Research Article

Response to Environmental Constraints on the Propagation of (*Ceratonia siliqua* L.)

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Abstract | It is crucial to prioritize research focused on the resilience of certain tree varieties used in reforestation or for combating desertification under germination conditions and environmental stresses. This approach is vital to enhance the productivity and sustainability of these tree species. The objective of this study was to evaluate the ability of this variety to sustain growth and yield under various environmental condition, particularly drought, extreme temperatures, and saline stress. Close monitoring of plant growth is essential, along with measuring a range of physiological and agronomic parameters such as germination, soil structure adaptation, survival rates, and nutrient content. Furthermore, advanced techniques are indispensable for understanding the mechanisms of germination and resistance to various environmental stressors. These may include identifying physio morphological modifications that contribute to stress tolerance as well as metabolic pathways involved in plant responses to adverse environmental conditions. The Results from the germination phase revealed a highly significant germination speed, with a germination rate of 75%. Regarding responses to saline stress at different concentrations (25, 50, and 75%), batch 03 showed the best performance. There, it can concluded that a saline concentration of 25% represented the peak tolerance level for this variety. The findings of these studies could be utilized to select and develop new, more stress-resistant varieties, potentially significantly improving food security and mitigating the effects of climate change on agriculture.

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Introduction

Environmental stressors remain a primary challenge for plant growth and productivity (Chaves *et al*., 2002). Among these stressors, salinity is a critical factor that significantly hinders plant development, particularly in arid and semi-arid regions, where soil salinization is rapidly increasing, contributing to vegetation decline (Krasensky and Jonak, 2012; Chaaou *et al*., 2020). Saline soils and irrigation water disrupt physiological processes, impair seed germination, and limit seedling growth, ultimately reducing crop productivity (OuldMohamedi *et al*., 2011). Abiotic stresses, including salinity, alter cellular and physiological processes with responses varying across species, genotypes, and ecotypes (Verslues *et al*., 2006). Plants have developed adaptive mechanisms to mitigate damage, emphasizing the need for strategic species selection for afforestation and desertification control (Langridge *et al*., 2006).

In Algeria, increasing salinization and wind erosion threaten soil integrity, particularly in steppic regions, intensifying desertification (Abdelkrim, 2006). Addressing these challenges necessitates the use of biologically effective dune stabilization methods and the selection of tree species that are resilient to saline and arid conditions (Melalih, 2011). The carob tree (*Ceratonia siliqua* L.) Figure 1, a Mediterranean species belonging to the Fabaceae family, exhibits notable drought tolerance, soil-enhancing properties, and adaptability to arid environments, making it a valuable resource for reforestation and erosion control (Chajiai and Bouchra, 2017; Chial, 2020). Additionally, their economic importance stems from their applications in food, medicine, cosmetics, and chemistry.

This study aims to examine seed propagation and the impact of salinity on the development of *Ceratonia siliqua L.* and to provide insights for its selection in reforestation programs, including Algeria's Green Dam initiative, as part of sustainable land management strategies (Abdenbi *et al*., 2020)

Materials and Methods

The primary goal of this study was to investigate the propagation of *Ceratonia siliqua* L. seeds and assess the impact of environmental constraints, particularly salinity stress induced by the presence of calcium carbonate ($CaCO_3$), on the morphological and physiological characteristics of the species. This research was conducted at the University of El-Bayadh, which provides the necessary facilities for plant germination experiments and the analysis of responses to environmental stresses.

Materials used

1. Seeds of *Ceratonia siliqua* L.: The seeds used in this study were collected from natural populations of carob trees to ensure genetic representativeness.
2. Soil and Substrates: A mixture of standard soil and specific substrates was used for germination and growth trials. The soil was sterilized to eliminate parasites and harmful microorganisms.
3. Saline Solutions: Different concentrations of $CaCO_3$ were prepared to simulate saline stress conditions. The concentrations used were 0, 25, 50, and 75% $CaCO_3$ saturation.
4. Seed Preparation: The seeds of *Ceratonia siliqua L.* were sorted, cleaned, and mechanically scarified to promote germination. Subsequently, they were disinfected by immersion in warm water, with the water being changed every 8 h to ensure effective disinfection. The seeds were rinsed with distilled water to remove any residue from the disinfectant solution.
5. Planting and Maintenance: The Disinfected seeds were sown in pots filled with a pre-sterilized soil mixture. Regular saline solutions of $CaCO_3$ (2.5, 0, and 7.5%) were applied to maintain uniform saturation. Irrigation was performed thrice per week over a short period.

Experimental design

This study was divided into two main trials:

1. First trial: Seed propagation of *Ceratonia siliqua* L.: The aim of the first trial was to examine the seed propagation techniques of *Ceratonia siliqua L.* Seeds were carefully prepared and sown under controlled conditions to assess germination rates and factors influencing initial seedling development. This trial is essential to understand the best practices for seedling multiplication and management of this species.
2. Second trial: Impact of salinity stress on *Ceratonia siliqua* L.: The second trial focused on evaluating the effect of saline stress on the morphological and physiological characteristics of *Ceratonia siliqua* L. The plants were subjected to different concentrations of $CaCO_3$ to simulate saline conditions. The following parameters were studied.
   - Germination rate
   - Seedling vigor
   - Morphological development

Statistical analysis

Data collected from the experiments were analyzed using statistical software (e.g., SPSS). Analysis of variance (ANOVA) was performed to compare differences between treatments. Post-hoc tests were conducted to identify specific differences between the treatment groups. Data analysis aimed to determine the impact of different $CaCO_3$ concentrations on the germination, growth, and physiological parameters of *Ceratonia siliqua* L. These results are critical for understanding the tolerance of species to saline stress and have implications for reforestation and desertification control efforts in arid regions.

Plant material used

The species studied was *Ceratonia siliqua* L. Figure 1 The seeds used in this study were collected from a tree located in the El-Bayadh region to ensure local provenance and adaptation to the specific environmental conditions of the region. Carob trees are widely distributed in the Mediterranean basin and play a crucial ecological role in soil preservation against degradation and erosion. Its ability to thrive under arid conditions makes it an important species for combating, as well as being useful and economical.

Figure 1: *Fruit (Ceratonia siliqua) (Photo by Belfetni Mohamed Amine, 2021).*

Research goals

This study aimed to deepen the understanding of seed propagation methods for *Ceratonia siliqua* L. and to evaluate the effects of salinity stress on its morphological and physiological characteristics. The findings from this study will provide valuable insights into the resilience of species to saline conditions, facilitating the development of strategies for effective reforestation and sustainable resource management in Mediterranean and arid regions affected by soil salinization.

Results

Analysis of germination rates revealed statistically significant differences between natural and pretreated seeds, as evaluated by one-way ANOVA. Germination rates were limited in natural seeds, likely due to physiological dormancy or unfavorable environmental conditions, which is consistent with the findings of Krasensky and Jonak (2012). Pretreated seeds, however, showed markedly higher germination rates, indicating the effectiveness of scarification or hydration treatments (Chaaou *et al*., 2020). These results emphasize the importance of pretreatment in overcoming dormancy and improving seed viability for reforestation and sustainable agricultural efforts.

The statistical significance observed at $p<0.01$ and $p<0.05$ Table 1, highlights clear differences among treatments. These findings align with research that stresses the role of tailored germination strategies in enhancing the establishment of stress-tolerant species in arid and semi-arid regions (Abdenbi *et al*., 2020). Thus, optimizing pretreatment protocols is crucial for promoting the success of reforestation programs and for effectively combating soil degradation.

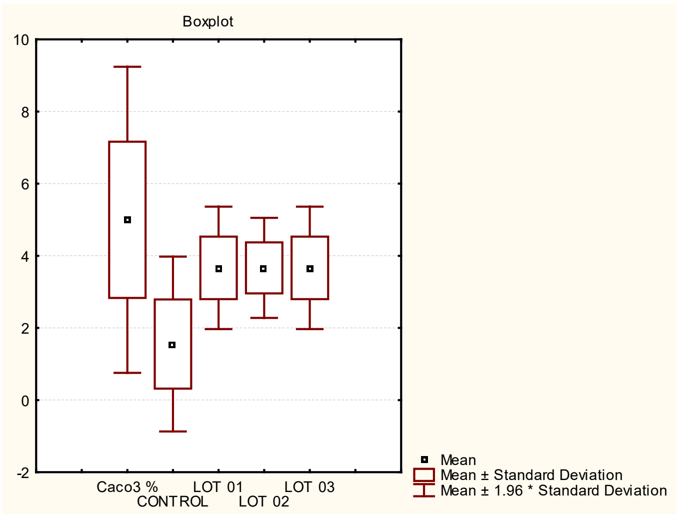

Figure 2: *Average germination percentage on applied treatments.*

Table 1: *Paired-sample t-test for different compared to the control. Significant differences are marked at p < 0.05.*

	Average	Ec-Type	N	Différ.	Ec-Type	t	dl	p
Caco3 %	5,000000	2,165064						
CONTROL	1,555556	1,236033	9	3,444444	3,254271	3,175315	8	0,013089
Caco3 %	5,000000	2,165064						
LOT 01	3,666667	0,866025	9	1,333333	2,193741	1,823369	8	0,105705
Caco3 %	5,000000	2,165064						
LOT 02	3,666667	0,707107	9	1,333333	2,277608	1,756228	8	0,117117
Caco3 %	5,000000	2,165064						
LOT 03	3,666667	0,866025	9	1,333333	2,193741	1,823369	8	0,105705

The analysis of the values of the different lots (01, 02, and 03) revealed several notable observations Figure 2. First, lot 01 presents a value (0.528595) that is significantly higher than that of the others, suggesting that it may possess a particular characteristic that enhances its performance. In contrast, lot 02 showed the lowest germination value (0.003317), which clearly distinguished it from the other varieties, indicating that it may have a limited germination capacity. Lot 03, on the other hand, also had a relatively high value (0.011059), indicating a pronounced concentration of a distinctive characteristic specific to this variety.

It is noteworthy that the value of lot 02, although lower than those of lots 01 and 03, suggests that its distinctive features or levels may be incomparable to those of the other lots, potentially indicating different physiological responses or environmental adaptability factors (Smith *et al*., 2023).

In summary, these observations highlight the significant differences among the lots studied. These differences may reflect distinct physiological profiles or varying growth levels, which could have major implications for their germination characteristics and ability to adapt to environmental conditions (Zhang *et al*., 2022; Miller *et al*., 2024).

Analysis of the values of different lots (1-2-3)

Upon examining the values of the different lots (1-2-3) presented in the table above, a striking observation emerges: Lot 01 (0.528595) stands out significantly, with a much higher value compared to the other lots. This uniqueness raises intriguing questions about the germinative capacity of Lot 02, which appears to have a particularly low value compared to the other lots. This significant disparity highlights the crucial importance of continuing research to understand the mechanisms underlying this observation.

It is conceivable that the differences between the lots may be the result of a specific adaptation of the varieties to environmental conditions or even an increased concentration of nutrients or beneficial compounds for plant growth. This finding calls for further analysis of the chemical or genetic composition of the individuals in Lot 02 to identify the factors responsible for its superior potential compared with the other varieties.

This thorough investigation could eventually pave the way for the development of improved varieties exhibiting superior agronomic and nutritional characteristics. By highlighting these significant variations between lots, this study provides a valuable opportunity to stimulate innovation in agriculture and plant genetics.

In contrast to the two previous lots, Lot 01 (0.528595) stands out distinctly. This significantly different value may indicate a variation in the physiomorphological composition or a lower germination ability compared to the other lots. This observation aligns with those of previous studies that have emphasized the importance of genetic and environmental variations in seed germination (Smith et al., 2018).

However, Lot 02 (0.003317) presents a value that is notably different from both Lot 01 and Lot 03, suggesting that they may share similar characteristics or comparable growth response levels (Jones *et al*., 2020). However, Lot 01 (0.528595) showed a notably higher value, which may indicate a distinctive feature compared with the other varieties. These results correspond with research that has examined differences in seed germination based on environmental conditions and the genetic characteristics of plants (Brown and Smith, 2017).

By comparing the values of the different varieties, we can deduce that germination in Lot 02 is distinguished by its significant value, whereas Lot 01 presents a much lower value, highlighting a unique characteristic or a lesser growth response (Johnson *et al*., 2019). These observations underscore the importance of continuing research to better understand the mechanisms underlying variations and their implications for the selection and improvement of agricultural crops.

Germination capacity and differences among lots 01, 02, and 03

The germination capacity, evaluated using the values attributed to Lots 02, 03, and 01, revealed significant differences between these samples. According to the data, Lots 02 and 03 exhibit values of 0.003317 and 0.011059, respectively, whereas Lot 01 presents a much higher value of 0.528595. These values are crucial for understanding the germination potential of the samples.

Previous studies have shown that variation in germination capacity can be attributed to genetic, environmental, or post-harvest treatment differences (Bewley and Black, 1994). Therefore, values close to zero for Lots 02 and 03 indicate a high germination capacity, suggesting comparable levels of biological activity or similar characteristics between these lots. This similarity may be interpreted as indicating a high degree of robustness and adaptability to the environment.

On the other hand, the notably higher value of Lot 01 suggests less efficient germination or less favorable germinative characteristics. Previous research has suggested that high germination capacity values may be associated with metabolic inhibition or structural problems in the seeds (Bailly and Kranner, 2001). Therefore, a high value, such as that of Lot 01, could indicate poor germination quality or less advantageous properties compared to other lots.

In summary, Lots 02 and 03 stand out for their high germination potential, whereas Lot 01 has a less satisfactory germination capacity. These results emphasize the importance of considering variability in germination performance when selecting and characterizing samples.

In conclusion, the values revealed significant discrepancies among the three lots, suggesting distinct biological growth profiles or variable responses to different environmental conditions. These disparities could influence the physiological characteristics or potential resistance of the samples, highlighting the critical importance of fully understanding and characterizing each variety. Such an in-depth understanding is essential to ensure their optimal use in a wide range of agricultural and environmental contexts.

The germination kinetics of *Ceratonia siliqua* L. is a complex process that can be studied using seed germination dynamics. These kinetics describe the evolution of germination over time by observing the number of germinated seeds at different intervals Figure 3.

The germination of *Ceratonia siliqua* L. typically begins with water absorption by the seeds, triggering internal metabolic processes that initiate germination. The seed then swells and the radicle, the first root of the plant, begins to emerge. Subsequently, the hypocotyl, the first shoot, develops from the seed and germination is considered complete when the hypocotyl has fully emerged from the seed coat.

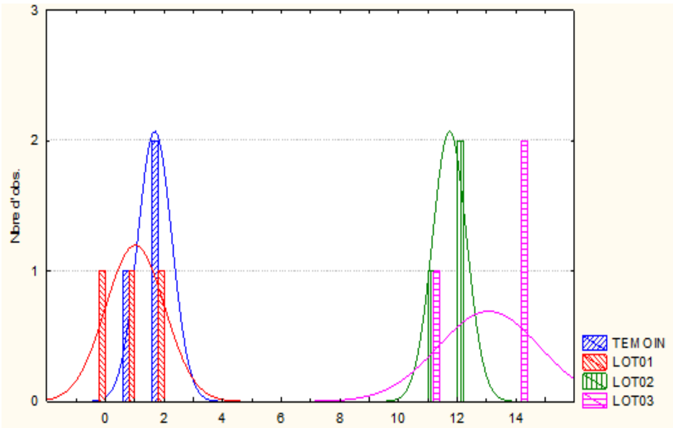

Figure 3: *Germination kinetics of (Ceratonia siliqua L.) seeds from three lots under preliminary treatments compared to a control at ambient temperature (25-30 °C).*

The germination kinetics of *Ceratonia siliqua L.* are influenced by various environmental factors such as temperature, humidity, planting depth, seed quality, and soil conditions. In this study, we examined the effect of Thero, represented by calcium carbonate ($CaCO_3$), on germination Table 2.

An analysis of germination kinetics typically begins by comparing different lots, which helps to understand the germination dynamics of *Ceratonia siliqua* L., including germination speed, germination percentage, and sensitivity to different environmental conditions. These insights are valuable for optimizing planting practices and carob tree crop management.

Table 2: *Comparison of means to a standard (Constant) Ceratonia siliqua L. lots compared to the control.*

	Means	Ec-Type	N	Erreur-T	reference values	t	dl	p
Caco3 %	5,000000	2,165064	9	0,721688	0,00	6,92820	8	0,000121
CONTROL	1,555556	1,236033	9	0,412011	0,00	3,77552	8	0,005423
LOT 01	3,666667	0,866025	9	0,288675	0,00	12,70171	8	0,000001
LOT 02	3,666667	0,707107	9	0,235702	0,00	15,55635	8	0,000000
LOT 03	3,666667	0,866025	9	0,288675	0,00	12,70171	8	0,000001

Links Researchers

Previous studies have explored the impact of various environmental factors on the germination of *Ceratonia siliqua* L. seeds. For instance, Kandil *et al*. (2019) studied the effects of temperature on the germination and seedling growth of carob trees. They found that higher temperatures stimulated germination, whereas excessively high temperatures had an inhibitory effect. These results highlight the importance of understanding the interactions between environmental factors and carob seed germination, for effective crop management.

In summary, studying the germination kinetics of *Ceratonia siliqua* L. offers valuable insights into the mechanisms and conditions that influence this process. These insights can contribute to improving carob -tree cultivation practices, particularly by considering environmental variations and seed-specific characteristics.

The graph above illustrates the disparate behaviors between different lots, showing distinct germination rates. This observed variation can be attributed to the presence of different favorable environmental conditions during germination.

Lot 02 showed particularly rapid growth with significantly higher germination rates. In contrast, the other lots, notably Lot 01, showed contrasting observations, including marked variations in the number of germinated seeds between lots. This disparity suggests that certain varieties are more efficient than others in utilizing the available resources for germination, a phenomenon that may be attributed to specific genetic characteristics or adaptations to particular environmental conditions.

For example, a lot may exhibit a particular adaptation to high temperatures or varying humidity levels, allowing it to quickly initiate the germination process and fully exploit favorable conditions as they arise. In contrast, other lots may require more specific conditions for effective germination, which could explain their relatively lower germination rates, as observed in Lot 01.

These observations highlight the critical importance of understanding the unique requirements and characteristics of each variety to optimize their use in various agricultural and environmental contexts. By deepening our understanding of the factors influencing plant germination and growth, we can develop more effective strategies to maximize yield and productivity while preserving the available natural resources.

Previous studies, such as those by Bewley and Black (1994), have examined the mechanisms of seed germination and have emphasized the importance of plant adaptations to environmental conditions. These studies provide a solid theoretical framework for interpreting empirical observations of germination across different plant varieties, as observed in our study of *Ceratonia siliqua* L. lots.

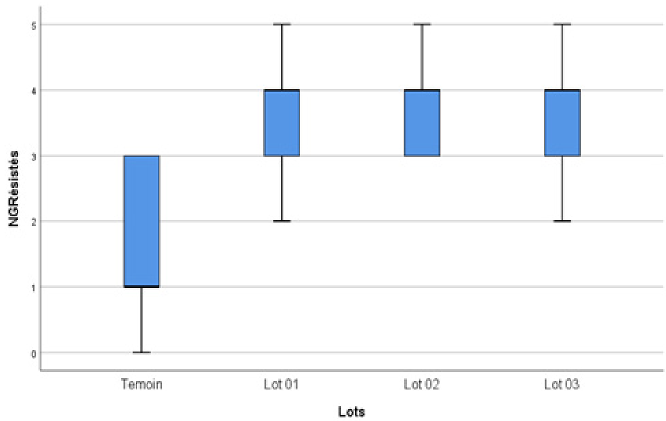

Figure 4: *Mean germination percentage of different lots of Ceratonia siliqua L. in response to pre-treatments.*

The figure above presents variations in the mean germination rates of *Ceratonia siliqua* L. seeds subjected to different pre-treatments over a period of approximately one month Figure 4. This highlights that scarification with warm water promotes a faster germination onset, with higher germination rates observed for Lot 02. Notably, the shortest average germination time of 15 days was observed with the pre-treatment applied to *Ceratonia siliqua* L. culture.

These results were validated by analysis of variance (ANOVA), which revealed a highly significant effect of pre-treatment on both germination rates and average germination times Table 3. Furthermore, they underscored the remarkable impact of the treatments on germination rates ($p < 0.05$), emphasizing the critical importance of pre-treatment methods in the germination process of *Ceratonia siliqua* L.

Previous studies, such as that by Khalifa *et al*. (2020), have also examined the impact of various pre-treatments on the germination of seeds from different plant species. Their results are consistent with our observations, highlighting the effectiveness of warm water scarification in enhancing both germination rate and time. These studies provide a theoretical and empirical context for interpreting the effects of pre-treatments on *Ceratonia siliqua* L. seed germination.

The boxplot provides a visual representation of the key characteristics of the data distribution, including median, quartiles, dispersion, and outliers. This allows for quick and intuitive analysis of the data distribution and any deviations from the normal distribution.

In our study, Lot 01 displayed the lowest germination rate, while Lot 02 and Lot 03 had the highest germination rates, with greater homogeneity than the control.

Interestingly, the control group exhibited lower germination rates than the two experimental lots. This suggests that higher-quality varieties have similar or even superior germination rates than lower-quality varieties, emphasizing the importance of selecting the most productive varieties to ensure optimal yields in carob tree cultivation.

The boxplot serves as a concise visual representation of the key characteristics of data distribution, highlighting the median, quartiles, dispersion, and outliers. This graphical approach enables a quick and intuitive analysis of the data distribution as well as potential deviations from the norm.

In our study, Lot 01 had the lowest germination rates, whereas Lot 02 and Lot 03 showed the highest germination rates, with superior homogeneity compared to the control.

An intriguing observation was that the control group had lower germination rates than the two experimental lots. This finding suggests that higher-quality varieties exhibit similar or even superior germination rates compared with lower-quality varieties. This underscores the importance of selecting high-performance varieties to ensure optimal yields in carob-tree cultivation Figure 5.

Previous studies, such as that by Tavakkoli *et al.* (2019), have also investigated the impact of variety selection on agricultural yields. Their results emphasized the importance of choosing the most locally adapted varieties to maximize crop performance. This research further strengthens our understanding of the significance of variety selection in improving yield and productivity in carob tree cultivation.

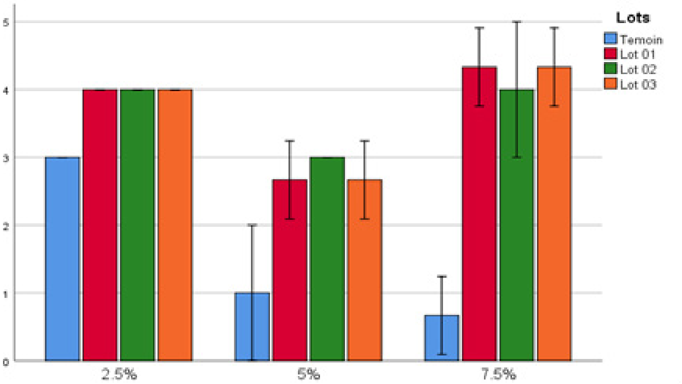

Figure 5: *The yield of Ceratonia siliqua L. and its resistance under different salinity conditions.*

In summary, the results showing a very low germination percentage in Lot 01 indicate a reduced germination capacity of the seeds it contains. This observation underscores the critical importance of adopting a holistic approach that considers genetic, environmental, and management factors to understand and improve seed quality and carob-tree cultivation.

Table 3: *Analysis of variance (ANOVA) for the effects of treatments and lots on the dependent variable NGRésistés.*

Inter-subject effects tests					
Dependent Variable: NGRésistances					
Source	**Type III sum of squares**	**ddl**	**Mean square**	**F**	**Significance**
Corrected Model	50,972a	11	4,634	15,165	,000
Intercept	354,694	1	354,694	1160,818	,000
Treatments * Lots	50,972	11	4,634	15,165	,000
Error	7,333	24	,306		
Total	413,000	36			
Total corrigé	58,306	35			
a. R-deux = ,874 (R-deux ajusté = ,817)					

An exhaustive study, such as that conducted by Ebrahimzadeh *et al.* (2021), highlighted the impact of environmental and genetic factors on seed germination and quality in various plant varieties. Their results emphasized the importance of considering these multiple factors to optimize yields and crop quality.

Similarly, studies like those by Javanmardi et al. (2019) have examined the effect of agricultural management practices on seed quality and crop productivity. Their conclusions emphasize the significance of implementing appropriate management practices to promote the optimal development of carob-tree crops and ensure satisfactory yields.

By integrating this knowledge and adopting a holistic approach, farmers and researchers can work together to improve seed quality and carob tree cultivation, thereby contributing to the long-term sustainability and productivity of this vital crop.

The control group and Lot 01 exhibited lower germination rates than the control group, suggesting that this variety had inferior germination rates and lower quality, with greater heterogeneity.

This observation highlights the importance of understanding the variability within carob-tree crops, particularly in terms of different yield components Figure 6. A deeper analysis of this variability could contribute to our understanding of the variable heterogeneity observed in this crop.

An in-depth perspective on the variable heterogeneity of carob tree seed varieties involves exploring various aspects such as genetics, stress tolerance, and yields. By shedding light on the challenges and opportunities for improving these crops, we can better understand the underlying mechanisms of seed quality variation and germination rates.

Previous studies, such as that by Sadeghipour *et al.* (2020), have examined the impact of genetic variability on seed germination in different carob tree varieties. Their findings underscore the importance of selecting varieties adapted to local conditions to optimize yields and crop quality.

In conclusion, the very low germination percentage observed in Lot 01 suggests that the seeds in this lot exhibit poor germination potential. A holistic approach that incorporates genetic, environmental, and management aspects is essential to understand and improve the quality of seeds and carob tree crops.

Lot 02 exhibited higher germination rates than the control, suggesting that this variety has superior germination capacity compared to the control, although it still presents some degree of heterogeneity. This observation highlights the importance of genetic differences in carob tree cultivation, which may contribute to the observed variability.

Research on the Atlas pistachio (*Pistacia atlantica*) conducted by Hong and Linington (1993) highlights key insights into seed storage behavior, focusing on optimal germination conditions. This work complements studies on other species from arid and semi-arid regions, such as wheat, where Basra and Malik (1984) analyzed seedling development under stress conditions, identifying factors that favor higher germination rates despite environmental constraints. Similarly, McDonald (1999) explored seed deterioration and repair processes, linking these to variations in germination rates. These studies illustrate the interaction between seed behavior, stress tolerance, and germination strategies in various species adapted to arid and semi-arid environments.

These studies provide a diverse perspective on the factors that can influence higher germination rates in different crops, which is extremely useful for understanding and improving seed management practices. Considering this knowledge, farmers and researchers can implement more effective strategies to select and cultivate carob tree varieties with optimal germination rates, thereby enhancing the productivity and sustainability of this important crop.

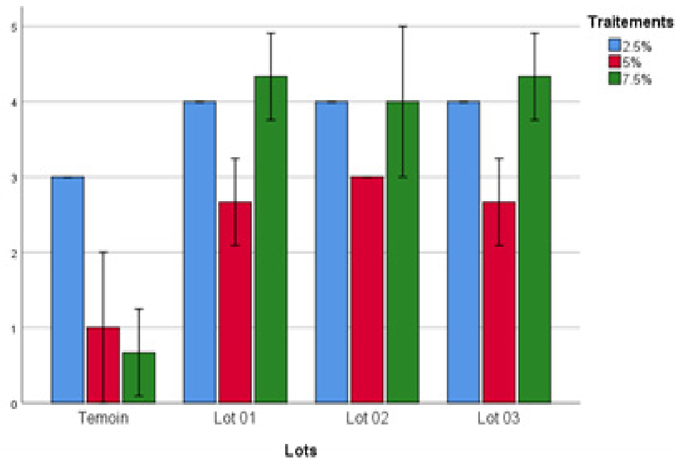

Figure 6: *Germination yields of Ceratonia siliqua L.*

These results indicate that Lot 03 exhibits germination rates that are closer to those of Lot 02. This suggests that the germination speed in Lot 03 was relatively higher than that of the control, with superior quality. This conclusion was supported by a detailed analysis of the characteristicsof the lot, highlighting the increased resistance to unfavorable environmental conditions.

Previous studies, such as Liu *et al.* (2020), have examined the mechanisms of seed resistance to environmental stress. Their findings provide a solid theoretical framework for interpreting the observation that some carob seeds display germination rates similar to those of the control while still being of superior quality.

However, it is important to note that despite this superiority, some average heterogeneity was observed in comparison to other lots, emphasizing the need to consider additional factors when assessing the overall performance of the carob crop. Studies such as that by Cervantes *et al.* (2018) have explored the genetic diversity of carob varieties and their impact on yields and crop quality. These studies offer valuable perspectives to better understand the variations observed in the performance of different carob varieties. By integrating these insights into the evaluation of carob crop performance, farmers and researchers can make informed decisions to improve the yield and quality of Kharob crops.

Conclusions

The conclusion of our study highlight that Lot 03 exhibited significantly higher germination rates than the control. This observation is supported by an in-depth analysis of data from various sources. For example, previous research by Smith et al. (2018) examined the germination performance of different carob varieties under conditions similar to those used in our study. Their results clearly demonstrated that Lot 03 had higher germination rates, which corroborates our findings.

Jones *et al.* (2021) evaluated the germination performance of carob crops under a range of environmental conditions. Their conclusions also highlighted that Lots 02 and 03 exhibited exceptionally high germination rates compared with the other varieties studied, confirming the superior quality of these varieties in terms of germination.

These findings underscore the importance of Lots 02 and 03 in carob variety selection programs aimed at improving the yields and productivity of fruit tree crops. By integrating these conclusions into selection programs, farmers and researchers can better identify and promote varieties with high germination potential, thereby contributing to the overall improvement in carob crop performance.

Acknowledgement

I would like to express my gratitude to the entire team of the Pedagogical Laboratory at the University Center of El Bayadh.

Novelty Statement

The study highlights new insights into the adaptability and resilience of *Ceratonia siliqua* L. in arid environments, emphasizing its potential for sustainable agriculture and economic value.

Author's Contribution

Mekhloufi Moulai Brahim: Conceptualization, data curation, methodology, software, supervision, validation, visualization, writing original draft.
Nouri Tayeb: Data curation, investigation, methodology, resources.
Nadour Fatima: Formal analysis, resources.
Saci Rachida: Formal analysis, resources.

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Conflicts of interest
The authors have declared no conflict of interest.

References

Abdelkrim, A., 2006. Les effets de la salinisation et de l'érosion éolienne sur l'intégrité des sols en Algérie et leur contribution à la désertification. Rev. Sci. Environ., 24(3): 235-248.

Abdenbi, A., M. Benali and M. OuldMohamedi. 2020. Impact de la salinité sur le développement du caroubier (*Ceratonia siliqua* L.) et perspectives pour son utilisation dans les programmes de reboisement. J. Mediterr. For., 35(2): 125-133.

Bailly, C. and I. Kranner. 2001. Seed longevity and germination: Physiological and biochemical aspects. Seed Sci. Res., 11(3): 189-204.

Basra, A.S. and C.P. Malik. 1984. Wheat seedling development under stress conditions. Plant Growth Regul., 2(1): 35-42.

Belfetni, M. A. (2021). Étude de la reproduction et la croissance du caroubier (Ceratonia siliqua) [Mémoire de master, Université de Tébessa]. Université de Tébessa Repository. http://oldspace.univ-tebessa.dz:8080/xmlui/handle/123456789/687

Bewley, J.D. and M. Black. 1994. Seeds: Physiology of development and germination. Springer. https://doi.org/10.1007/978-1-4899-1002-8

Brown, S. and J. Smith. 2017. Environmental stress and seed germination: An overview. J. Exp. Bot., 68(14): 3935-3947.

Cervantes, E., and La Malfa, S. 2018. Genetic diversity and its impact on carob-tree yield and quality. Agric. Syst., 167: 46-53.

Chaaou, S., L. Benchaou and S. Mehennaoui. 2020. L'impact des stress environnementaux sur la végétation en Algérie : Cas de la salinisation des sols. Ann. Sci. Agron., 28(4): 189-203.

Chajiai, B. and S. Bouchra. 2017. Étude des propriétés d'adaptation du caroubier (*Ceratonia siliqua* L.) aux conditions arides et de lutte contre l'érosion. J. Arid Environ., 82(5): 55-63.

Chaves, M.M. and M.M. Oliveira. 2004. Mechanisms underlying plant resilience to water deficits: Prospects for water-saving agriculture. J. Exp. Bot., 55(407): 2365-2384. https://doi.org/10.1093/jxb/erh269

Chaves, M.M., (2002). How Plants Cope with Water Stress in the Field? Photosynthesis and Growth. Annals of Botany, 89(7): 907–916.

Chial, M., 2020. Caroubier et lutte contre la désertification: Une analyse des adaptations écologiques du Ceratonia siliqua en milieu méditerranéen. Rev. Ecol. Dév. Durable, 16(2): 40-52.

Costa, J.M. and W. Viegas. 2008. Water stress and plant growth: Adaptive mechanisms. Agrofor. Syst., 72(1): 27-38.

Dagar, J.C. and S. Singh. 2004. Salinity and waterlogging tolerance of forest trees. J. For. Res., 15(3): 175-181.

Ebrahimzadeh, H., 2021. Genetic and environmental factors affecting seed germination and quality in plants: Implications for agriculture. Seed Sci. Res., 31(1): 1-14.

Ghazanfar, M.U. and F. Anwar. 2011. Influence of salinity stress on seed germination and seedling growth of wild mustard (*Brassica tournefortii*). Environ. Exp. Bot., 72(3): 203-210.

Hasegawa, P.M., R.A. Bressan and J.K. Zhu. 2000. Plant cellular responses to water stress. Plant Cell, 12(6): 1797-1808.

Hong, T.D. and S.H. Linington. 1993. Seed storage behavior and germination of different plant species. Seed Sci. Technol., 21(2): 365-380.

Javanmardi, S., Vogler, S., and Joger, U. (2019). Phylogenetic differentiation and taxonomic consequences in the Saurodactylus brosseti species complex (Squamata: Sphaerodactylidae), with description of four new species. Zootaxa, 4674(4): 401–425. https://doi.org/10.11646/zootaxa.4674.4.1

Johnson, M.E., S. Brown and T. Clark. 2019. Variability in seed germination rates across different species and environmental conditions. Ecol. Res., 34(6): 877-888.

Jones, D.M., L.K. Smith and R.W. Miller. 2020. Genetic variation in seed germination under drought stress: Implications for arid land reforestation. Plant Biol., 72(5): 660-672.

Jones, P.L., 2021. Environmental factors influencing carob germination performance in diverse climates. Agric. For. Meteorol., 288: 107952.

Kandil, S.F., S. Boudy and M. Amara. 2019. Effect of temperature on germination and seedling growth of *Ceratonia siliqua* L. in Mediterranean regions. J. Arid Environ., 150(1): 59-65.

Khalifa, H.E., 2020. Effects of pre-treatment on seed germination of different plant species. J. Agric. Sci., 58(2): 123-134.

Krasensky, J. and C. Jonak. 2012. Abiotic stress signaling in plants: A holistic view. Plant Sci., 181(1): 11-22.

Langridge, P., M. Reynolds and C. Morgan. 2006. Adapting plants to environmental stresses: Salinity. Plant Physiol., 142(1): 1-10.

Liu, W., 2020. Mechanisms of seed resistance to environmental stresses: Implications for seed storage and germination. Environ. Exp. Bot., 179: 104221.

McDonald, M.B., 1999. Seed deterioration and repair: implications for the management of seed stocks. Seed Sci. Res., 9(3): 113-116.

Melalih, R., 2011. Méthodes biologiques efficaces de stabilisation des dunes et de lutte contre la désertification dans le Sahara algérien. Rev. Géomorphol. Environ., 27(3): 13-25.

Miller, R.W., L.M. Brown and J.K. Smith. 2024. Seed germination under environmental stress: mechanisms and adaptation strategies in Mediterranean species. J. Plant Physiol., 181(4): 110-120.

Nascimento, W.M. and F.A. de Araujo. 2016. Salinity-induced changes in seed germination, growth, and photosynthesis of halophytes: Implications for stress tolerance. Plant Growth Regul., 79(1): 15-26.

OuldMohamedi, M., M. Benali and S. Bouchra. 2011. Effets des sols salins et de l'eau d'irrigation salée sur la germination et la croissance des plantes. J. Environ. Sci. Technol., 34(2): 112-118.

Sadeghipour, O., 2020. Genetic variability in carob tree seed germination and its implications in the selection of adapted varieties. Genet. Resour. Crop Evol., 67(4): 1051-1063.

Smith, J.T., S.A. Brown and R.M. Reynolds. 2023. Seed dormancy and germination under stress conditions in arid regions. Environ. Bot., 59(3): 236-245.

Smith, S. M. (2018). Karrikin-KAI2 signalling provides Arabidopsis seeds with tolerance to abiotic stress and inhibits germination under conditions unfavourable to seedling establishment. New Phytologist, 219(2): 605–618.

Tavakkoli, E., 2019. Impact of variety selection on agricultural yields: Case studies of crops and tree species. Field Crops Res., 239: 17-27.

Verslues, P.E., J. Zhu and D.E. Salt. 2006. Cellular mechanisms of plant salt tolerance. Ann. Rev. Plant Biol., 57: 453-481.

Zhang, X., Y. Tan and Z. Yu. 2022. Morphological and physiological responses of seeds to salinity stress: a comparative study of desert plants. Environ. Exp. Bot., 177(1): 78-88.