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Enhancing germination performance and vigor of lettuce and napa cabbage seeds through simple seed priming techniques under controlled conditions

ROFIQOH PURNAMA RIA♥, FITRA FADHILAH RIZAR, DEDIK BUDAINTA, MARLIN SEFRILA, FITRA GUSTIAR
College of Agriculture, Universitas Sriwijaya. Jl. Raya Palembang-Prabumulih Km. 32, Indralaya, Ogan Ilir 30662, South Sumatra, Indonesia.
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Abstract. *Ria RP, Rizar FF, Budainta D, Sefrila M, Gustiar F. 2026. Enhancing germination performance and vigor of lettuce and napa cabbage seeds through simple seed priming techniques under controlled conditions. Asian J Agric 10: g100175. https://doi.org/10.13057/asianjagric/g100175.* Introduced leafy vegetable seeds marketed for urban farming are often subjected to prolonged storage and suboptimal handling before use, which may reduce seed vigor, delay germination, and lead to non-uniform seedling emergence. This study evaluated simple seed priming treatments to improve germination performance in four commercial leafy vegetable seed types: butterhead lettuce, red romaine lettuce, green lettuce, and napa cabbage. The experiment was conducted in September 2025 at the Seed Technology Laboratory, Universitas Sriwijaya, Indonesia, using a factorial completely randomized design. Seeds were subjected to four treatments: untreated control, warm water priming at 60°C for 15 minutes, 60% shallot extract for 30 minutes, and 70% coconut water for 30 minutes. Germination percentage was recorded every 6 hours (h) for 48 h, and physiological parameters, including T50, Mean Germination Time, Germination Index, Vigor Index, Relative Germination Index (RGI), and shoot emergence percentage, were calculated. Warm water reduced T50 to 18.48 h and shallot extract to 19.38 h, compared with 36.69 h in the control, indicating faster germination. These findings indicate that warm water and shallot extract are promising simple priming methods for improving the laboratory germination performance of commercial leafy vegetable seeds, although validation under nursery or field conditions is still needed.

Keywords: Germination, olericulture, seed priming, vigor

INTRODUCTION

Urban agriculture has developed rapidly in response to increasing public awareness of healthy diets, food safety, and environmentally friendly production systems (Cano-Verdugo et al. 2024). Urban farming is viewed as a practical approach to producing fresh vegetables, improving household nutrition, and strengthening local food resilience. Its close relationship with organic cultivation principles enhances its relevance, because many urban growers prefer simple, low-input, and non-synthetic production methods that are safer for household consumption and more compatible with ecological sustainability (Bhattarai and Adhikari 2023). One of the main strengths of urban farming lies in its flexibility to cultivate fast-growing vegetable crops in containers, polybags, rooftops, and other space-efficient planting arrangements. Commercial leafy vegetables such as butterhead lettuce, red romaine lettuce, green lettuce, and napa cabbage are widely used in urban farming because they have short production cycles, simple management requirements, and high household demand (Kartika et al. 2021b; Ria et al. 2023; Lakitan et al. 2025). Previous research has also shown that butterhead lettuce exhibits distinct growth and recovery responses under water-related stress in tropical urban environments, highlighting its relevance as an important leafy vegetable for controlled and urban cultivation studies (Muda et al. 2024).

Seed quality is a critical determinant of crop establishment because it influences germination percentage, emergence speed, seedling uniformity, and early vigor. This issue is particularly relevant for commercial leafy vegetable seeds distributed through relatively long supply chains before reaching urban growers. During shipment, warehousing, and retail handling, seeds may be exposed to fluctuating environmental conditions that may reduce vigor and delay physiological activation during imbibition, resulting in slower and less uniform seedling establishment (Thirusendura and Saraswathy 2018; Gebeyehu 2020). Seed deterioration during storage and handling is commonly associated with membrane disorganization, reduced enzymatic efficiency, impaired reserve mobilization, and increased sensitivity to suboptimal germination conditions. Recent evidence also confirms that low and non-uniform germination is closely related to reduced seedling vigor, poor seedling establishment, and changes in membrane stability and respiratory activity during early germination (Sharaf et al. 2026). These changes do not always eliminate viability, but they often slow germination and reduce synchrony, which are critical for uniform seedling establishment. For small-scale urban growers, non-uniform emergence can reduce planting efficiency and complicate crop management (Ria et al. 2020).

This problem is relevant for leafy vegetables, including several lettuce types and napa cabbage, because seed performance may vary among commercially available seed lots used in urban farming systems (Bisi et al. 2023). Because many commercial leafy vegetable seeds are not planted immediately after packaging, differences in storage duration and seed aging can lead to variation in germination behavior, even when seeds still appear commercially acceptable (Finch-Savage and Bassel 2016). In deteriorated or low-vigor seeds, priming may partially restore germination performance by improving hydration uniformity and reactivating early metabolic processes before visible germination begins (Paparella et al. 2015).

Seed priming offers a simple pre-sowing approach to address this problem because it involves controlled hydration before radicle protrusion. Warm water priming can enhance imbibition and accelerate germination-related processes, whereas shallot extract and coconut water may provide natural bioactive compounds that support germination and early seedling growth (Kartika et al. 2021a; Resigia et al. 2024). Coconut water also contains natural hormones, vitamins, sugars, and minerals that may contribute to germination enhancement under appropriate conditions (Zulfiqar 2021). However, comparative information on practical low-cost priming methods for commercial leafy vegetable seeds used in urban farming systems remains limited. In particular, little information is available on how different commercially available leafy vegetable seed types respond compared to low-cost priming agents that are practical for small-scale urban growers. This is important because prolonged storage and handling may reduce germination speed and seedling uniformity. Therefore, this study evaluated the effectiveness of warm water, shallot extract, and coconut water priming in improving germination performance and seed vigor of four commercial leafy vegetable seed types under laboratory conditions. The novelty of this study lies in the comparative evaluation of simple, low-cost priming treatments across four commercial leafy vegetable seed types commonly used in urban farming, particularly seed lots tested close to their expiration date. This study to provide a practical laboratory screening of accessible priming methods for low-input urban farming contexts.

MATERIALS AND METHODS

This study was conducted at the Seed Technology Laboratory, Faculty of Agriculture, Universitas Sriwijaya, Indonesia, in September 2025. The experiment was arranged in a Factorial Completely Randomized Design (FCRD) with two factors. The first factor was seed type, consisting of four levels: butterhead lettuce (*Lactuca sativa* var. *capitata* L.), red romaine lettuce (*L. s.* var. *longifolia* L.), napa cabbage (*Brassica rapa* subsp. *pekinensis* (Lour.) Hanelt), and green lettuce (*L. sativa* L.). The second factor was seed priming treatment, consisting of four levels: untreated control, warm-water priming, 60% shallot extract, and 70% coconut water. Each treatment combination was replicated five times, resulting in 80 experimental units. Each experimental unit consisted of one Petri dish containing 20 seeds of one seed type subjected to one priming treatment. In total, 1,600 seeds were used in this experiment.

Preparation of priming treatments and germination test

Warm-water priming was conducted by soaking the seeds in water maintained at 60°C for 15 min. The temperature was thermostatically controlled and monitored using a laboratory thermometer throughout the soaking period. This temperature-duration combination was selected as a short-duration warm-water priming treatment to enhance hydration and accelerate early germination processes while limiting exposure time to reduce the risk of heat-induced damage. Shallot extract was prepared from fresh shallot bulbs, which were homogenized and then filtered. The 60% shallot extract solution was prepared by mixing 600 mL of crude shallot extract with distilled water to a final volume of 1 L. The coconut water treatment used fresh mature coconut water, which was filtered before dilution. The 70% coconut water solution was prepared by mixing 700 mL of coconut water with distilled water to a final volume of 1 L. After soaking, the seeds were air-dried at room temperature for 1 h until visible free surface moisture disappeared. All germination procedures were carried out under controlled laboratory conditions at 30°C and approximately 70% relative humidity. Seeds were considered germinated when the radicle protruded at least 1 mm. After the observation period, the seedlings were maintained under the same laboratory germination conditions until day 7 to evaluate shoot emergence and seedling growth.

Research parameters

The variables measured were Germination Percentage (GP), time to 50% germination (T50) (Coolbear et al. 1984), Mean Germination Time (MGT) (Ellis and Roberts 1981), Germination Index (GI) (Khan and Ungar 1998), Vigor Index (VI) (Abdul-Baki and Anderson 1973), Germination Rate (GR), Relative Germination Index (RGI), and Shoot Emergence Percentage (SE). Relative Germination Index (RGI) was calculated by dividing the GI value of each treatment by the GI value of the corresponding control and multiplying by 100. Thus, the control value was standardized to 100%, and values above 100% indicated improvement relative to the untreated control within the same seed type.

$$T50 = ti + [(N/2 - ni)(tj - ti)/(nj - ni)]$$

Where: N is the final number of germinated seeds, and ni and nj are the cumulative numbers of seeds germinated at times ti and tj, respectively, where $ni < N/2 < nj$.

$$MGT = \Sigma(nT)/\Sigma n$$

Where: n is the number of seeds newly germinated at time T, and T is the time from the beginning of the germination test.

GI= Σ(% germination seed/germination period)

Where: Germination Index (GI) was calculated according to Khan and Ungar (1998) as the cumulative sum of germinated seeds divided by the corresponding observation time, thereby incorporating the progression of germination throughout the observation period.

VI = GP × seedling length

Where: Seedling length was measured from normal seedlings on day 7 after sowing.

GR = Σ(Gi/Ti)

Where: Gi is the number or percentage of seeds germinated on day i and Ti is the corresponding time after sowing. In the present study, GR was used to describe the speed of germination response.

Shoot emergence was recorded on day 7 after sowing as the percentage of seeds that developed visible shoots under the same germination conditions used during the first 48 h.

SE (%) = (n/N) × 100

Where: n is the number of seeds that produced visible shoots and N is the total number of seeds sown. To avoid ambiguity, germination observations up to 48 h and shoot emergence on day 7 were treated as separate developmental stages, representing early germination and subsequent seedling development, respectively.

Statistical analysis

All data were analyzed by Analysis of Variance (ANOVA) based on a Factorial Completely Randomized Design (FCRD). The model tested the effects of seed type, priming treatment, and their interaction. Significant interaction effects were followed by comparison and interpretation of the interaction means, whereas non-significant interactions were followed by interpretation of the main effects. Prior to ANOVA, statistical assumptions including normality of residuals and homogeneity of variance were evaluated in RStudio based on residual diagnostic procedures. When ANOVA showed significant treatment effects, mean comparisons were performed using the Least Significant Difference (LSD) test at the 5% significance level. All statistical analyses were carried out using RStudio.

RESULTS AND DISCUSSION

Germination performance differed significantly among the tested seed types and priming treatments. Across seed type means, germination percentage remained generally high, reaching up to 95.00%, indicating that the seed lots were viable. Across treatment means, warm water and shallot extract produced higher germination percentages than the untreated control and coconut water treatment, with several seed type-treatment combinations reaching 100.00% (Figure 1).

Time to 50% germination (T50) also differed significantly among seed types and priming treatments. Lower T50 values indicate faster germination. Green lettuce had the lowest T50, whereas butterhead lettuce had the highest value. Among priming treatment, warm water and shallot extract reduced T50 relative to the control, whereas coconut water showed limited improvement (Figure 2).

For seed type means, Mean Germination Time (MGT) ranged from 26.35 to 34.52 h. Butterhead lettuce had the highest MGT (34.52 h), whereas red romaine lettuce and green lettuce had the lowest values (26.35 h). Germination Index (GI) was highest in green lettuce (0.920), followed by red romaine lettuce (0.820), napa cabbage (0.770), and butterhead lettuce (0.640). Vigor Index (VI) was highest in red romaine lettuce (795.19) and green lettuce (777.95), whereas napa cabbage had the lowest value. Relative Germination Index (RGI) was calculated relative to the untreated control within each seed type; therefore, the control for each seed type was standardized to 100, and values above 100 indicate improvement over the corresponding untreated control rather than direct biological superiority among seed types. RGI was highest in red romaine lettuce (206.69) and green lettuce (205.60), intermediate in butterhead lettuce (167.80), and lowest in napa cabbage (126.96) (Table 1).

For treatment means, warm water and shallot extract improved germination performance relative to the untreated control. MGT decreased from 36.88 h in the control to 24.36 h under warm water and 21.44 h under shallot extract, whereas coconut water had the highest MGT (38.51 h). GI increased from 0.546 in the control to 1.053 under warm water and 1.022 under shallot extract, while coconut water remained low at 0.542. VI was higher under warm water (727.50), shallot extract (727.33), and coconut water (707.21) than in the control (600.23). Because RGI was expressed on a percentage basis relative to the corresponding untreated control, the control treatment was fixed at 100.00, while warm water, shallot extract, and coconut water produced values of 210.92, 208.08, and 111.35, respectively (Table 2).

A significant interaction between seed type and priming treatment was observed for T50, germination percentage, and MGT. The highest T50 values were recorded in untreated butterhead lettuce (46.14 h) and untreated napa cabbage (46.49 h). The lowest T50 values were recorded in green lettuce treated with shallot extract (13.92 h) and warm water (14.48 h), followed by napa cabbage treated with warm water (16.71 h). Germination percentage reached 100.00% in most warm-water and shallot-extract combinations, whereas the lowest value was observed in untreated green lettuce (86.00%). For MGT, the lowest values were found in green lettuce treated with shallot extract (15.92 h) and warm water (16.28 h). For napa cabbage, warm water resulted in a T50 of 16.71 h and an MGT of 33.72 h (Table 3).

A significant interaction between seed type and priming treatment was also observed for GI, VI, and RGI. The highest GI was recorded in green lettuce treated with shallot extract (1.390), followed by green lettuce treated with warm water (1.282) and napa cabbage treated with warm water (1.114). The highest VI was observed in green lettuce treated with shallot extract (853.33), followed by red romaine lettuce treated with shallot extract (844.00) and red romaine lettuce treated with warm water (839.33). Because RGI was calculated relative to the corresponding control within each seed type, the interaction values in Table 4 describe the magnitude of treatment response within each seed type rather than absolute differences across all seed types. RGI values ranged from 79.13 to 269.83 across treatment combinations. The highest RGI value was recorded in green lettuce treated with shallot extract, whereas the lowest RGI value was recorded in napa cabbage treated with coconut water.

Significant differences were also observed fo shoot emergence (Figure 3). Butterhead lettuce showed the highest early sprouting value at 88.40%, whereas green lettuce showed the lowest. Among priming treatments, control and coconut water resulted in higher shoot emergence value than warm water and shallot extract. These results indicate that slower early germination did not necessarily correspond with lower subsequent seedling development.

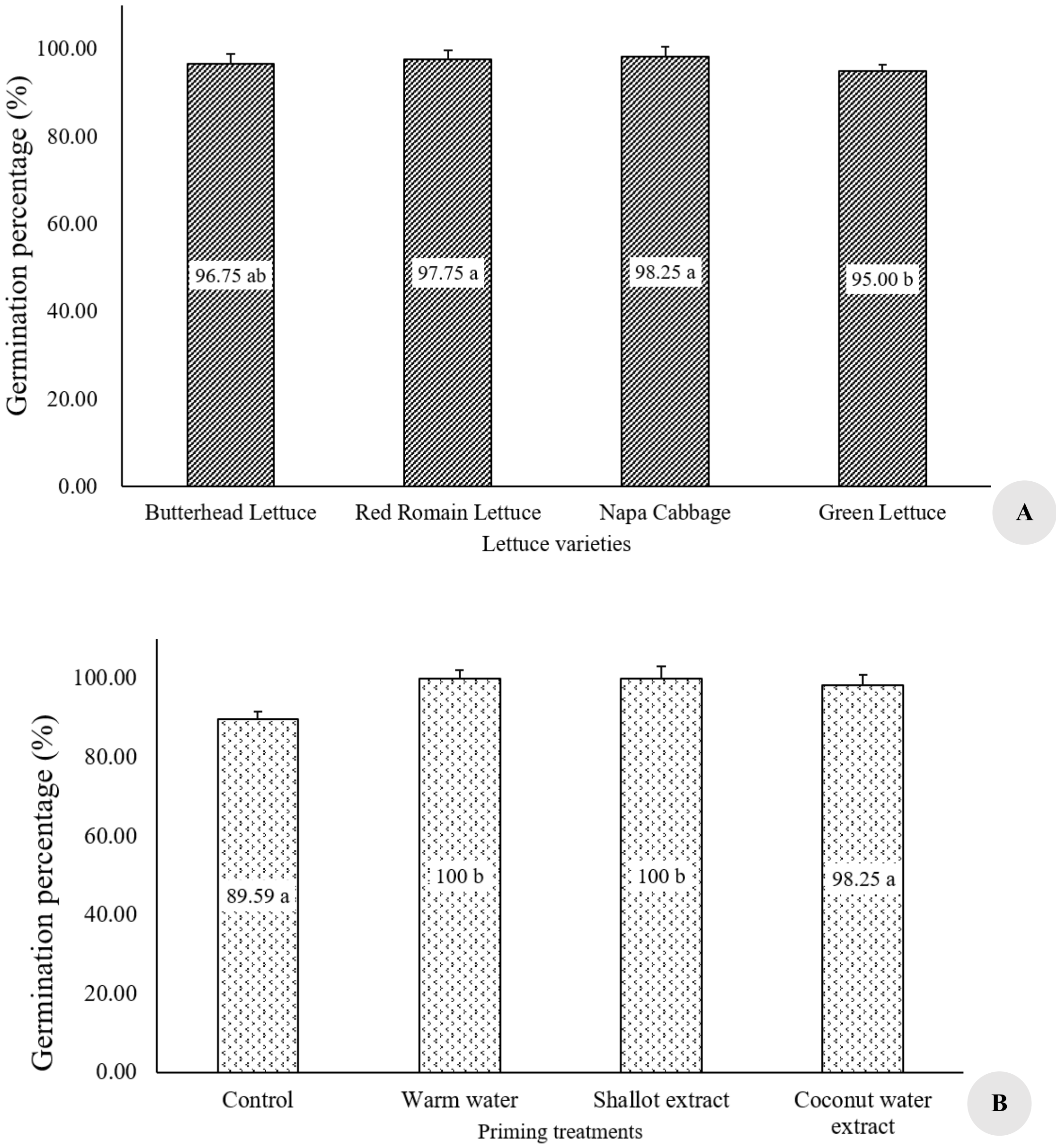

Figure 1. Germination percentage of lettuce and napa cabbage seeds as affected by seed type (A) and priming treatment (B). Different letters indicate significant differences at the LSD level of 0.05 with LSD Value = 2.60. Error bars represent Standard Error (SE)

Table 1. Mean Germination Time, Germination Index, Vigor Index, relative Germination Index (%), and shoot emergence of leafy vegetable seed types

Lettuce varieties	Mean Germination Time (hours)	Germination Index (GI)	Vigor Index	Relative Germination Index (RGI) (%)	Shoot emergence (day)
Butterhead (B)	34.52a	0.640d	627.31b	167.80b	4.97a
Red Romain (R)	26.35c	0.820b	795.19a	206.69a	5.19a
Napa Cabbage (N)	32.90ab	0.770c	561.81d	126.96c	4.87ab
Green Lettuce (G)	26.35c	0.920a	777.95c	205.60a	3.38b
LSD 0.05	5.58	0.040	27.18	126.96	0.52

Note: Different letters indicate significant differences at the LSD level of 0.05. Relative Germination Index (RGI) was calculated relative to the untreated control within each seed type, with the corresponding control standardized to 100. Therefore, RGI values describe the relative response to priming within each seed type and should not be interpreted as direct absolute differences among seed types

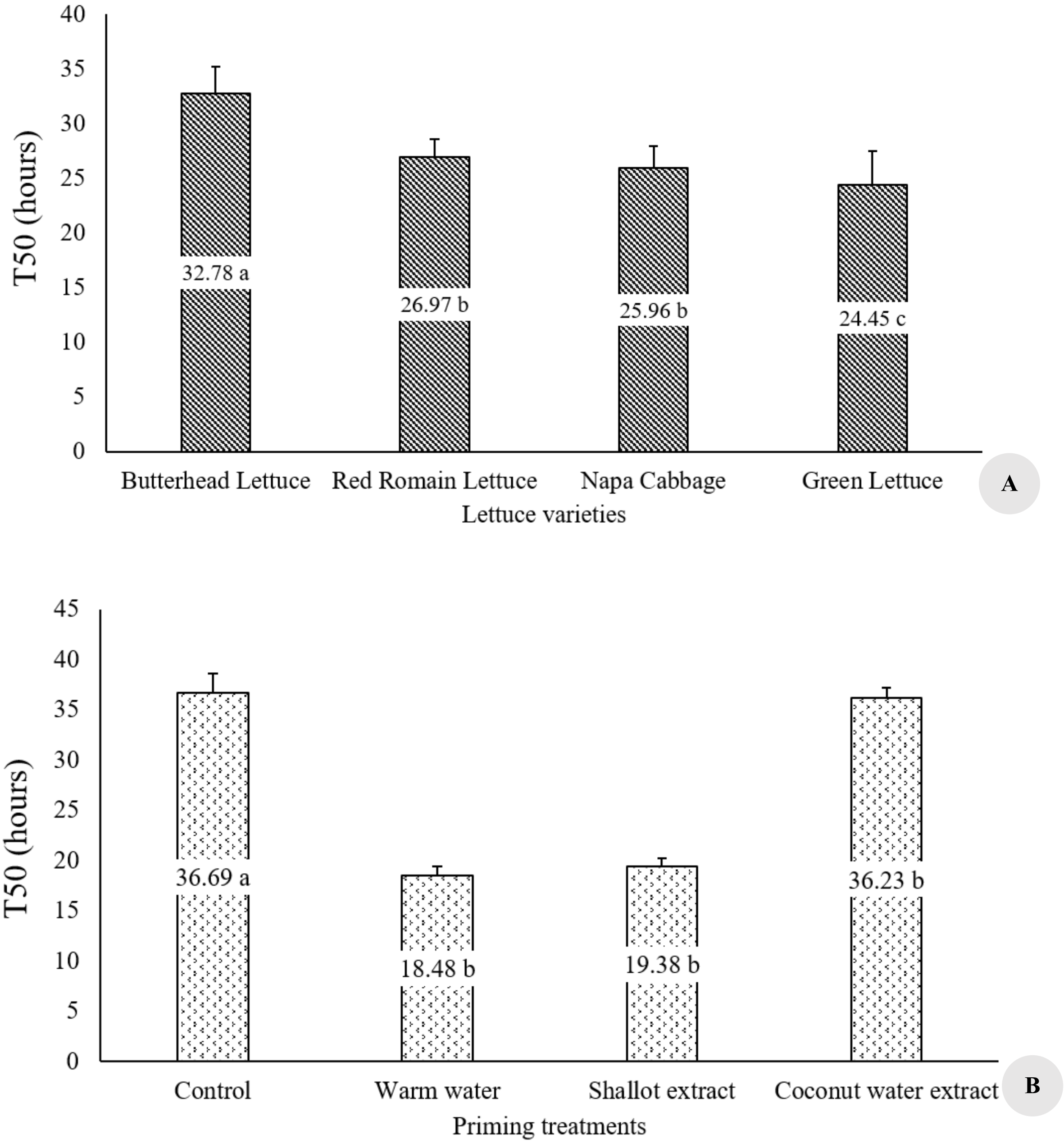

Figure 2. Time to 50% germination (T50) of lettuce and napa cabbage seeds as affected by seed type (A) and priming treatment (B). Different letters indicate significant differences at the LSD level of 0.05 with LSD value 1.76. Error bars represent Standard Error (SE)

Table 2. Priming treatment effects on Mean Germination Time, Germination Index, Vigor Index, relative Germination Index (%), and shoot emergence of leafy vegetable seed types

Priming treatment	Mean Germination Time (hours)	Germination Index (GI)	Vigor Index (VI)	Relative Germination Index (RGI) (%)	Shoot emergence (day)
Control (K)	36.88a	0.546b	600.23b	100.00c	5.88a
Warm water (W)	24.36b	1053a	727.50a	210.92a	3.62b
Shallot extract (S)	21.44b	1022a	727.33a	208.08a	4.14b
Coconut Water (C)	38.51a	0.542b	707.21a	111.35b	5.76a
LSD 0.05	5.58	0.04	27.18	10.04	0.52

Note: Different letters indicate significant differences at the LSD level of 0.05. Relative Germination Index (RGI) is expressed as a percentage relative to the untreated control within each seed type. Accordingly, the control value was fixed at 100, and values above 100 indicate improvement over the corresponding untreated control

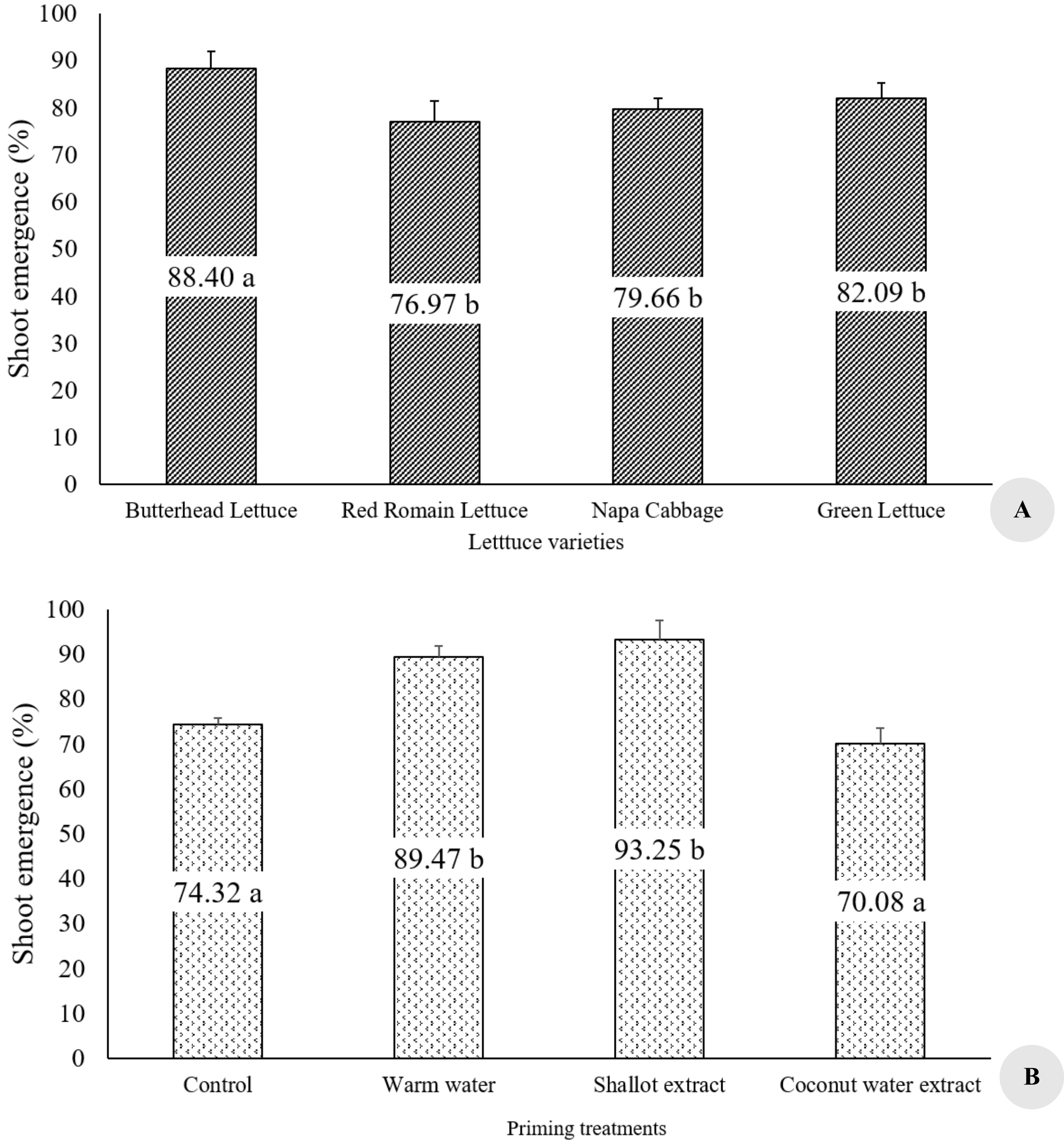

Figure 3. Shoot emergence percentage of lettuce and napa cabbage seeds as affected by seed type (A) and priming treatment (B). Different letters indicate significant differences at the LSD level of 0.05 with LSD value 6.75. Error bars represent Standard Error (SE)

Table 3. Interaction of leafy vegetable seeds and priming on T50, germination percentage (%) and Mean Germination Time (hours)

	T50% (hours)	Germination percentage (%)	Mean Germination Time (hours)
BK	46.14 ± 1.55a	88.00 ± 2.92cd	46.90 ± 1.37a
BW	25.60 ± 0.62e	100.00 ± 0.02a	27.12 ± 0.36def
BS	21.37 ± 0.88a	100.00 ± 0.01a	23.40 ± 0.89defg
BC	38.65 ± 1.87bc	99.00 ± 0.08ab	40.66 ± 2.21abc
RK	29.01 ± 0.93d	91.00 ± 1.87cde	30.75 ± 1.47def
RW	18.18 ± 0.53fg	100.00 ± 3.74a	27.12 ± 6.27def
RS	18.78 ± 0.34 fg	100.00 ± 0.01a	21.36 ± 0.27efg
RC	31.82 ± 0.58d	100.00 ± 0.02a	33.00 ± 1.07bcd
NK	46.49 ± 0.98a	94.00 ± 2.32bc	30.76 ± 0.51cde
NW	16.71 ± 1.46gh	100.00 ± 4.36a	33.72 ± 0.94bcd
NS	23.44 ± 0.53e	100.00 ± 0.04a	25.08 ± 0.50defg
NC	37.10 ± 0.84bc	100.00 ± 0.12a	42.03 ± 1.03abc
GK	42.13 ± 2.25a	86.00 ± 1.00e	39.12 ± 1.44abc
GW	14.48 ± 0.52h	100.00 ± 2.92a	16.28 ± 0.29fg
GS	13.92 ± 0.57h	100.00 ± 0.02a	15.92 ± 0.20fg
GC	37.34 ± 2.55c	94.00 ± 0.30bc	38.36 ± 1.23abc
LSD 5%	3.52	5.21	11.17

Note: Data are presented as mean ± SE. Different letters indicate significant differences at the LSD 0.05 level. Abbreviations represent seed type × priming treatment combinations as follows: BK: Butterhead x Control, BW: Butterhead x Warm water, BS: Butterhead x Shallot extract, BC: Butterhead x Coconut extract, RK: Red romain x Control, RW: Red romain x Warm water, RS: Red romain x Shallot extract, RC: Red romain x Coconut extract, NK: Napa x Control, NW: Napa x Warm water, NS: Napa x Shallot extract, NC: Napa x Coconut extract, GK: Green lettuce x Control, GW: Green lettuce x Warm water, GS: Green lettuce x Shallot extract, GC: Green lettuce x Coconut extract

Table 4. Interaction of leafy vegetable seeds and priming on Germination Index (GI), Vigor Index (VI), and relative Germination Index (%)

	Germination Index (GI)	Vigor Index	GI Relative
BK	0.40 ± 0.03h	587.23 ± 25.21ef	100.00 ± 0.01i
BW	0.80 ± 0.02e	648.00 ± 12.76cd	184.90 ± 4.74cd
BS	0.87 ± 0.10e	631.33 ± 20.11cde	202.97 ± 20.04c
BC	0.50 ± 0.03g	642.67 ± 20.97cd	115.53 ± 6.43fg
RK	0.63 ± 0.03f	668.10 ± 19.39c	100.00 ± 0.01i
RW	1.02 ± 0.03cd	839.33 ± 4.88ab	237.20 ± 5.05b
RS	0.99 ± 0.01cd	844.00 ± 8.65 ab	230.59 ± 1.55b
RC	0.66 ± 0.01f	829.33 ± 11.66ab	152.29 ± 0.79e
NK	0.65 ± 0.02f	499.93 ± 44.35g	100.00 ± 0.01i
NW	1.11 ± 0.02c	600.66 ± 14.36def	172.79 ± 4.93d
NS	0.83 ± 0.02e	580.66 ± 9.23ef	128.96 ± 4.39f
NC	0.51 ± 0.01g	566.00 ± 20.23f	79.13 ± 2.50h
GK	0.52 ± 0.04g	645.67 ± 12.34cd	100.00 ± 28.75i
GW	1.28 ± 0.01b	822.00 ± 3.03ab	248.79 ± 5.10b
GS	1.39 ± 0.00a	853.33 ± 0.73a	269.83 ± 9.03a
GC	0.51 ± 0.03g	790.83 ± 6.70b	98.44 ± 8.26gh
LSD 5%	0.10	54.36	20.08

Note: Data are presented as mean ± SE. Different letters indicate significant differences at the LSD 0.05 level. Relative Germination Index (RGI) was calculated as the GI of each priming treatment divided by the GI of the untreated control within the same seed type, multiplied by 100. Thus, each untreated control was standardized to 100, and values above 100 indicate improvement relative to the corresponding control. Abbreviations represent seed type × priming treatment combinations as follows: BK: Butterhead x Control, BW: Butterhead x Warm water, BS: Butterhead x Shallot extract, BC: Butterhead x Coconut extract, RK: Red romain x Control, RW: Red romain x Warm water, RS: Red romain x Shallot extract, RC: Red romain x Coconut extract, NK: Napa x Control, NW: Napa x Warm water, NS: Napa x Shallot extract, NC: Napa x Coconut extract, GK: Green lettuce x Control, GW: Green lettuce x Warm water, GS: Green lettuce x Shallot extract, GC: Green lettuce x Coconut extract

Discussion

Effect of different priming treatments on germination of tested lettuce and napa cabbage seeds

The results of this study showed that warm water and shallot extract were the most effective priming treatments for improving germination performance of the tested leafy vegetable seeds. These treatments reduced T50 and Mean Germination Time and increased Germination Index, Vigor Index, and relative Germination Index compared with the untreated control and coconut water treatment. Since the untreated control still showed relatively high germination percentage, the main benefit of priming in this study was related to faster and more uniform germination rather than recovery of poor seed viability. Since these physiological processes were not directly evaluated in this study, the discussion is limited to general interpretation based on previous reports (Talpur et al. 2024; Hasanović et al. 2025; Rhaman 2025). Accordingly, the practical value of priming in this study lies mainly in improving the speed and uniformity of laboratory germination.

The positive response to warm-water priming may be associated with improved hydration during the early stage of germination. The reduction in T50 under warm water and shallot extract indicates faster germination. The relatively high germination percentage in the untreated control suggests that the main effect of priming in this study was associated with improvement in germination speed and vigor rather than recovery of seed performance. This interpretation is consistent with the view that hydration-based treatments can facilitate imbibition and support physiological processes associated with seed germination (Cabrera-Santos et al. 2021; Upretee et al. 2024). Similar evidence has also been reported in lettuce, where hydropriming improved physiological performance and seedling establishment (Adhikari et al. 2024; Kumari et al. 2026). Under the conditions of the present study, warm water priming improved germination performance without visible evidence of injury, suggesting that the applied temperature and exposure duration remained tolerable for the tested seeds.

Shallot extract also produced favorable responses, with effects comparable to warm water in several germination and vigor parameters. This response may be related to the presence of bioactive compounds and natural growth-regulating substances reported in shallot, although the chemical composition of the extract used this study was not analyzed. Therefore, the explanation should be treated as a literature-based inference rather than a confirmed mechanism (Kartika et al. 2021a; Resigia et al. 2024). The favorable response at the 60% concentration suggests that this level was effective under the tested conditions, possibly providing sufficient stimulation without causing excessive osmotic stress. Similar observations were reported by Yunindanova et al. (2018), who reported that shallot extract effectively increases germination rate through its hormonal content, while Ruksiriwanich et al. (2022) highlighted the presence of important bioactive compounds in shallot. Similar findings have also been reported in studies describing the role of plant-based biostimulants and priming treatments in supporting plant metabolism, germination performance and early seedling development (Ellouzi et al. 2024; Han et al. 2024). In the present study, the practical importance of shallot extract lies in its ability to produce responses comparable to warm water in several variables, especially T50, GI, and RGI.

Coconut water also improved several germination variables relative to the control, but its effect was weaker than that of warm water and shallot extract. Coconut water contains natural hormones, vitamins, sugars, and minerals, but the present study did not compare different concentrations. The lower response observed at the 70% concentration suggest that this treatment level may not have been optimal for the tested seeds. Previous studies have reported that higher coconut water concentrations may reduce germination responses, possibly because of osmotic effects (Carganilla et al. 2025). This is also consistent with Talpur et al. (2024), who reported that the effectiveness of coconut water depends on treatment conditions and plant species. In the present study, coconut water showed relatively high Vigor Index values, but its effect on accelerating germination was limited as indicated by GI and MGT values. Overall, coconut water produced less consistent responses than warm water and shallot extract under laboratory conditions.

Simple priming treatments were effective in improving germination speed and uniformity. Warm water and shallot extract were the most effective treatments under the present laboratory conditions. Rapid and synchronized germination may contribute to more uniform early seedling establishment, which is important for crop management and stand uniformity (Finch-Savage and Bassel 2016; Reed et al. 2022). However, since the present experiment was conducted under laboratory conditions, the practical relevance of these treatments for low-input cultivation systems should be interpreted cautiously and still requires further evaluation under nursery or field conditions.

Seed-type responses to priming treatments

Seed type affected germination performance and response to priming treatments. Green lettuce and red romaine lettuce responded more positively to warm water and shallot extract, showing faster germination and higher vigor related values than the other seed types. In contrast, butterhead lettuce showed a different pattern with slower early germination but relatively high shoot emergence by day 7. These differences indicate that the tested seed types responded differently to the applied priming treatments.

Variation in seed response may be related to inherent seed characteristics. Seed coat properties, embryo development, dormancy level, and reserve mobilization have been reported to influence germination behavior (Ghannad et al. 2022; Bhatla and Kathpalia 2023; Liu et al. 2025). Other traits such as permeability and metabolic activity are also associated with seed performance and responsiveness to priming (Taylor 2020; Upretee et al. 2024). In lettuce, genotype-related differences have previously been linked with variation in germination behavior and sensitivity under less favorable environments (Wei et al. 2024; Oh et al. 2025). The contrasting response observed in butterhead lettuce further suggests that early germination and subsequent seedling development did not always follow the same pattern.

The interaction between seed type treatment showed that the same treatment did not produce equivalent responses across all tested seeds (Paparella et al. 2015). This observation is consistent with recent findings showing that genotype influences responsiveness to priming treatments (Hasanović et al. 2025; Rhaman 2025). The present results further indicate that priming effectiveness should be evaluated according to seed type because responses differed even under the same treatment conditions. Therefore, simple priming approaches may not provide uniform effects across commercial leafy vegetable seeds.

Responses observed in this study emphasize that successful priming depends not only on the priming material but also on the physiological characteristics of the target seed type. Warm water and shallot extract were generally beneficial, but their effects were more pronounced in Green Lettuce and Red Romaine, while Butterhead showed a distinct germination pattern despite its high early sprouting value. These findings are practically relevant for selecting simple priming methods for commercial leafy vegetable seeds, but their interpretation should remain limited to laboratory germination performance. Further nursery or field validation is still needed before broader cultivation recommendations can be made (Wei et al. 2024; Hasanović et al. 2025).

In conclusion, simple seed priming improved germination speed and vigor of the tested commercial leafy vegetable seeds under laboratory conditions. Warm water and shallot extract showed the most favorable responses, while coconut water produced less consistent effects. However, because this study was limited to laboratory germination testing and did not include physiological, biochemical, nursery, or field evaluations, the findings should not be generalized directly to cultivation conditions. Further studies are needed to evaluate seedling performance under nursery or field conditions.

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REFERENCES

Abdul-Baki AA, Anderson JD. 1973. Vigor determination in soybean seed by multiple criteria. Crop Sci 13 (6): 630-633. https://doi.org/10.2135/cropsci1973.0011183X001300060013x.

Adhikari B, Olorunwa OJ, Horgan TE, Wilson J, Barickman TC, Li T, Bheemanahalli R. 2024. Seed priming attenuates the impact of salt stress and enhances lettuce yields. J Agric Food Res 15: 100947. https://doi.org/10.1016/j.jafr.2023.100947.

Bhatla SC, Kathpalia R. 2023. Seed dormancy and germination. In: Bhatla SC, Lal MA (eds.). Plant physiology, Development and Metabolism. Springer Nature Singapore, Singapore. https://doi.org/10.1007/978-981-99-5736-1_28.

Bhattarai K, Adhikari AP. 2023. Promoting urban farming for creating sustainable cities in Nepal. Urban Sci 7 (2): 54. https://doi.org/10.3390/urbansci7020054.

Bisi VSR, Silvestre W, Rodrigues LS. 2023. Germinative performance of lettuce (*Lactuca sativa* L.) landrace seeds for organic production. Rev Eletrônica Científica UERGS 9 (2): 74-82. https://doi.org/10.21674/2448-0479.92.74-82.

Cabrera-Santos D, Ordoñez-Salanueva CA, Sampayo-Maldonado S, Campos JE, Orozco-Segovia A, Flores-Ortiz CM. 2021. Chia (*Salvia hispanica* L.) seed soaking, germination, and fatty acid behavior at different temperatures. Agriculture 11 (6): 498. https://doi.org/10.3390/agriculture11060498.

Cano-Verdugo G, Flores-García BD, Núñez-Rocha GM, Ávila-Ortíz MN, Nakagoshi-Cepeda MAA. 2024. Impact of urban farming on health: A systematic review. J Public Health 46 (3): e500-e509. https://doi.org/10.1093/pubmed/fdae056.

Carganilla J, Aquino J, Dinay-og J, Cumahling GJ, Valdez M. 2025. Efficacy of coconut water as a seed priming agent for enhancing germination and emergence of rice. J Interdiscip Perspect 3 (11): 199-205. https://doi.org/10.69569/jip.2025.663.

Coolbear P, Francis A, Grierson D. 1984. The effect of low temperature pre-sowing treatment on the germination performance and membrane integrity of artificially aged tomato seeds. J Exp Bot 35 (11): 1609-1617. https://doi.org/10.1093/jxb/35.11.1609.

Ellis RH, Roberts EH. 1981. The quantification of ageing and survival in orthodox seeds. Seed Sci Technol 9: 373-409.

Ellouzi H, Ben Slimene Debez I, Amraoui S, Rabhi M, Hanana M, Alyami NM, Debez A, Abdelly C, Zorrig W. 2024. Effect of seed priming with auxin on ROS detoxification and carbohydrate metabolism and their relationship with germination and early seedling establishment in salt stressed maize. BMC Plant Biol 24: 704. https://doi.org/10.1186/s12870-024-05413-w.

Finch-Savage WE, Bassel GW. 2016. Seed vigour and crop establishment: Extending performance beyond adaptation. J Exp Bot 67 (3): 567-591. https://doi.org/10.1093/jxb/erv490.

Gebeyehu B. 2020. Review on the effect of seed storage period and storage environment on seed quality. Intl J Appl Agric Sci 6 (6): 185-190. https://doi.org/10.11648/j.ijaas.20200606.14.

Ghannad R, Haghjou MM, Raza A, Hasanuzzaman M. 2022. Induction of hydrolytic enzyme activities in dormant seeds of *Dracocephalum kotschyi* Boiss. causes improvement of germination and seedling vigor indices. Acta Physiol Plant 44 (4): 48. https://doi.org/10.1007/s11738-022-03381-y.

Han M, Kasim S, Yang Z, Deng X, Saidi NB, Uddin MK, Shuib EM. 2024. Plant extracts as biostimulant agents: A promising strategy for managing environmental stress in sustainable agriculture. Phyton-Intl J Exp Bot 93 (9): 2149-2166. https://doi.org/10.32604/phyton.2024.054009.

Hasanović M, Durmić-Pašić A, Karalija E. 2025. Seed priming beyond stress adaptation: Broadening the agronomic horizon. Agronomy 15 (8): 1829. https://doi.org/10.3390/agronomy15081829.

Kartika K, Lakitan B, Ria RP, Putri HH. 2021b. Effect of the cultivation systems and split fertilizer applications on the growth and yields of tatsoi (*Brassica rapa* subsp. *narinosa*). Trends Sci 18 (21): 344. https://doi.org/10.48048/tis.2021.344.

Kartika K, Lakitan B, Ria RP. 2021a. Hydro- and osmo-priming effects on upland rice exposed to drought conditions at vegetative and reproductive stages. CMUJ Nat Sci 20 (3): e2021053. https://doi.org/10.12982/CMUJNS.2021.053.

Khan MA, Ungar IA. 1998. Germination of the salt tolerant shrub *Suaeda fruticosa* from Pakistan: Salinity and temperature responses. Seed Sci Technol 26: 657-667.

Kumari KB, Pal A, Sen S, Ranjan RD, Atta K, Srivastava AK. 2026. Comparative efficacy of gibberellic acid and melatonin seed priming on germination and biochemical responses of maize under drought stress. Front Plant Sci 17: 1753761. https://doi.org/10.3389/fpls.2026.1753761.

Lakitan B, Fhadilah N, Muda SA, Irmawati, Ria RP. 2025. Impacts of artificial shading on growth and some morphological traits of romaine lettuce (*Lactuca sativa* L. cv. Romaine) cultivated in urban areas. Intl J Agric Technol 21 (4): 1329-1346. https://doi.org/10.63369/ijat.2025.21.4.1329-1346.

Liu L, Wang Z, Wu Y, Shen Y. 2025. Hormonal and storage metabolic regulation of germination in *Toona sinensis*. Horticulturae 11 (6): 685. https://doi.org/10.3390/horticulturae11060685.

Muda SA, Lakitan B, Ramadhani F, Juwinda. 2024. Butterhead lettuce growth under shallow water tables and its recovery on tropical urban ecosystem. Adv Hort Sci 38 (4): 327. https://doi.org/10.36253/ahsc-16233.

Oh S, Ahn E, Shi A, Mou B, Park S. 2025. Genome-wide association studies in lettuce reveal the interplay of seed age, color, and germination under high temperatures. Sci Rep 15: 733. https://doi.org/10.1038/s41598-024-84197-3.

Paparella S, Araújo SDS, Rossi G, Wijayasinghe M, Carbonera D, Balestrazzi A. 2015. Seed priming: State of the art and new perspectives. Plant Cell Rep 34 (8): 1281-1293. https://doi.org/10.1007/s00299-015-1784-y.

Reed RC, Bradford KJ, Khanday I. 2022. Seed germination and vigor: Ensuring crop sustainability in a changing climate. Heredity 128 (6): 450-459. https://doi.org/10.1038/s41437-022-00497-2.

Resigia E, Swasti E, Putri NE, Kusumawati A, Hasibuan SP. 2024. Effect of seed soaking with natural growth regulators on germination of red rice line SF 12-2-12. AGRIUM: Jurnal Ilmu Pertanian 27 (1): 44-53. https://doi.org/10.30596/agrium.v27i1.17636.

Rhaman MS. 2025. Seed priming before the sprout: Revisiting an established technique for stress-resilient germination. Seeds 4 (3): 29. https://doi.org/10.3390/seeds4030029.

Ria RP, Lakitan B, Sulaiman F, Kartika K, Suwignyo RA. 2020. Cross-ecosystem utilizing primed seeds of upland rice varieties for enriching crop diversity at riparian wetland during dry season. Biodiversitas 21 (7): 3008-3017. https://doi.org/10.13057/biodiv/d210718.

Ria RP, Lakitan B, Sulaiman F, Yakup Y. 2023. Searching for suitable cultivation system of Swiss chard (*Beta vulgaris* subsp. *cicla* (L.) W.D.J. Koch) in the tropical lowland. J Hortic Res 31 (1): 81-90. https://doi.org/10.2478/johr-2023-0022.

Ruksiriwanich W, Khantham C, Muangsanguan A, Chittasupho C, Rachtanapun P, Jantanasakulwong K, Barba FJ. 2022. Phytochemical constitution, anti-inflammation, anti-androgen, and hair growth-promoting potential of shallot (*Allium ascalonicum* L.) extract. Plants 11 (11): 1499. https://doi.org/10.3390/plants11111499.

Sharaf Z, Habibi N, Fakhri A, Faqiri SM. 2026. Seed priming to induce seed germination, seedling growth and enzymatic activity in watermelon. Sci Nat 113: 43. https://doi.org/10.1007/s00114-026-02100-8.

Talpur A, Khaskheli AA, Talpur MYMK, Nizamani N, Hassan G. 2024. Optimizing potential of coconut water as an organic priming agent for jujube (*Ziziphus mauritiana* L.). J Hortic Agric Sci 1 (1): 53-60. https://doi.org/10.63459/jhas.2024.1.10.

Taylor AG. 2020. Seed Storage, Germination, Quality, and Enhancements. The Physiology of Vegetable Crops. CABI, Wallingford, UK. https://doi.org/10.1079/9781786393777.0001.

Thirusendura Selvi D, Saraswathy S. 2018. Seed viability, seed deterioration and seed quality improvements in stored onion seeds: A review. J Hortic Sci Biotechnol 93 (1): 1-7. https://doi.org/10.1080/14620316.2017.1343103.

Upretee P, Bandara MS, Tanino KK. 2024. The role of seed characteristics on water uptake preceding germination. Seeds 3 (4): 559-574. https://doi.org/10.3390/seeds3040038.

Wei J, Zhang Q, Zhang Y, Yang L, Zeng Z, Zhou Y, Chen B. 2024. Advance in the thermoinhibition of lettuce (*Lactuca sativa* L.) seed germination. Plants 13 (15): 2051. https://doi.org/10.3390/plants13152051.

Yunindanova MB, Budiastuti MS, Purnomo D. 2018. The analysis of endogenous auxin of shallot and its effect on the germination and the growth of organically cultivated melon (*Cucumis melo*). IOP Conf Ser Earth Environ Sci 215 (1): 012018. https://doi.org/10.1088/1755-1315/215/1/012018.

Zulfiqar F. 2021. Effect of seed priming on horticultural crops. Sci Hortic 286: 110197. https://doi.org/10.1016/j.scienta.2021.110197.