 8). Additionally, the ratio of 1:15 exhibited the highest inhibitory effect on radicle length under the allelopathic influence of *A. nilotica* (figure 9).

Field experiment

Species, distance from tree, and the interaction between species and distance from tree were found to be significant factors influencing the number of plants of Roman chamomile (Table 3). The results of the analysis of variance for species and distance from the tree revealed a significant difference among the studied factors, with significant variations observed across all treatments. The density of Roman chamomile exhibited an increase with greater distance from the tree (figure 10).

Discussion

The results of the study indicate that treatments involving *A. nilotica* had the most pronounced effect on reducing the germination percentage, germination rate, radicle length, and plumule length of Roman chamomile. This allelopathic effect of the genus *Acacia* is supported by previous studies. Al-Wakeel et al. (2007) found that *A. nilotica* had a significant impact on the germination and growth of *Pisum sativum*. Chlorophyll a, b and carotenoids were found to accumulate in pea shoots exposed to lower concentrations of *Acacia* leaf residues, alongside an increase in total sugar content, predominantly in the insoluble fraction. Furthermore, the application of lower doses of *Acacia* leaf residues promoted the growth of both pea shoots and roots. In contrast, higher doses exhibited an inhibitory effect on seedling growth, indicating a concentration-dependent response.

Souto et al. (2001) reported that *Acacia* melanoxylon had a strong inhibitory effect on herbaceous plants. El-Khawas and Shehata (2005) also demonstrated the allelopathic potential of *A. nilotica* on *Zea mays* and *Phaseolus vulgaris*. Additionally, the inhibitory effect of *A. nilotica* on the germination and establishment of *Triticum aestivum* has been documented (Bharsakle et al., 2020).

The results of a study conducted by Choudhari et al. (2018) showed that increasing concentrations of the leaf leachates of *A. nilotica* had an inhibitory effect on germination param-

Table 1. Variance analysis of the effects of extracts of tree species on the germination characteristic of Roman chamomile.

Source of variations	df	Mean Square			
		Germination percentage	Germination rate	Radicle length	Plumule length
Species	2	2164.33**	144.63**	151.18**	17.01**
Extract	3	5877.33**	252.27**	498.81**	72.05**
Species × Extract	6	252.33**	17.37**	20.19**	2.09**
Error	36	9.33	0.59	0.66	0.07

**: Significant differences between treatments at 1% probability level.

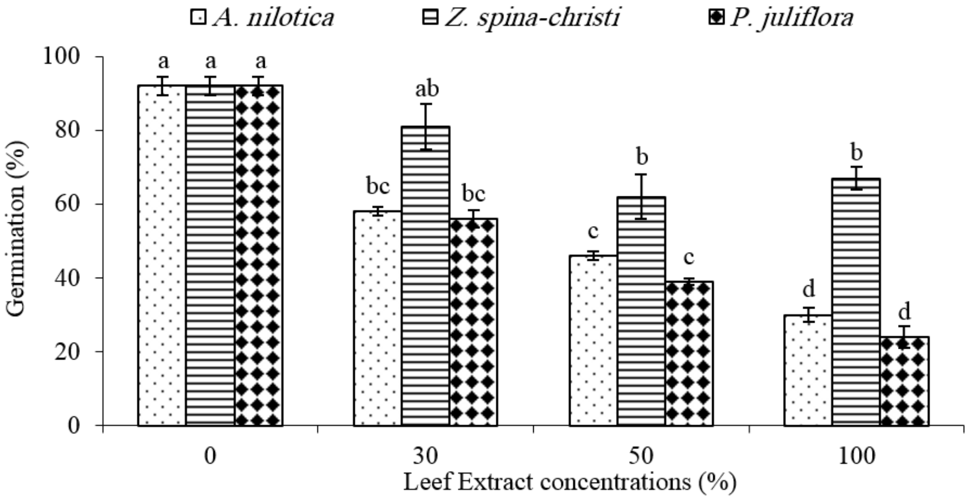

Figure 2. Effect of leaf extracts of 3 tree species on germination percentage of Roman chamomile (Dissimilar lowercase letters indicate a statistically significant difference among treatments).

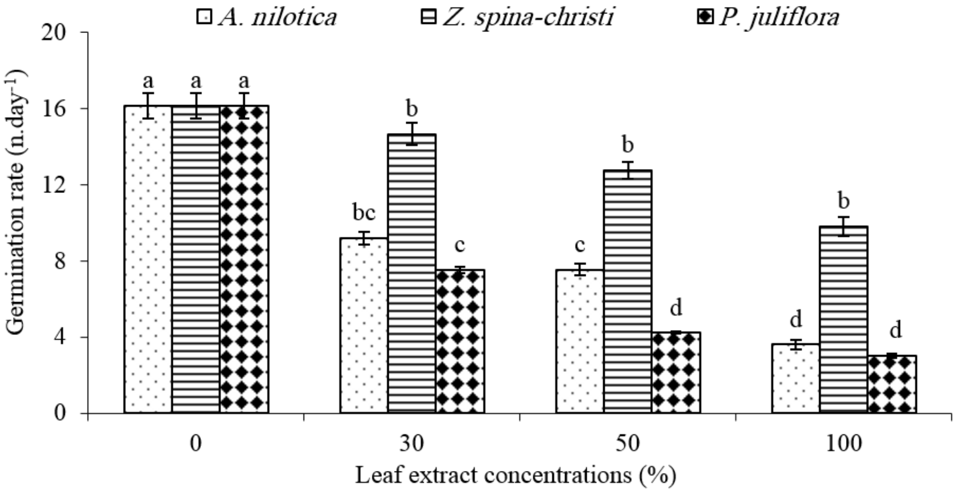

Figure 3. Effect of leaf extracts of 3 tree species on germination rate of Roman chamomile (Dissimilar lowercase letters indicate a statistically significant difference among treatments).

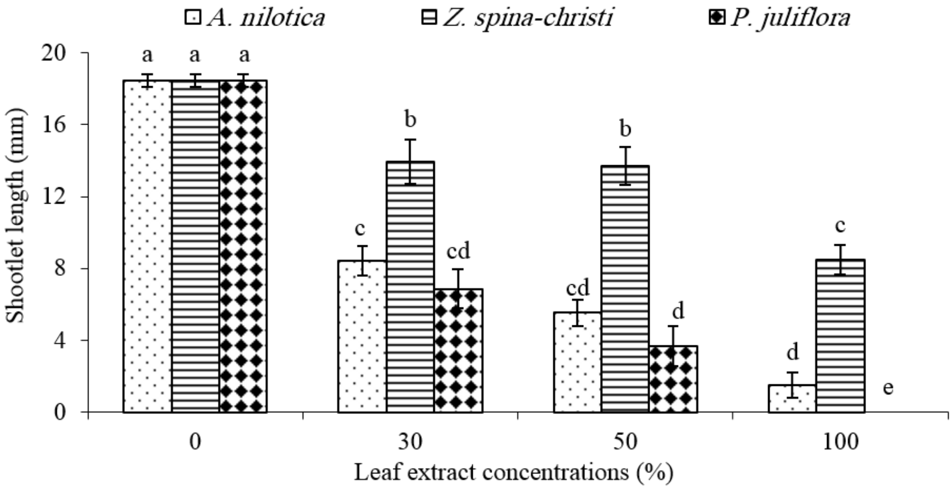

Figure 4. Effect of leaf extracts of 3 tree species on plumule length of Roman chamomile (Dissimilar lowercase letters indicate a statistically significant difference among treatments).

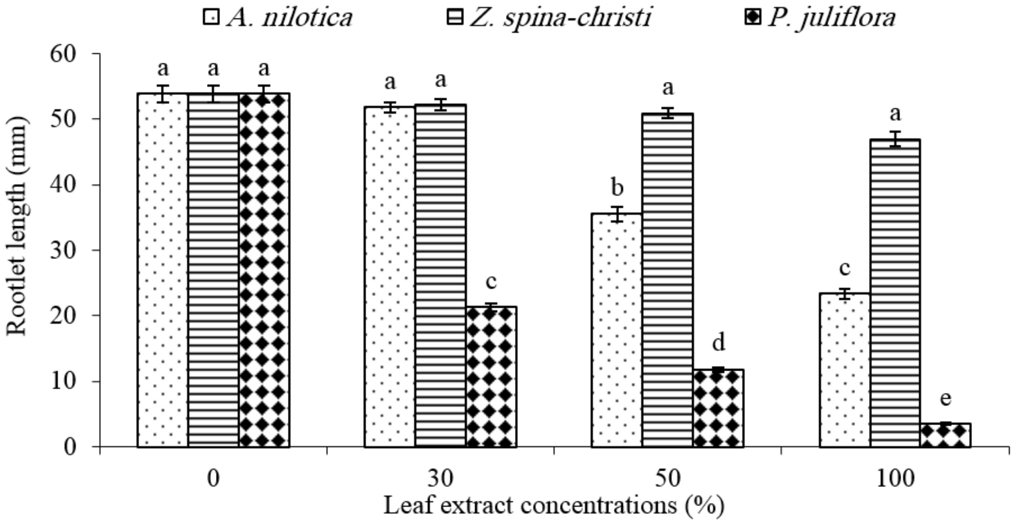

Figure 5. Effect of leaf extracts of 3 tree species on radicle length of Roman chamomile (Dissimilar lower-case letters indicate statistically significant differences between treatments).

eters, plumule, and radicle length of *Beta Vulgaris* var. *Bengalensis*. Similar results were observed in greenhouse conditions regarding germination parameters. The leaf leachates exhibited both stimulatory and inhibitory effects on spinach growth (shoot and root length), significantly affecting shoot height while having a non-significant impact on root length. Aqueous extracts derived from the fresh leaves, bark, and pods of *A. nilotica* were examined by Dhanai et al. (2013) for allelopatic potential effects on wheat (*Triticum aestivum*). The results regarding seed germination and shoot-root length ratio revealed that the inhibitory impact was directly related to the concentration of the aqueous extracts. Significant negative effects on seed germination and shoot-root length ratio of wheat were observed, with the inhibitory impact of the aqueous extracts intensifying as the concentration of fresh leaf, pod, and bark extracts increased from 5% to 20%.The inhibitory effect was more pronounced on shoot length compared to root length, with the pod extract demonstrating the highest inhibitory effect among the different parts of *A. nilotica*.

A laboratory trial was conducted by Bharsakle et al. (2020) to evaluate the allelopathic effects of four concentrations (20%, 15%, 10%, and 5%) of aqueous extracts of fresh *A. nilotica* leaf, along with a control (distilled water), on seed germination and shoot-root length ratio of maize, soybean, wheat, and chickpea. Their results showed that leaf leachates of *A. nilotica* significantly reduced seed germination percentage in maize, wheat, and chickpea at all concentrations, while promoting seed germination percentage in soybean at lower concentrations (only 5%). Additionally, the leachates decreased the shoot-root length ratio of maize, wheat, and chickpeas while increasing the shoot-root length ratio of soybeans.

The leaf extract and litter-sand mixture of *P. juliflora* also exhibited a significant difference compared to the control in all experiments, with the studied factors decreasing as the concentration of extracts and the amount of litter-to-sand mixture increased. This inhibitory effect aligns with previous research highlighting the allelopathic properties of *P. juliflora* on seed germination and seedling growth. Tsombou et al. (2022) investigated the effects of litter extracts from the exotic species *P. juliflora* and *P. pallida*, as well as the native *P. cineraria*, on seed germination and seedling dry weight of two weedy plants (*Amaranthus graecizans* and *Sisymbrium irio*) and the native Senecio flavus. Results revealed that untreated seeds of the three species displayed over 95% germination in the Petri dishes. Increasing concentrations of litter from both invasive *Prosopis* species hin-

Table 2. Analysis of variance for the effect of litter-to-sand ratio on germination percentage and speed, radicle and plumule length of Roman chamomile in greenhouse conditions.

Source of variations	df	Mean Square			
		Germination percentage	Germination rate	Radicle length	Plumule length
Species (S)	2	1306.37**	163.23**	23.94**	143.47**
Litter-to-Sand ratio (L)	3	1523.42**	782.311**	13.59**	121.58**
L × S	6	216.73**	441.18**	3.23**	28.34**
Error	36	9.68	0.08	0.074	0.4

**: Significant differences between treatments at 1% probability level.

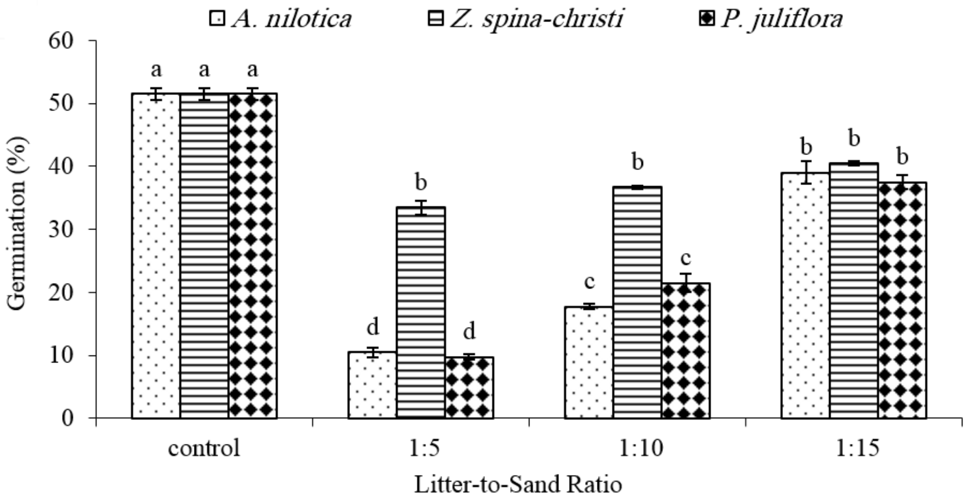

Figure 6. Effect of litter-to-sand ratio of the three studied tree species on the germination percentage of Roman chamomile under greenhouse conditions (Dissimilar lowercase letters indicate a statistically significant difference among treatments).

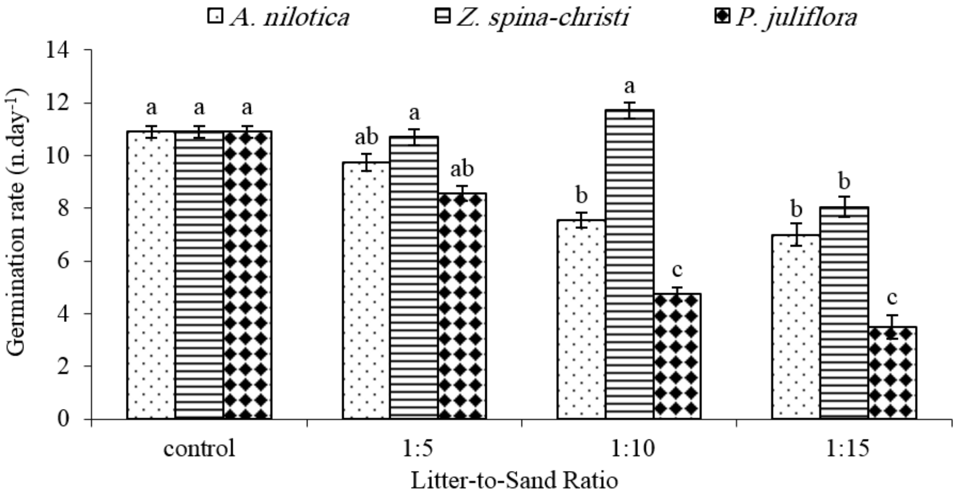

Figure 7. Effect of litter-to-sand ratio of the 3 studied tree species on the germination rate of Roman chamomile under greenhouse conditions (Dissimilar lowercase letters indicate a statistically significant difference among treatments).

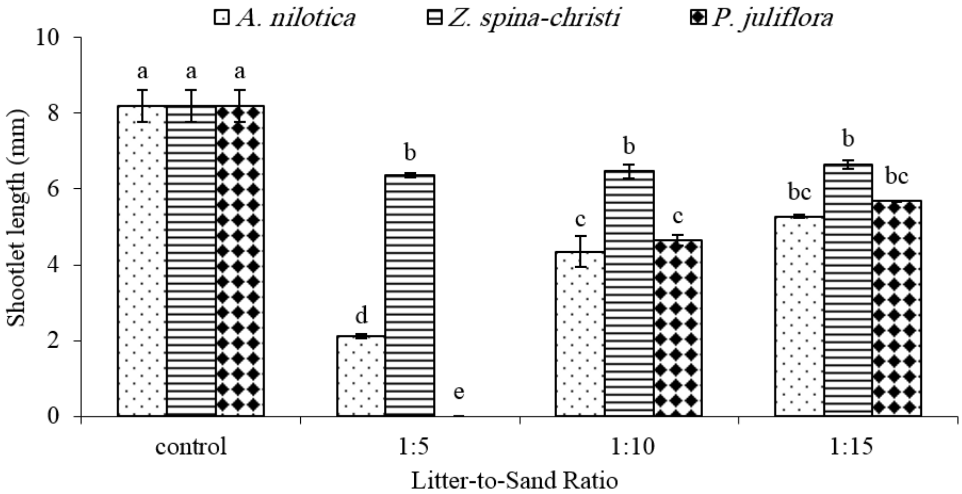

Figure 8. Effect of litter-to-sand ratio of the 3 studied tree species on plumule length of Roman chamomile under greenhouse conditions (Dissimilar lowercase letters indicate a statistically significant difference among treatments).

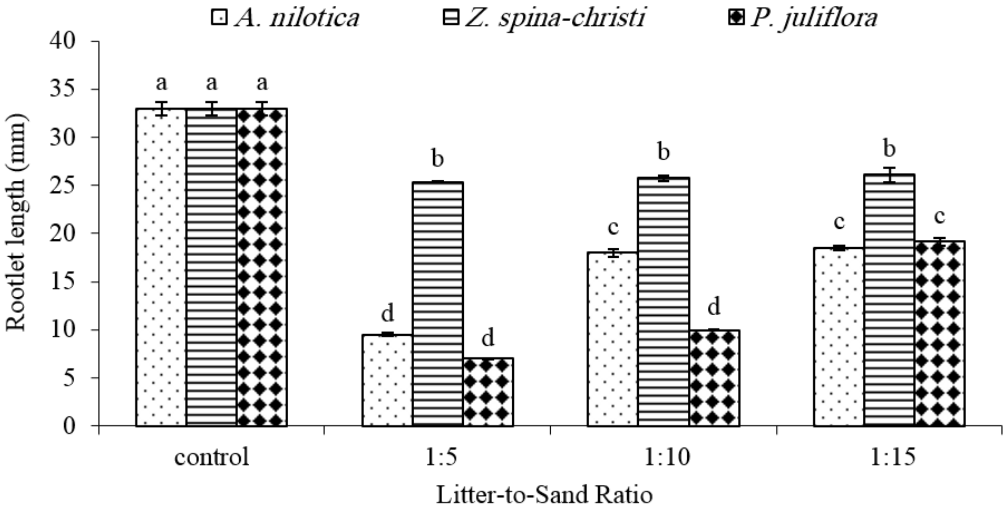

Figure 9. Effect of litter-to-sand ratio of the 3 studied tree species on radicle length of Roman chamomile under greenhouse conditions (Dissimilar lowercase letters indicate a statistically significant difference among treatments).

dered the germination of the native Senecio flavus and significantly reduced the germination percentage and seedling weight of the weedy plants of *A. graecizans* and *Sisymbrium irio*. In contrast, extracts from the native *P. cineraria* had notable inhibitory effects on seed germination and seedling growth of the native *Senecio flavus* but had limited impacts on the weedy *A. graecizans* and *Sisymbrium irio*. Their findings supported the notion of a greater impact of exotic species compared to native congeners on local plants. Al Musalami et al. (2023) investigated the allelopathic effects of *P. juliflora* on two prevalent arid plant species, *P. cineraria* and *Vachellia tortilis*. Seedlings of both species were grown in soils containing *P. juliflora* leaf and pod powders and monitored for 28 days. Their results revealed no discernible differences in growth parameters or chlorophyll content between the two species. However, *P. cineraria*

Table 3. Analysis of variance of the distance effect of the 3 tree species on the number of Roman chamomile plants in the field conditions.

Source of variations	df	MS
Species (S)	2	357.91^{**}
Distance from tree (D)	2	333.34^{**}
S × D	4	197.58^{**}
Error	81	1.43

**: Significant differences between treatments at 1% probability level.

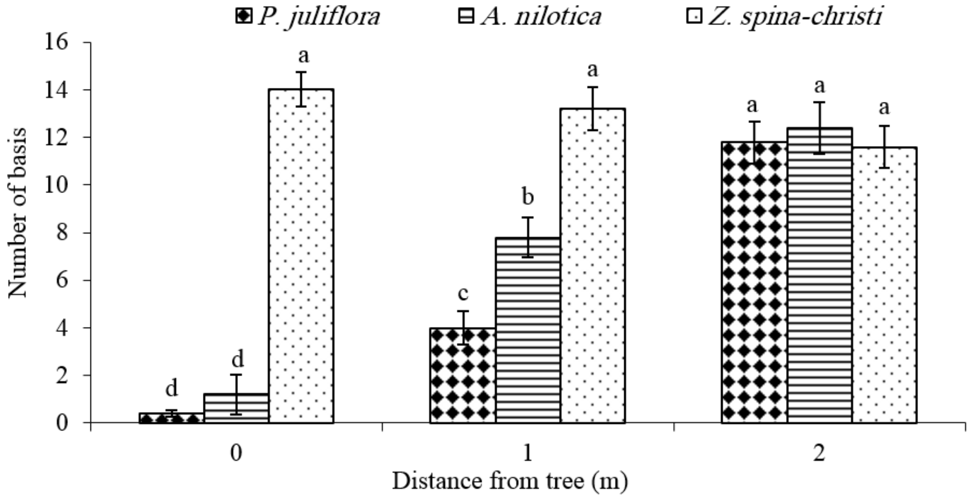

Figure 10. Interaction of distance from 3 tree species on the number of Roman chamomile (Dissimilar lowercase letters indicate a statistically significant difference among treatments).

seedlings exhibited a significant increase in proline content following exposure to *P. juliflora* powders, suggesting a stress response induced by the invasive plant. Their findings underscore the importance of measuring free proline as an ecophysiological marker in future investigations of *P. juliflora* invasion.

Brito Damasceno et al. (2020) affirmed that the allelopathic metabolites produced by *P. juliflora* are derived from two main biosynthetic pathways: shikimic acid metabolites and piperidine alkaloids. The allelopathic metabolites of this species have contributed to its status as a highly invasive species in non-native environments. This tree species has been classified as one of the world's 100 most invasive species, with a global distribution. This invasive behavior is primarily attributed to the release of leaves and allelochemicals from its roots and fruits, which inhibit the germination of seeds from neighboring species. Consequently, the presence of *P. juliflora* leads to ecosystem-level changes, resulting in the formation of monospecific stands and alterations in the chemical and physical properties of the soil. The allelopathic metabolites produced by *P. juliflora* are derived from two main biosynthetic pathways: shikimic acid metabolites and piperidine alkaloids. While some species within the genus *Prosopis* have significant negative impacts on biodiversity, ecosystem services, and local economies in their native habitats, others offer various benefits to local communities. In general, *P. juliflora* has proven to be a versatile resource with wide-ranging applications in the food, cosmetic, pharmaceutical, agricultural, and renewable energy sectors, contributing to advancements in various scientific and technological fields. However, the invasive nature of *P. juliflora* poses a significant threat to the indigenous flora of arid regions, primarily driven by allelopathy (Choudhari et al., 2018; Tsombou et al., 2022).

While some species within the genus *Prosopis* have significant negative impacts on biodiversity, ecosystem services, and local economies in their native habitats, others offer various benefits to local communities. In general, *P. juliflora* has proven to be a versatile resource with wide-ranging applications in the food, cosmetic, pharmaceutical, agricultural, and renewable energy sectors, contributing to advancements in various scientific and technological fields. However, the invasive nature of *P. juliflora* poses a significant threat to the indigenous flora of arid regions, primarily driven by allelopathy (Brito Damasceno et al., 2020; Al Musalami et al., 2023).

In this study, the leaf extract of *Z. spina-christi* had a lesser impact on the germination traits of Roman chamomile compared to the other two species. This is consistent with studies that classify *Z. spina-christi* as a species with lower allelopathic properties compared to *P. juliflora* and *A. nilotica* (Elaloui et al., 2016; Naghmouchi and Alsubeie, 2020; Hanna and Goran, 2023).

The field study corroborated the findings from the laboratory and greenhouse experiments. The density of Roman chamomile increased with greater distance from *A. nilotica* and *P. juliflora*, indicating an impact on the plant's distribution. On the other hand, *Z. spina-christi* demonstrated a different pattern, supporting its role as a supporter and nurse species that can enhance the presence of Roman chamomile in natural conditions.

Conclusion

These results were further supported by field treatments, which confirmed the inhibitory effects of the leaf extracts on Roman chamomile. The findings of this study demonstrated that leaf extracts of *P. juliflora*, *A. nilotica*, and *Z. spina-christi* have a significant inhibitory effect on the germination percentage, radicle length, and plumule length of Roman chamomile when compared to the control. Moreover, as the concentration of leaf extracts increased, there was a corresponding decrease in germination percentage, speed, radicle length, and plumule length. Among the species tested, the leaf extract of *P. juliflora* had the most pronounced impact on all measured variables. In the greenhouse experiment, it was found that the ratio of litter to sand had a significant influence on the germination and radicle length of Roman chamomile, with higher proportions of sand leading to increased values for these variables compared to leaves. The combination of *P. juliflora* leaf extract with sand exhibited the highest allelopathic effects. On the other hand, *Z. spina-christi* demonstrated a contrasting behavior, suggesting its potential role in promoting the growth of Roman chamomile in its natural habitat.

Considering the significant presence and medicinal importance of Roman chamomile in the study area, as well as the allelopathic effects of *A. nilotica* and *P. juliflora* on other plants, it is recommended to prioritize planting species like *Z. spina-christi* due to their native status and compatibility with regional soil and climate conditions. While *P. juliflora* may still have utility in harsh environments where other species struggle to establish, careful consideration should be given to mitigate its potential allelopathic effects.

Authors Contributions

The first author took the lead in preparing materials, collecting data, conducting analyses, and drafting the initial version of the manuscript. The final version was meticulously rewritten, reviewed, and endorsed by the second author.

Availability of Data and Materials

All available and required data have been incorporated in the manuscript.

Conflict of Interests

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

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