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RESEARCH PAPER

The impact of elevated temperatures and CO_2 on seed germination and early plant morphology: The case of native Fabaceae plants in the UAE

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Abstract

This study aimed to investigate the impact of elevated temperature and CO_2 on three arid UAE plants (*Prosopis cineraria*, *Senna italica*, and *Tephrosia nubica*) and ultimately to identify species that thrive well under these conditions. The plants were grown and monitored under two different environments (Greenhouse conditions, elevated CO_2 (eCO_2) with 800–1000 ppm). Seed germination percentage (G) and plant morphological characteristics like number of leaves and root/shoot ratio were observed to assess the different plant growth in each treatment. All species displayed a decrease in germination percentage with increasing temperatures, and eCO_2 did not improved the germination percentage with these elevated temperatures compared to greenhouse treatment. *P. cineraria* displayed a significant increase in all morphological characteristics with eCO_2 compared to greenhouse treatment (number of leaves: 670, shoot length: 40 cm, root length: 42 cm, shoot weight: 2 g, dry shoot weight: 0.61 g, root weight: 0.53 g, dry root weight: 0.24 g). Overall, *S. italica* and *T. nubica* displayed a significant decrease with eCO_2.

Keywords

Climate change, Elevated CO_2, Fabaceae, Plant morphology, Seed Germination

Introduction

Elevated CO_2 levels and rising temperatures have significantly transformed environmental properties, primarily impacting the agricultural sector and posing threats due to their negative consequences (Onyekachi et al. 2019). This change, categorized by enlarged levels of carbon dioxide and greenhouse gases along with unusual temperature rises (Rosenzweig et al. 2014), arises from both human activities and natural phenomena like solar radiation variations and volcanic eruptions (Riebeek 2010). Experimental methods such as enclosed chambers and freeair carbon enrichment (FACE) facilities have been used over the past four decades to amplify atmospheric CO_2 levels, with FACE providing a more realistic simulation of field environments (Ainsworth et al. 2008; Domec et al. 2017). These studies have shed light on the connections between environmental conditions, land management practices, and plant morphology and physiology, assisting in the creation of models to forecast crop yields and forest efficiency in water and temperature stressed environments (Reid et al. 2003; Tor-ngern et al. 2015).

Different plant species respond varyingly to CO_2 fertilization, with woody species presenting more prominent photosynthetic and productivity responses compared to grassland species (Nowak et al. 2004). Elevated CO_2 generally increases leaf-level photosynthesis and reduces stomatal conductance in C3 species, while its impact on C4 species is less noteworthy due to their internal CO_2 concentrating mechanisms (Palmroth et al. 2006; Medlyn et al. 2015; Domec et al. 2017). The main direct effect of elevated CO_2 on plant growth is an increase in carbohydrate availability, leading to improved plant productivity and water-use efficacy (King et al. 2001). This increased productivity is linked with greater leaf area and more effective water use, which encourage cell multiplying through cell division and development, ultimately altering plant anatomy and physiology (Poorter et al. 2012; Gimeno et al. 2016; Domec et al. 2017).

The Fabaceae family, more commonly known as legumes, contains over 19,000 species worldwide (Xu and Deng 2017), presenting varied valuable characteristics such as nitrogen-fixing abilities and economic importance as food crops (El Sabagh et al. 2020). This plant family plays a vital ecological role, extending from soil fertility improvement to providing habitat for wildlife and essential nutrients (Alam et al. 2017).

Prosopis cineraria, locally termed the “Ghaf” tree in the UAE, thrives in arid climates (Garg and Mittal 2013). Resistant with its deep roots and gentle flora, *P. cineraria* holds significance in traditional medicine, providing remedies for asthma, digestive ailments, and skin conditions (Janbaz et al. 2012), and serves in agricultural purposes for soil stabilization and renewal (Gupta et al. 1998). Furthermore, it aids as an essential source of honey due to its aromatic blossoms, further highlighting its multifaceted significance (Afifi and Alrub 2018).

Senna italica, commonly known as Italian senna, is a leguminous plant indigenous to the Mediterranean region, extensively found across the Middle East, North Africa, and parts of Asia (Olorukooba et al. 2022; Omer et al. 2022). Additionally, it holds importance in traditional medicine for treating skin ailments, fevers, and inflammations (Omer et al. 2022), while having additional purposes like natural dye production and yielding edible seeds (Olorukooba et al. 2022).

Tephrosia nubica, a leguminous shrub reaching heights of 2 meters, is known for its useful applications in agriculture, environmental conservation, and traditional medicine. Identified by its lush green and violet blooms after rainfall (Jongbloed 2003), *T. nubica* is used for treating ailments such as fever, gastrointestinal issues, and malaria in traditional medicine (Al-Yousef et al. 2020), while also contributing to soil fertility through nitrogen fixation, serving as both a cover crop and green manure (Coulot and Coulot 2022).

The aim of this study is to understand the impact of elevated temperature and CO_2 gas on the seed germination percentage, as well as the impact of elevated CO_2 on the plant morphology of early stages of the three important plant species: *Senna italica*, *Tephrosia nubica*, and *Prosopis cineraria*. Comparing the plant growth in greenhouse conditions against controlled growth chambers will give us a better understanding to the overall performance of plants with CO_2 fertilization. Moreover, subjecting the seed to different levels of temperature and supplying with eCO_2 will provide a better understanding on the potentials of CO_2 in improving seed germination under elevated temperatures.

Methodology

Seed collection and germination

All species were collected from different locations in Al-Ain City, United Arab Emirates: (United Arab Emirates University main campus (24.2006°N, 55.6760°E), Al-Ain Zoo (24.1739°N, 55.7359°E) and Local Plants Park Asharij (24.0718°N, 55.4523°E) (Debouza et al. 2024). After finalizing and applying the most appropriate seed germination pretreatment method for each plant species according to previous work (Debouza et al. 2024), 100 seeds of each species were subjected to eight different environments (GreenHouse, 40 °C, 45 °C, 50 °C, eCO_2, 40 °C + eCO_2, 45 °C + eCO_2, 50 °C + eCO_2). Germination percentage was calculated for each environment based on equations reported previously by (Al-Ansari and Ksiksi 2016).

Early plant morphology

For the young seedling assessment, 15 seeds from each species were sown in 30 cm pots with potting mix. One greenhouse experiment was carried out from the period of August to December, 2022. The greenhouse experiment was considered “control” against one experiment that was applied in growth chambers (Binder- Model KBW 720 | Growth chambers with light) in the lab. The average temperature in the greenhouse was 34.2 °C / 29.8 °C (day/night) inside the greenhouse, and CO_2 level was an average of 430 ppm. A controlled growth chamber was used to create an environment of 35 °C / 30 °C (day/night), and CO_2 level was between 800–1000 ppm. The elevated CO_2 (eCO_2) conditions were created by releasing CO_2 gas from an external tank to the growth chamber using attached pipes. The average temperatures and CO_2 were all measured by taking the average from data logger of air quality monitor (Extech CO210: Desktop Indoor Air Quality CO_2 Monitor/Datalogger). All plants from both treatments were watered as needed with distilled water.

Statistical analysis

One-way and Two-way ANOVA (factors: temperature and eCO_2) were used to compare the means of each treatment per species (GreenHouse, eCO_2, elevated temperatures, elevated temperatures and eCO_2 combined). All statistical analysis and graphs were generated using different packages available in RStudio software (Version: 2023.09.1+494.).

Results

Germination percentage: elevated temperature and CO_2

Germination percentage (G) of the three species under eight different treatments is displayed in Figure 1. All species displayed a decrease in germination percentage with

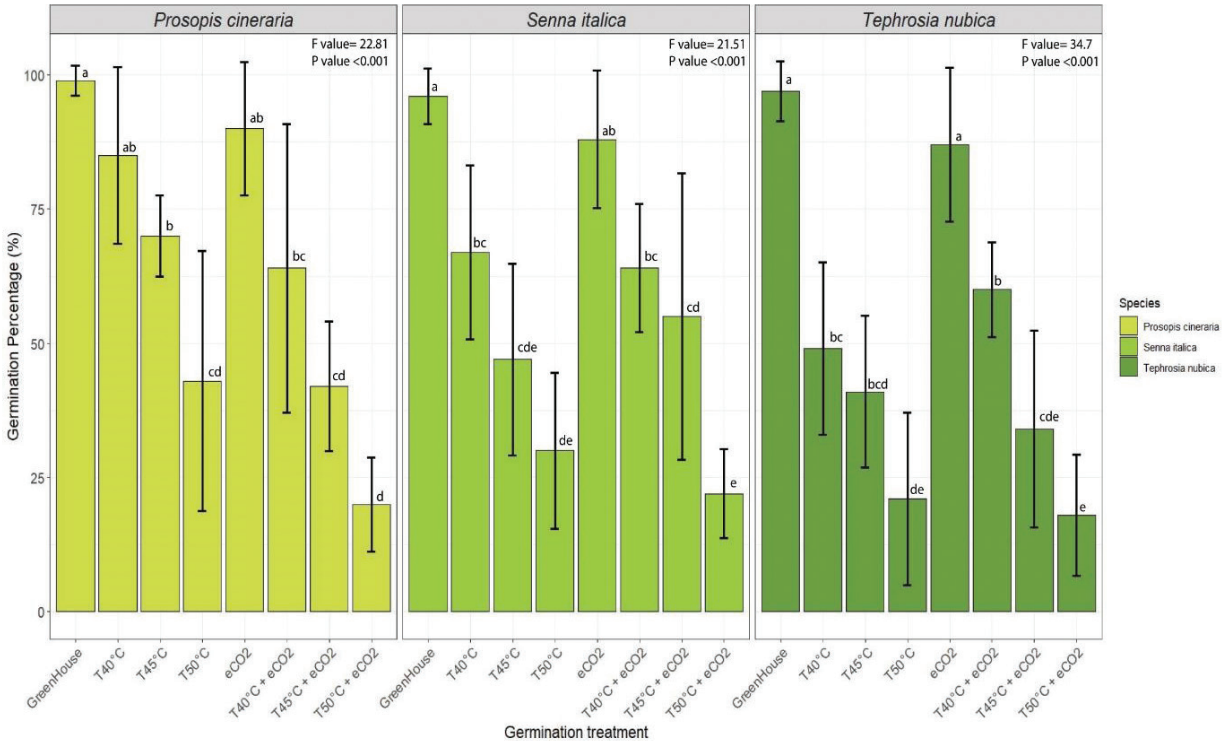

Figure 1. Germination percentage of the three different species, *Prosopis cineraria*, *Senna italica*, and *Tephrosia nubica* under eight different environments.

increasing temperatures, and eCO_2 had varying outcomes. *P. cineraria* and *S. italica* showed a significant decrease in germination percentage with the three levels of increased temperatures (40 °C, 45 °C, and 50 °C), and eCO_2 did not improved the germination percentage with elevated temperatures compared to greenhouse treatment. eCO_2 did not significantly decrease the germination percentage in *T. nubica* compared to greenhouse treatment. However, elevated CO_2 did not improve the germination percentage with elevated temperature.

Number of leaves

Figure 2 displays the number of leaves of the three species under four different conditions. In *P. cineraria*, there was a significant increase ($P < 0.001$) in the number of leaves (670 leaves) with eCO_2 compared to greenhouse plants. There was no significant difference in the number of leaves in *S. italica* plants in both treatments. *T. nubica* displayed a significant decrease in the number of leaves (138 leaves) with eCO_2 compared to control.

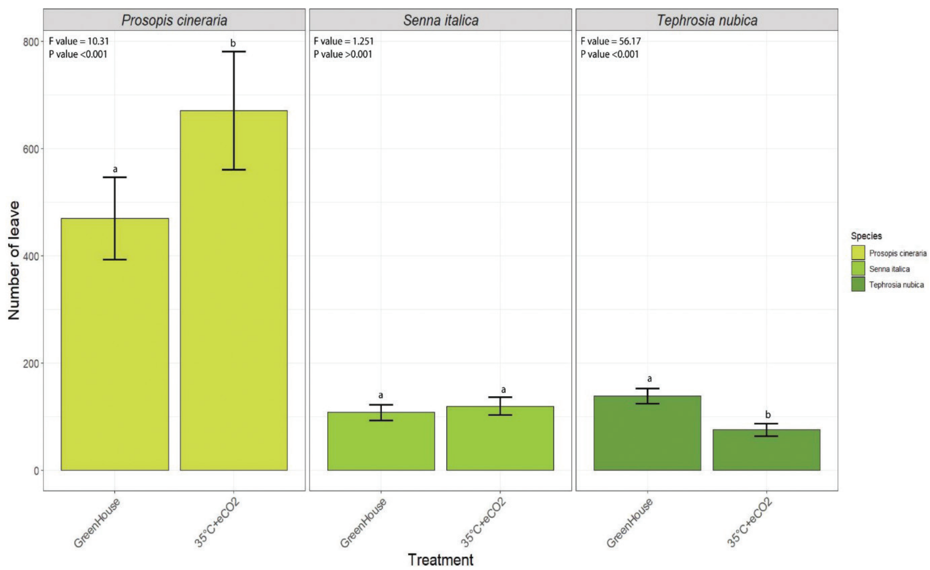

Figure 2. Number of leaves in the three different species, *Prosopis cineraria*, *Senna italica*, and *Tephrosia nubica*. The bars represent the means of 15 plants, the y-axis is the number of leaves while the x-axis represents the treatments (GreenHouse, 35C + eCO_2).

Shoot length

The three species displayed a significant change in shoot length with eCO_2 treatment (Figure 3).

P. cineraria showed a significant increase in shoot length (40 cm) with eCO_2, while *S. italica* and *T. nubica* significantly decreased (7.5 cm, 26 cm respectively) in shoot length with eCO_2 compared to greenhouse plants (Figure 9).

Root length

Similar to shoot length, all species displayed a significant change in root length (Figure 4). *S. italica* and *T. nubica* showed a decrease in root length (29 cm and 25 cm respectively) with eCO_2 compared to greenhouse treatment. *P. cineraria* displayed a significant increase (42 cm) in root length ($P < 0.001$) with CO_2 fertilization.

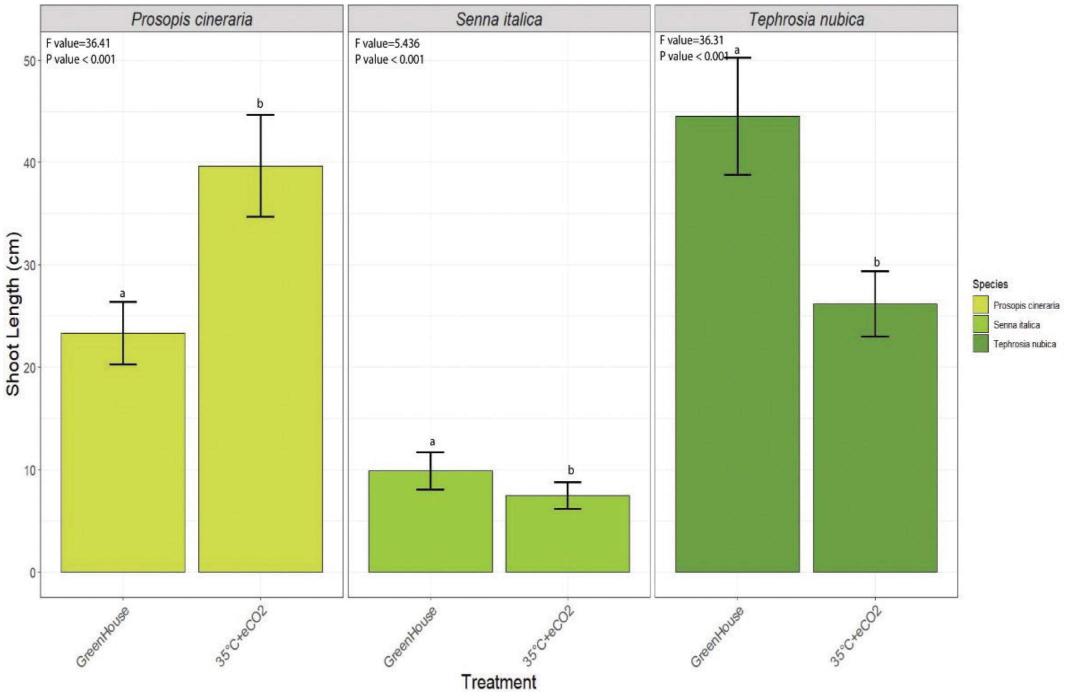

Figure 3. Shoot length in the three different species, *Prosopis cineraria*, *Senna italica*, and *Tephrosia nubica*. The bars represent the means of 15 plants, the y-axis is the shoot length while the x-axis represents the treatments (GreenHouse, 35C + eCO_2).

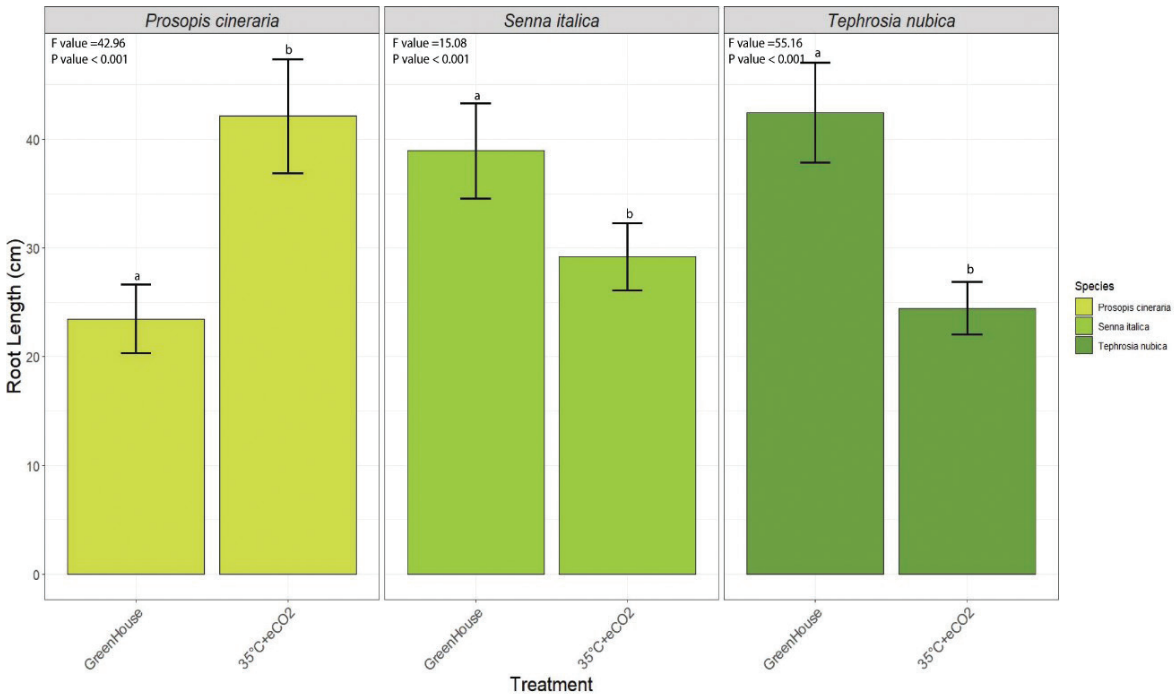

Figure 4. Root length in the three different species, *Prosopis cineraria*, *Senna italica*, and *Tephrosia nubica*. The bars represent the means of 15 plants, the y-axis is the root length while the x-axis represents the treatments (GreenHouse, 35C + eCO_2).

Shoot weight

Although there was a trend in the shoot weight of *S. italica*, there was no significant difference with CO_2 fertilization and greenhouse treatments (Figure 5). Similar to previous results, *P. cineraria* showed a significant improvement in shoot weight (2 g) with eCO_2 compared to greenhouse treatments. *T. nubica* had a significant decrease in shoot weight (2.5 g) with eCO_2 and performed better in the greenhouse condition.

Root weight

Similar to shoot weight, there was a trend in the root weight of *S. italica* but no significant difference was recorded (Figure 6). *T. nubica* significantly decreased with elevated CO_2 (0.35 g) compared to greenhouse conditions (0.68 g), while the opposite effect was recoded in *P. cineraria* which had a significant increase in root weight (0.53 g).

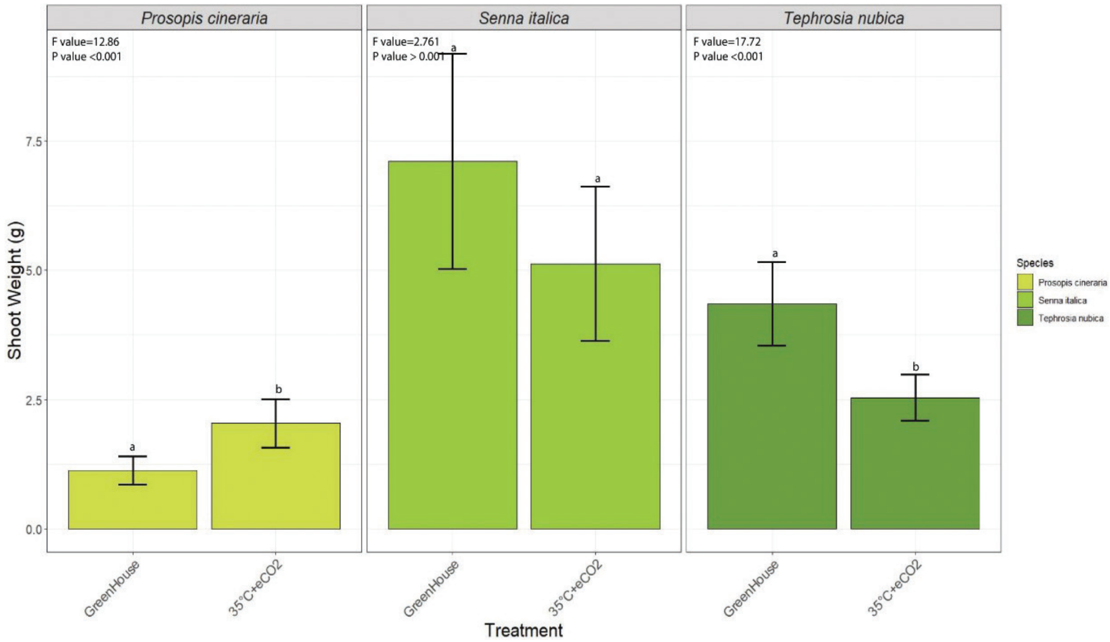

Figure 5. Shoot weight in the three different species, *Prosopis cineraria*, *Senna italica*, and *Tephrosia nubica*. The bars represent the means of 15 plants, the y-axis is the shoot weight while the x-axis represents the treatments (GreenHouse, 35C + eCO_2).

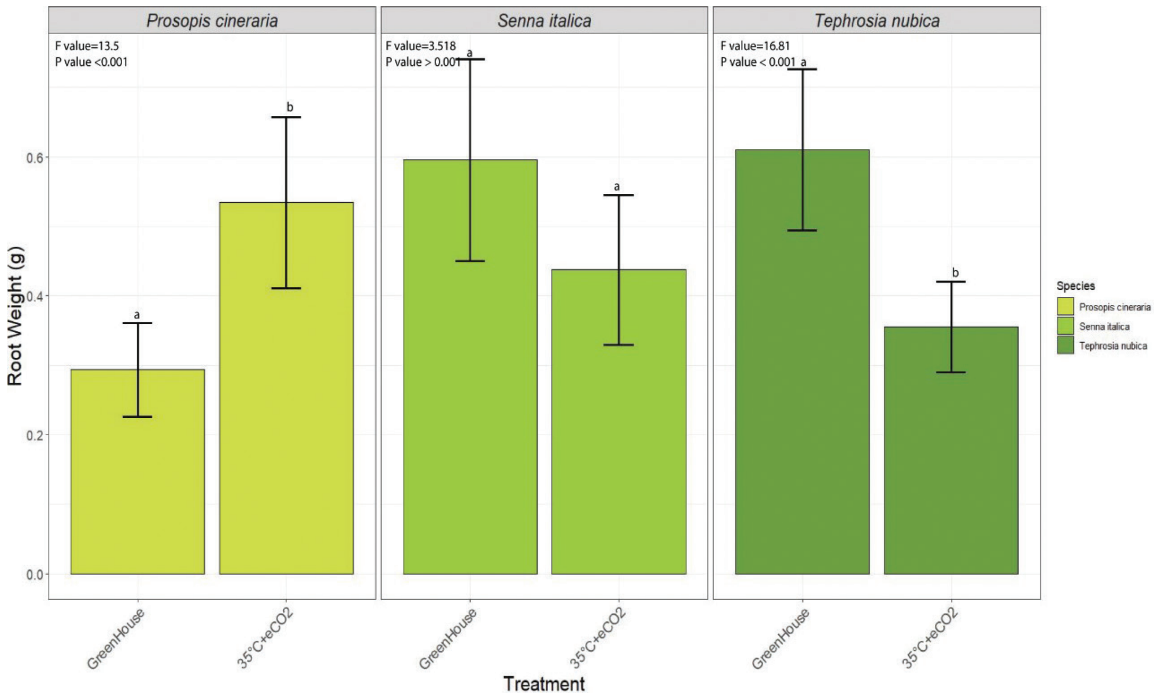

Figure 6. Root weight in the three different species, *Prosopis cineraria*, *Senna italica*, and *Tephrosia nubica*. The bars represent the means of 15 plants, the y-axis is the root weight while the x-axis represents the treatments (GreenHouse, 35C + eCO_2).

Dry shoot weight

Figure 7 displays the dry shoot weight of the plants. There was no significant change in the dry root weight of *S. italica*, although a trend can be noticed. *P. cineraria* had higher dry shoot weight (0.61 g) with eCO_2 compared to the greenhouse treatment. *T. nubica* yielded significantly lower dry shoot weights (1.5 g) with greenhouse treatment compared to eCO_2.

Dry root weight

P. cineraria yielded significantly higher dry root weight (0.24 g) with eCO_2 compared to greenhouse conditions (Figure 8). There was no significant difference in the dry root weight of *S. italica* in both treatments, while *T. nubica* had significantly lower dry root weight with eCO_2.

Discussion

The levels of greenhouse gasses, particularly CO_2 are rapidly increasing in the atmosphere (Walker et al. 2021). Plant display various responses to CO_2 fertilization, and in some cases it can display a positive effect on plant overall growth. According to our overall findings, elevated CO_2 had a significant increase in the growth of *P. cineraria* while the other two species *T. nubica* and *S. italica* yielded a significant decrease in plant overall growth. On the seed germination level, elevated temperature and CO_2 had varying outcomes.

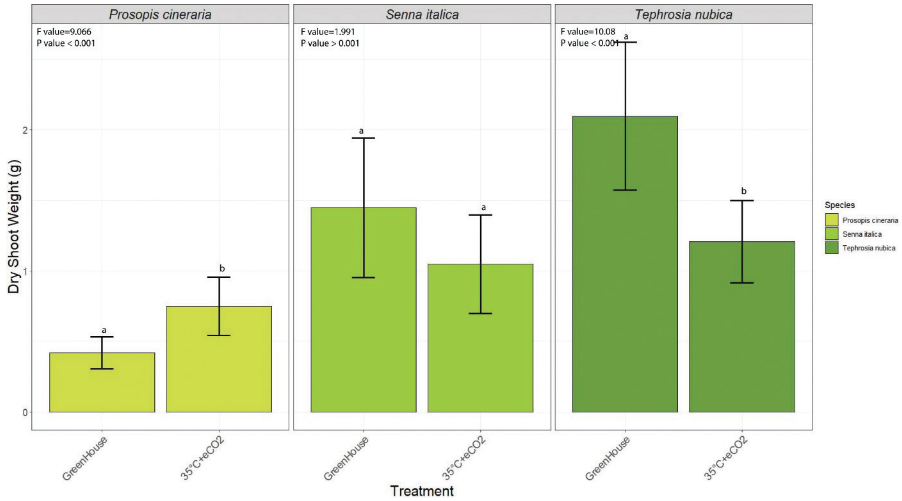

Figure 7. Dry shoot length in the three different species, *Prosopis cineraria*, *Senna italica*, and *Tephrosia nubica*. The bars represent the means of 15 plants, the y-axis is the dry shoot length while the x-axis represents the treatments (GreenHouse, 35C + eCO_2).

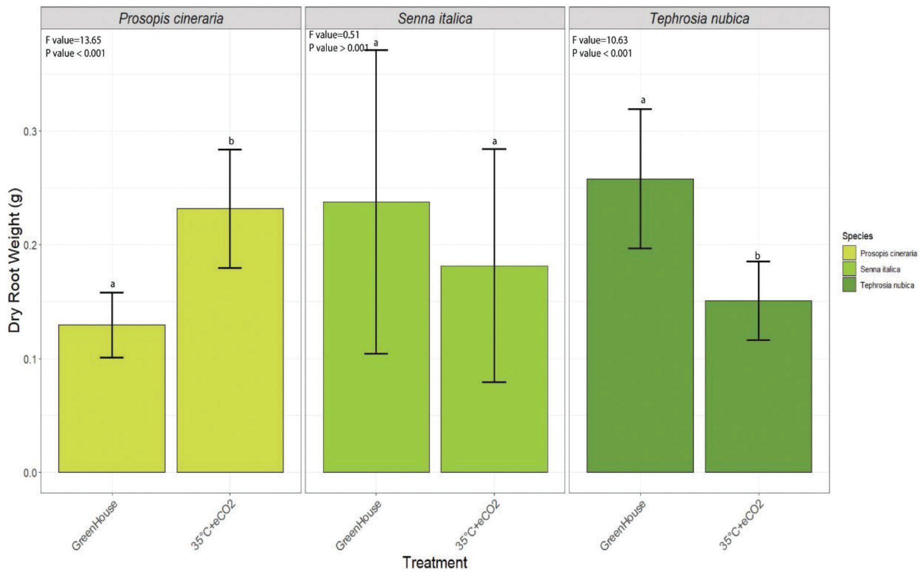

Figure 8. Dry root weight in the three different species, *Prosopis cineraria*, *Senna italica*, and *Tephrosia nubica*. The bars represent the means of 15 plants, the y-axis is the dry root weight while the x-axis represents the treatments (GreenHouse, 35C + eCO_2).

Figure 9. A. Five month old *T. nubica* plants with eCO_2 (left) and Greenhouse (right); **B.** Five month old *S. italica* plants with eCO_2 (left) and Greenhouse (right); **C.** Five month old *P. cineraria* plants with eCO_2 (left) and Greenhouse (right).

Effect of temperature and CO_2 levels on germination percentage

The results indicate a decrease in germination percentage with increasing temperatures across all species, which aligns with the general understanding of temperature's impact on seed germination. Elevated CO_2 had varying outcomes on germination percentage among species. While *P. cineraria* and *S. italica* displayed a significant decrease in germination percentage at elevated temperatures, *T. nubica* didn't show a significant decrease with eCO_2. Contrary to expectations, eCO_2 didn't improve germination percentage at elevated temperatures compared to greenhouse conditions. This suggests that the combined effect of temperature and CO_2 levels might not always benefit germination. In previous literature, similar results of decreased germination levels were reported in different species such as *Arabidopsis thaliana* and several tree species (Andalo et al. 1996; Kim and Han 2018).

Leaf number response to CO_2 enrichment

P. cineraria exhibited a significant increase in leaf number with eCO_2 compared to greenhouse conditions, signifying a positive response to elevated CO_2 levels. In contrast, *T. nubica* displayed a significant decrease in leaf number with eCO_2, suggesting species-specific responses to CO_2 enrichment. *S. italica* didn't display a significant difference in leaf number between the treatments, denoting a neutral effect of CO_2 enrichment on leaf production in this species.

Shoot and root morphological changes with eCO_2

Previous literature reported a negative effect on root morphology of plants (Hiltpold, Moore, and Johnson 2020). However, in our research, the species exhibited significant changes in shoot length and root length under eCO_2 treatment. *P. cineraria* presented an increase in both shoot and root length with eCO_2, showing a stimulatory effect on growth. *S. italica* and *T. nubica* exhibited decreases in shoot and root length with eCO_2, suggesting once again a species-specific responses and potential limitations or inhibitions in growth under elevated CO_2 levels for these species.

Shoot and root weight responses to eCO_2

P. cineraria revealed increased shoot weight with eCO_2, further supporting the positive effect of elevated CO_2 levels on growth. *T. nubica*, however, showed a decrease in shoot weight with eCO_2, indicating a conflicting response to CO_2 enrichment. Similarly, root weight responses varied among species, with *P. cineraria* showing an increase and *T. nubica* showing a decrease in root weight under eCO_2 treatment.

Dry shoot weight and dry root weight

Dry shoot weight results were consistent with the trends recorded in shoot weight, specifying that the observed changes were persistent. Dry root weight responses were less pronounced, with *S. italica* showing a trend but no significant difference between treatments, while *T. nubica* exhibited a significant decrease in dry root weight with eCO_2.

Implications and future directions

The present study highlights the complex species-specific responses of plants to elevated CO_2 levels and temperature changes. Further research is necessary to investigate the fundamental physiological mechanisms driving these responses and to assess the long-term impacts on plant growth and production. Understanding how different plant species respond to changing environmental conditions is vital for forecasting and managing ecosystem dynamics in the face of climate change. Moreover, this knowledge is particularly important to valuable native plant species and the efforts put into species conservation.

Conclusion

In conclusion, the results reveal that the combined influence of temperature and elevated CO_2 levels produces varied responses in seed germination, leaf number, shoot and root morphology, as well as biomass across different native UAE plant species. While some species show growth improvement under elevated CO_2, others experience declines in growth. These findings emphasize the complexity of plant responses to changing environmental conditions and highlight the importance of considering species-specific features when measuring the impacts of climate change on plant ecosystems. Further research clarifying the underlying physiological mechanisms driving these responses is critical for evolving operative strategies to alleviate the effects of climate change on global vegetation patterns and ecosystem dynamics, particularly desert ecosystems.

Author contributions

Experimental design was created by both authors. Nour ElHouda Debouza was responsible for conducting the experimental work, data collection and analysis, and writing the initial draft of the paper. Taoufik Ksiksi helped with editing and prof reading.

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