Combines Effects of Drought and Heat Stress on Germination and Early Seedling Growth of Selected Brassicaceae Species

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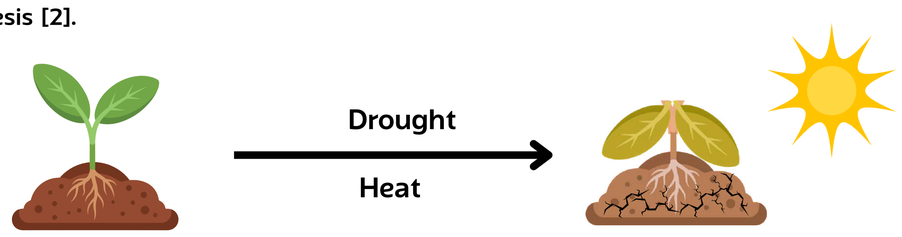
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Abstract

Drought and heat stress often occur together under climate change and negatively affect seed germination and early seedling growth in Brassicaceae. This study examined the effects of PEG-induced drought and high temperature (35 ± 2 °C), both individually and combined. Both stresses significantly reduced germination and seedling growth, with combined stress causing stronger inhibition. Species showed different responses: Pak choy (P1) had the highest tolerance, Chinese radish (P4), Chinese mustard (P5), and Kale queen (P6) showed moderate tolerance, while Red cabbage (P8) and Watercress (P9) were highly sensitive. The results highlight the importance of selecting stress-tolerant species under future climate conditions.

Introduction and objectives

Brassicaceae vegetables are globally important crops with high economic value. However, rising temperatures and increasing drought events threaten their productivity, particularly during early developmental stages [1]. Heat stress elevates leaf temperature, disrupts cellular processes, and induces oxidative damage, while drought reduces water availability, causing stomatal closure and limiting photosynthesis [2].



When these stresses occur simultaneously, their effects intensify, leading to severe physiological damage, reduced germination, impaired seedling growth, and ultimately plant mortality. Despite this growing climate challenge, information on early-stage responses of different Brassicaceae species to combined heat and drought stress remains limited. Therefore, this study evaluates the effects of heat, drought, and their interaction on seed germination and early seedling growth in nine Brassicaceae species to identify stress-tolerant genotypes for climate-resilient cultivation. The objectives of this study is to evaluate how drought, heat, and combined stress affect the germination of 9 specific Brassica species and to identify which Brassica are tolerant and sensitive to drought and heat stress.

Methodology

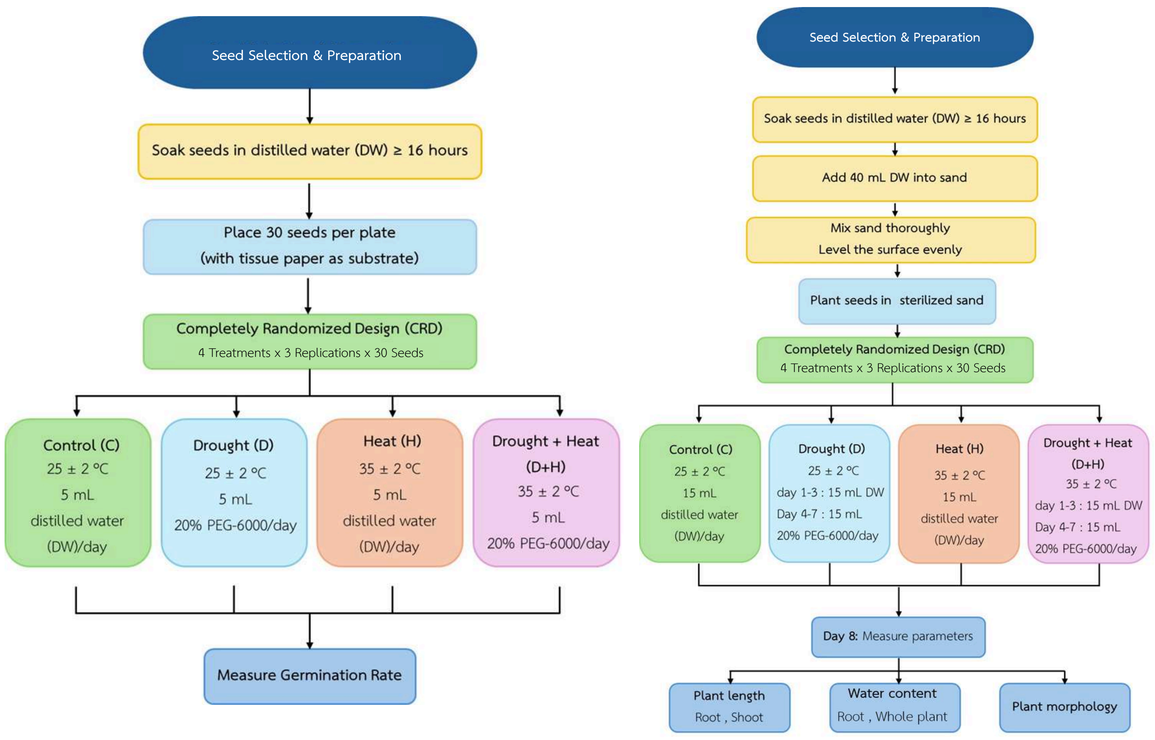


Table 1 Nine species of Brassicaceae vegetables were used in this experiment.

Species number	Common name	Scientific name
P1	Pak choy	*Brassica rapa* L. "Green pak choy"
P2	Edible rape	*Brassica rapa* L. "Edible rape"
P3	Kale	*Brassica oleracea* L. "Chinese kale"
P4	Chinese radish	*Raphanus raphanistrum* subsp. *sativus* (L.) Schmalh.
P5	Chinese mustard	*Brassica juncea (L.)* Czern. & Coss.
P6	Kale queen	*Brassica oleracea* L. "Kale queen"
P7	Broccoli	*Brassica oleracea* L. "Big green"
P8	Red cabbage	*Brassica oleracea* L. "Red cabbage"
P9	Watercress	*Nasturtium officinale* W.T. Aiton

Acknowledgements

The author would like to express sincere gratitude to Lecturer Dr. Sitthisak Intarasit for his invaluable guidance and support. This research was supported by Fundamental Fund 68 and 69. Appreciation is also extended to the Postharvest Physiology and Technology Laboratory, Department of Biology, Chiang Mai University.

Results and discussion

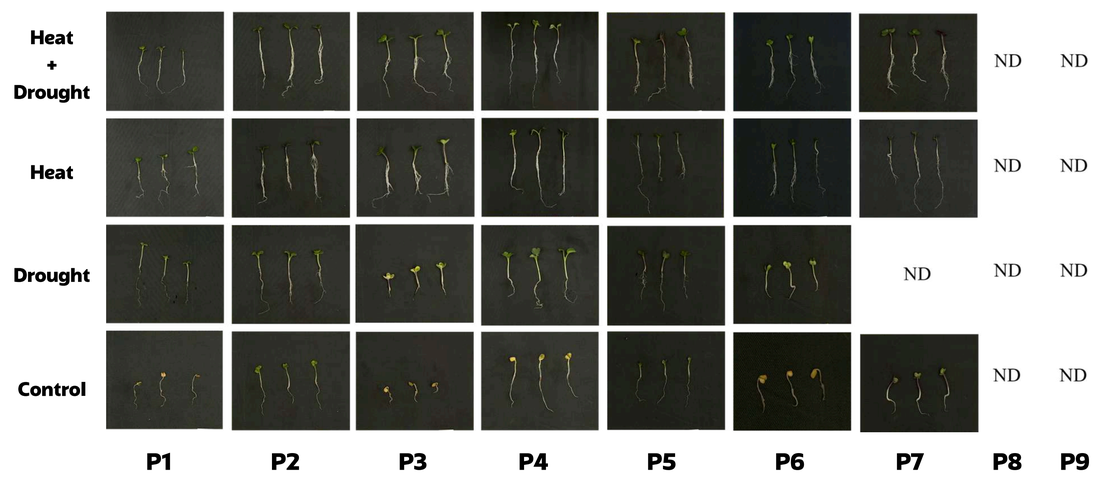


Figure 1 Morphology of Brassicaceae seedlings under different condition

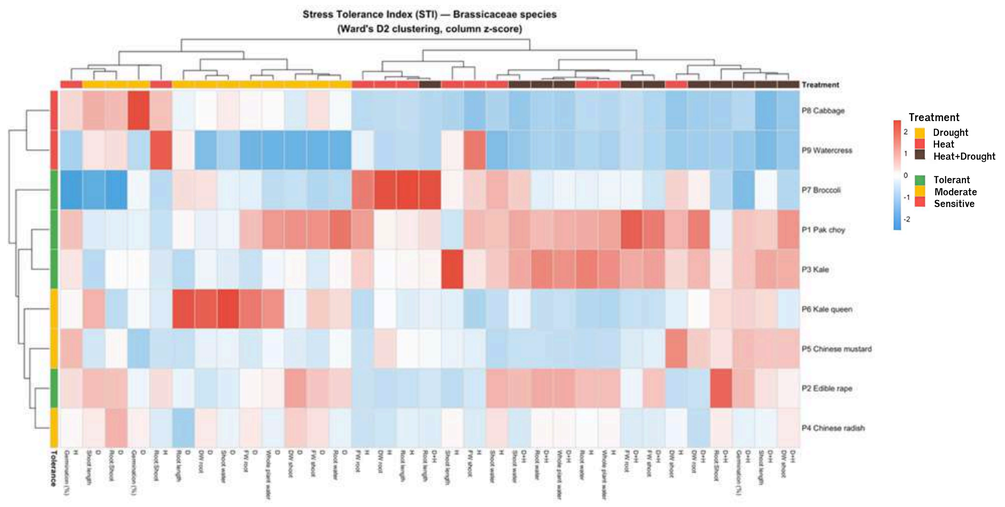
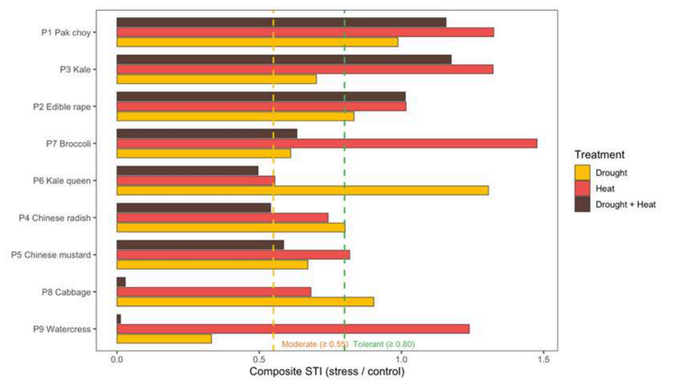


Figure 2 Hierarchical clustering heatmap of stress tolerance index (STI)



Species	Species	Overall STI	Overall class
P1	Pak choy	1.156	Tolerant
P3	Kale	1.066	Tolerant
P2	Edible rape	0.955	Tolerant
P7	Brocoli	0.907	Tolerant
P6	Kale queen	0.786	Moderate
P4	Chinese radish	0.695	Moderate
P5	Chinese mustard	0.692	Moderate
P8	Cabbage	0.538	Sensitive
P9	Watercress	0.528	Sensitive

Figure 3 Composite stress tolerance index (STI) and classification of tolerant to stress of Brassicaceae species

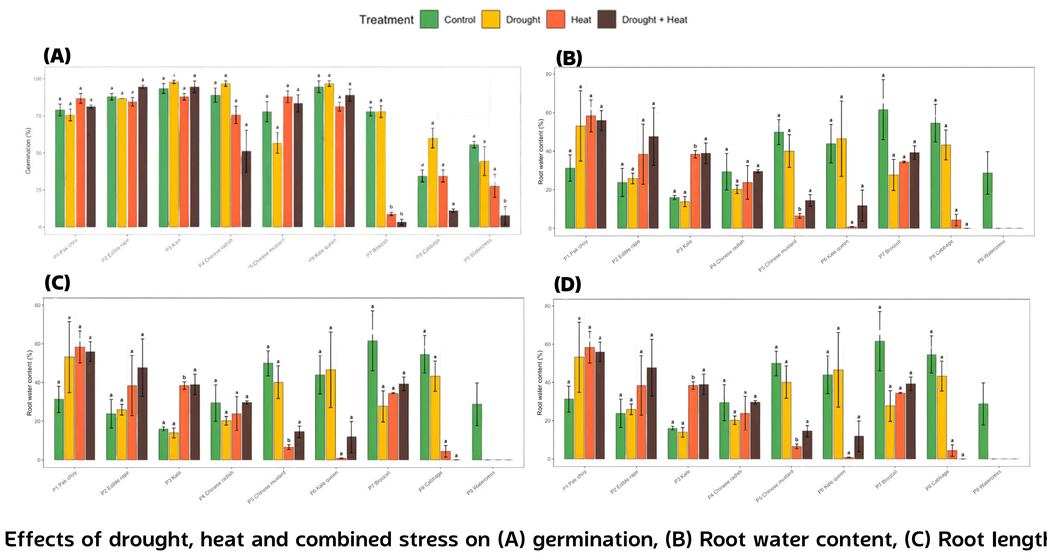


Figure 4 Effects of drought, heat and combined stress on (A) germination, (B) Root water content, (C) Root length and (D) whole root water content of Brassicaceae. Each value represents the mean ± standard error of the mean (SEM).

Combined drought and heat stress significantly inhibited germination, seedling growth, and biomass accumulation in Brassicaceae species (Figures 1 and 4), with the strongest negative effects observed under simultaneous stress conditions. Species responses were highly variable, indicating clear differences in stress tolerance. Pak choy and kale maintained relatively stable germination, growth, and higher composite Stress Tolerance Index (STI) values (Figures 2-3), suggesting greater physiological plasticity and the ability to maintain metabolic stability under stress. In contrast, watercress and red cabbage showed severe reductions in germination and growth, indicating high sensitivity to environmental stress (Figures 2-3). These differences are likely associated with physiological mechanisms such as osmotic adjustment, antioxidant defense capacity, and regulation of water balance [3]. Overall, the results demonstrate that tolerance to combined abiotic stress during early seedling development is strongly species-specific and highlight the importance of evaluating plant responses under multiple simultaneous stresses when screening crops for climate resilience.

Conclusion

Combined heat and drought stress caused the greatest reduction in early growth among the nine Brassica species. Based on composite STI and clustering analysis, the species were clearly classified into three groups, with pak choy most tolerant while red cabbage and watercress most sensitive.

References

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