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Effects of Soaking Duration and Red Onion Extract Concentration on Celery Seed Germination

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ABSTRACT

Background: Celery (*Apium graveolens*) is a horticultural crop with significant economic and culinary value, particularly in Indonesia, where leaf celery is more commonly cultivated. Despite growing interest in hydroponic farming in regions such as Bangka Belitung, celery cultivation remains limited due to challenges in seed germination, especially under lowland and hot climate conditions. Celery seeds are known for slow and inconsistent germination due to hard seed coats and naturally occurring germination inhibitors like coumarin. Seed soaking in plant growth regulators (PGRs), including natural alternatives such as red onion (*Allium cepa* L) extract—rich in gibberellins and auxins—has been proposed to enhance germination and seedling vigor.
Aims & Methods: This study aimed to investigate the effects of different soaking durations (24 and 48 hours) and concentrations (0%, 10%, 20%, and 30%) of red onion extract on the germination performance of celery seeds.
Result: The results of this study indicate that a 24-hour soaking duration is the most effective in enhancing celery seed germination as under these conditions, the seeds experience only brief exposure to low oxygen levels. However, soaking seeds in red onion extract at concentrations of 10% to 30% resulted in lower germination parameters compared to the 0% because the concentration is suspected to be too high for celery seeds. Analysis of the interaction between soaking duration and extract concentration revealed that control seeds (without soaking or directly sowing) achieved germination performance comparable to the best treatment combination in terms of germination power, germination speed index, and mean germination time. At the same time, the highest vigor index and seedling length were observed in seeds treated with 10% red onion extract for 24 hours, which also showed similar performance to the control treatment.

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1. Introduction

Celery (*Apium graveolens*) is a popular horticultural plant with high economic value, both as a culinary ingredient and for its health benefits. Leaf celery is more widely cultivated in Indonesia than stalk celery. Celery is an additive in food, typically used in small quantities but considered essential in many Indonesian dishes (Lase, 2020). In Bangka Belitung, more people are beginning to grow vegetables using hydroponic methods for household consumption or commercial purposes. However, celery cultivation using hydroponics is still limited, mainly due to frequent failures in the seedling stage, the lengthy germination process, poor seed quality, and hot climates, whereas celery generally grows better at high altitudes above approximately 900 meters above sea level (Rukmana, 1995; Wibowo, 2013).

The success of celery cultivation is heavily influenced by seed quality and the germination process. Celery seeds are known for their slow germination, and poor-quality seeds or those with low germination rates can lead to slow growth and suboptimal yields. According to Gupta et al. (2024), celery seed has a chemical compound called coumarin, which may prevent seed germination by leaching out of the seed coat. The hard seed coat (as the pericarp is made of a double layer of testa and endosperm) of celery does not allow water to be imbibed by the seeds, preventing the initiation of physiochemical transformation in seeds. Other factors contributing to low seed quality include prolonged storage, inappropriate storage conditions, and dehydrated seeds (Surtinah et al., 2018), which many farmers tend to overlook. Seeds stored for too long experience a decline in vigor, or deterioration (Jyoti & Malik, 2013). This loss of vigor can be addressed through invigorating treatments applied before germination (Dzakwan et al., 2023).

Soaking seeds in plant growth regulators (PGRs) is one method to enhance seed germination. Poor germination may be caused by low gibberellin levels, which keep seeds in a dormant state. On the other hand, endogenous gibberellin facilitates germination and helps break dormancy (Tetuko et al., 2015). The imbibition process is also crucial—rapid imbibition accelerates germination, and auxins play an essential role in this process (Farida, 2013).

Natural PGRs, such as shallot (*Allium ascalonicum* L), are extracted from plants. These natural PGRs offer an environmentally friendly alternative for stimulating seed germination. Onion and shallot bulbs are a natural source of gibberellins (Ichsan et al., 2015). Besides gibberellins, red onions contain Indole Acetic Acid (IAA), a highly active auxin that promotes plant growth (Alimudin et al., 2017). According to Kurniati et al. (2019), onion bulbs contain auxin (IAA: 156.01 ppm), cytokinins in the form of zeatin (122.34 ppm) and kinetin (140.11 ppm), and gibberellin (230.67 ppm). Research (Fitriani, 2019) shows red onion extract is an effective alternative for promoting root development. Dzakwan et al. (2023) also found that soaking chilli seeds with reduced vigor due to prolonged storage in 15% red onion extract improved their condition, showing results similar to those at 20% concentration.

The duration of seed soaking is an essential factor that influences germination. Proper soaking helps speed up germination by breaking seed dormancy and activating the enzymes needed for growth. Research of Komalasari and Arif (2019) revealed that soaking duration has positive significant effect on seed vigor, in terms of germination rate, shoot and root length and shoot and root dry weight, and electrolyte leakage. Additionally, soaking improves germination rate and uniformity as seeds absorb water more evenly. The ideal soaking duration varies by seed type. Some seeds need only a brief soak, while others require a more extended period. Optimal soaking times are typically available on seed packaging or agricultural references. Given the long germination period required for celery, pre-germination treatments are crucial for enhancing and accelerating germination. There is currently limited information on the effects of natural red onion PGR and soaking durations. Therefore, this study aims to investigate the impact of soaking celery seeds in various concentrations of natural red onion extract over different durations on germination rates and early plant growth. The varying soaking durations are expected to identify the optimal period for using this natural PGR to achieve the best results. Thus, this research is expected to contribute to developing sustainable celery cultivation technology and offer a natural-based solution to enhance agricultural productivity.

2. Methods

This research was conducted in December to January at the Agricultural Laboratory of the State Manufacturing Polytechnic of Bangka Belitung. Celery seeds with the trade brand Amigo were used in this study. The experiment was conducted with a Completely Randomized Design (CRD) with two factors and three replications. The first factor was the concentration of natural plant growth regulator (PGR) derived from red onion extract: 0%, 10%, 20%, and 30%. The second factor was the soaking duration: 24 hours and 48 hours. A control treatment, in which seeds were sown directly without soaking or red onion extract application, was also included. This was done so that if the interaction between onion extract concentration and soaking duration proved significant, the treatment combinations could also be compared to the control.

Celery seeds were divided into 8 treatment groups and 1 control group. The treatment combinations used were as follows:

1. Control (no soaking)
2. Soaking for 24 hour in red onion extract 0% (W1K1)
3. Soaking for 24 hour in red onion extract 10% (W1K2)
4. Soaking for 24 hour in red onion extract 20% (W1K3)
5. Soaking for 24 hour in red onion extract 30% (W1K4)
6. Soaking for 48 hour in red onion extract 0% (W2K1)
7. Soaking for 48 hour in red onion extract 10% (W2K2)
8. Soaking for 48 hour in red onion extract 20% (W2K3)
9. Soaking for 48 hour in red onion extract 30% (W2K4)

The red onion extract was prepared by blending red onions separately using a blender. The blended onions were then squeezed to separate the juice from the pulp. The extracted juice was diluted with distilled water to achieve the desired concentrations. Each treatment group used 30 celery seeds. The seeds were planted in rock wool at a depth of 0.5 cm. Observations were conducted on the following parameters: germination percentage, germination speed index, germination power, mean germination time, vigor index II, and seedling length. Seedling length was observed after one month, when 2–3 true leaves appeared.

The data obtained were analyzed using Analysis of Variance (ANOVA) at a 5% significance level. If significant differences were found, further analysis was conducted using Duncan's Multiple Range Test (DMRT) at the same significance level.

Germination Percentage (%)

The germination percentage was observed on the 21st day after planting. The germination percentage was calculated using the following formula:

$$GP\ (\%) = \frac{\mathrm{n}}{\mathrm{N}}\ x\ 100$$

Where:

- GP = Germination Percentage
- n = Number of seeds that germinated
- N = Total number of seeds sown

Germination Speed Index (GSI)

The Germination Speed Index was observed from day 1 to day 17 after sowing. The formula used is based on Copeland & McDonald (2001), as follows:

$$GSI = \frac{G1}{D1} + \frac{G2}{D2} + \frac{G3}{D3} ... + \frac{Gn}{Dn}$$

Where:

- GSI = Germination Speed Index
- G = Number of seeds germinated on each day
- D = Number of days since sowing
- Gn = Number of seeds germinated on day n
- Dn = Number of days since sowing on day n

Germination Power (%)

The observation was carried out on seeds that germinated normally from the 1st to the 8th observation after planting, to reflect initial seed vigor. The calculation of germination power was conducted using the ISTA (2010) formula as follows:

$$GP\ (\%) = \frac{\mathrm{n}}{\mathrm{N}}\ x\ 100$$

Where:

- GP = Germination Power (%)
- n = Number of normally germinated seeds (by the 8th day)
- N = Total number of seeds tested

Mean Germination Time (MGT)

Mean Germination Time was observed from day 1 to day 17 after sowing. The formula used is based on Labouriau (1983), as follows:

$$MGT = \frac{\Sigma\ (ni\ x\ ti)}{\Sigma\ ni}$$

Where:

- MGT = Mean Germination Time (in days)
- nt = Number of seeds germinated on day t
- t = Time in days after sowing

Vigor Index II

The Vigor Index (a combination of seedling length and germination percentage) was observed to measure growth energy and early growth potential. The formula used is as follows:

$$VI = SL\ x\ GP$$

Where:

- VI = Vigor Index II
- SL = Average seedling length (cm)
- GP = Germination Percentage (%)
-

3. Results

3.1 Germination percentage

Applying different soaking durations and concentrations of red onion extract did not result in statistically significant differences in the germination percentage of celery seeds. However, a general trend was observed in which seeds soaked for 24 hours showed a higher average germination percentage (90.55%) than those soaked for 48 hours. Among the various concentrations of red onion extract, the 30% concentration yielded the highest average germination percentage (89.45%), although the differences were not statistically significant. This indicates that higher concentrations of natural plant growth regulators may still support favorable germination, but not to a degree that differs meaningfully from lower concentrations or the control.

These findings suggest that celery seed germination is relatively stable across different treatments, but a 24-hour soaking duration combined with moderate to high concentrations of red onion extract may slightly enhance overall germination performance. The detailed germination percentages for each treatment combination are presented in Table 1.

Table 1. Germination percentage (%) of celery seeds treated with red onion extract at various concentrations and soaking durations

	Extract Concentration				
Soaking Duration	**K1 (0%)**	**K2 (10%)**	**K3 (20%)**	**K4 (30%)**	**Mean**
W1 (24 hours)	91.11	92.22	90	88.89	90.555
W2 (48 hours)	85.55	81.11	87.78	90	86.11
Mean	88.33	86.665	88.89	89.45	(-)

Note: Values followed by the same letter within a column are not significantly different at $p < 0.05$ according to Duncan's Multiple Range Test (DMRT)

Germination percentage indicates the proportion of seeds that successfully sprout under specific conditions within a defined period. It serves as a key indicator of seed viability and is often used to evaluate the effectiveness of pre-treatment methods aimed at improving seed performance. In this study, although the statistical analysis showed no significant differences between treatments, the trend suggests that soaking duration and extract concentration may still influence the physiological readiness of the seeds to germinate.

3.2 Germination Power (%)

Both soaking duration and red onion extract concentration were found to influence the germination power of celery seeds. Seeds soaked for 24 hours consistently produced higher germination power compared to those soaked for 48 hours. Specifically, soaking for 24 hours resulted in a germination power of 59.45%, suggesting that this duration provides optimal hydration to activate physiological processes without causing stress from prolonged water exposure (Table 2).

Table 2. Germination power (%) of celery seeds treated with red onion extract at various concentrations and soaking durations

	Extract Concentration				
Soaking Duration	**K1 (0%)**	**K2 (10%)**	**K3 (20%)**	**K4 (30%)**	**Mean**
W1 (24 hours)	66.67	63.33	51.11	56.67	59.45 a
W2 (48 hours)	56.89	23.33	24.44	18.89	30.89 b
Mean	61.78 a	43.33 b	37.78 b	37.78 b	(+)

Note: Values followed by the same letter within a column are not significantly different at $p < 0.05$ according to Duncan's Multiple Range Test (DMRT)

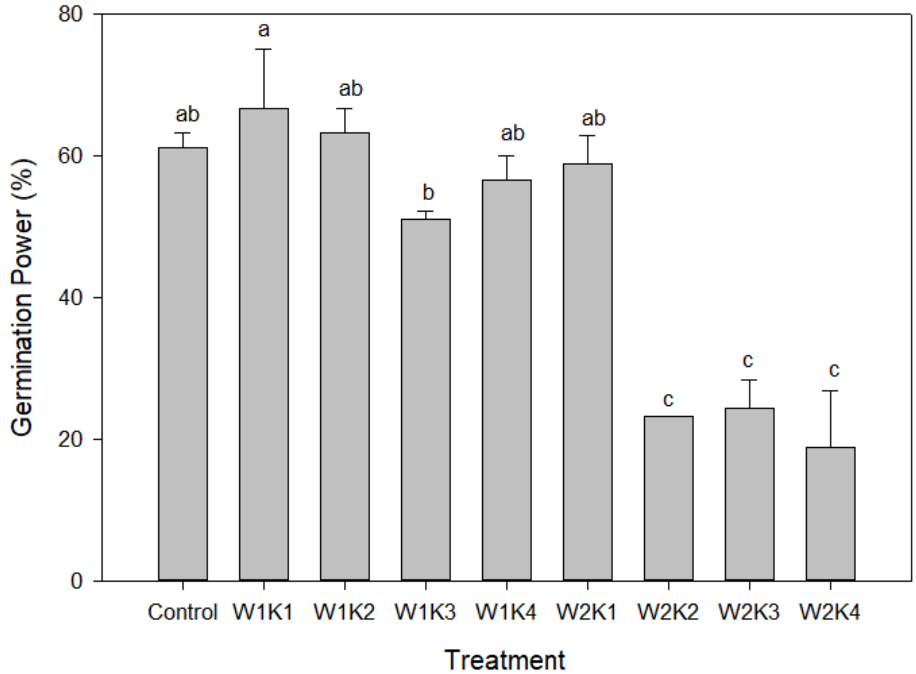

Figure 1. Differences in celery seed germination power under the interaction of soaking duration and red onion extract concentration compared to untreated seeds.

Regarding extract concentration, seeds soaked in 0% red onion extract (distilled water) achieved the highest germination power at 61.78%. This value significantly differed from the treatments with 10%, 20%, and 30% concentrations of red onion extract. However, no significant differences were observed among the extract-treated groups, indicating that increasing the concentration of red onion extract beyond a certain point does not further enhance germination power.

Nonetheless, a notable difference exists between the control and the various treatment combinations involving onion extract concentration and soaking duration (Figure 1). Compared to the control, K1W2, K2W1, and K4W1, the most effective treatment for enhancing seed germination power was K1W1, even though they were not significantly different. In contrast, seeds soaked in 30% onion extract for 48 hours (K4W2) exhibited the lowest germination power. This finding suggests that prolonged exposure (48 hours) to a high concentration of onion extract inhibits seed germination, as in the K4W2 treatment.

3.3 Germination Speed Index (GSI)

Both soaking duration and red onion extract concentration significantly influenced the germination speed index (GSI) of celery seeds. Seeds soaked for 24 hours exhibited a higher GSI, reaching 22.64, compared to those soaked for 48 hours. This suggests that a 24-hour soaking period allows optimal imbibition, activating key metabolic and enzymatic processes necessary for rapid germination. In contrast, extended soaking (48 hours) may slow germination due to possible oxygen limitation or excessive hydration, which can disrupt cellular function.

Likewise, the concentration of red onion extract had a significant effect on GSI. Seeds treated with 0% extract (distilled water) recorded the highest germination speed index (24.30), significantly different from those treated with 10%, 20%, and 30% concentrations. This pattern suggests that, although red onion extract contains natural growth regulators such as gibberellins and auxins, these compounds may exert an inhibitory effect, like excessive concentrations may disrupt hormonal balance or lead to osmotic stress, or may not be needed in early germination stages (Ogunyale et al., 2014). Moreover, there was no significant difference in GSI among the 10%, 20%, and 30% treatments, indicating a potential threshold beyond which additional hormone content does not further enhance germination speed (Table 3).

Table 3. Germination speed index of celery seeds treated with red onion extract at various concentrations and soaking durations

Soaking Duration	Extract Concentration				Mean
	K1 (0%)	K2 (10%)	K3 (20%)	K4 (30%)	
W1 (24 hours)	26.66	23.33	20.69	19.86	22.64 a
W2 (48 hours)	22.13	13.89	14.74	14.19	16.24 b
Mean	24.39 a	18.61 b	17.72 b	17.03 b	(+)

Note: Values followed by the same letter within a column are not significantly different at $p < 0.05$ according to Duncan's Multiple Range Test (DMRT).

A significant interaction was observed between soaking duration and red onion extract concentration on the germination speed index (GSI) of celery seeds. The highest GSI was recorded in seeds soaked in 0% red onion extract for 24 hours (K1W1), which differed significantly from most other treatments. However, this result was not significantly different from the control, K1W2, and K2W1, indicating that under certain conditions, lower or no extract concentrations may perform comparably well in terms of germination speed.

These findings highlight the importance of optimizing the duration of soaking and the concentration of natural bio stimulants. Although moderate concentrations like 10% can enhance germination speed compare to 20% and 30%, their effectiveness is closely tied to appropriate exposure time. The interaction effects are detailed in Figure 2, emphasizing the need for balanced application to achieve optimal seed germination performance.

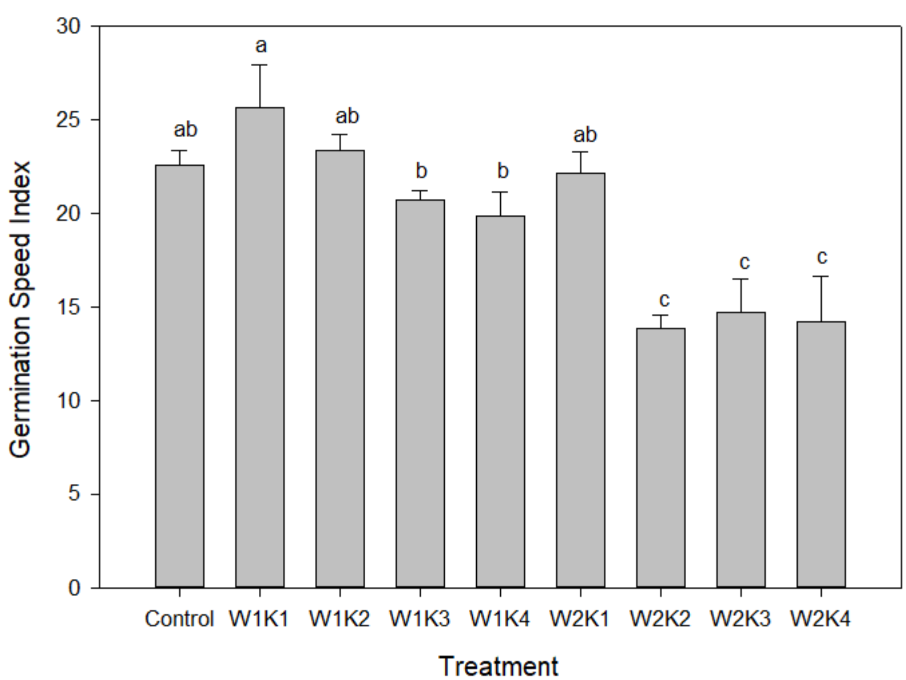

Figure 2. Differences in celery seed germination speed index under the interaction of soaking duration and red onion extract concentration compared to untreated seeds.

3.4 Mean Germination Time (MGT)

The application of varying soaking durations and red onion extract concentrations significantly affected celery seeds' mean germination time (MGT). Unlike germination percentage, germination speed index, and germination power, which generally decreased under prolonged soaking and higher extract concentrations, the MGT increased notably with a 48-hour soaking duration, reaching an average of 13.11 days. Similarly, seeds with the highest onion extract concentration (30%) exhibited a longer MGT (13.03 days) than those with lower concentrations.

Table 4. Mean germination time (day) of celery seeds treated with red onion extract at various concentrations and soaking durations

Soaking Duration	Extract Concentration				Mean
	K1 (0%)	K2 (10%)	K3 (20%)	K4 (30%)	
W1 (24 hours)	11.89	12.2	12.4	12.52	12.25 b
W2 (48 hours)	12.21	13.35	13.36	13.53	13.11 a
Mean	12.05 b	12.78 a	12.88 a	13.03 a	(+)

Note: Values followed by the same letter within a column are not significantly different at $p < 0.05$ according to Duncan's Multiple Range Test (DMRT).

The interaction between soaking duration and onion extract concentration significantly influenced the mean germination time (Figure 3). This means that the effect of soaking duration on germination time depends on the concentration of onion extract used, and vice versa. In other words, neither factor alone fully explains the variation in germination timing—instead, their combination determines the outcome.

The highest mean germination time was observed in treatment K4W2 (30% onion extract for 48 hours), indicating that the combined stress of a high concentration and prolonged soaking duration leads to a significant delay in germination. Interestingly, other combinations with a 48-hour soaking duration, such as K2W2 (10%) and K3W2 (20%), also resulted in relatively high mean germination times, though not significantly different from K4W2. This suggests that extended soaking duration intensifies the extract's inhibitory effect, even at moderate concentrations.

In contrast, the shortest mean germination time occurred in K1W1 (0% extract for 24 hours), which was not significantly different from the control, K1W2 (0% extract for 48 hours), and K2W1 (10% extract for 24 hours). These combinations involved either low extract concentrations, shorter soaking durations, or both, which appear to pose less stress on seeds and allow for quicker germination.

Overall, this interaction highlights that seed germination is most negatively affected when both soaking duration and onion extract concentration are high. Therefore, when using onion extract for seed treatment, it is essential to balance these two factors carefully to avoid delaying germination and potentially reducing seedling vigor.

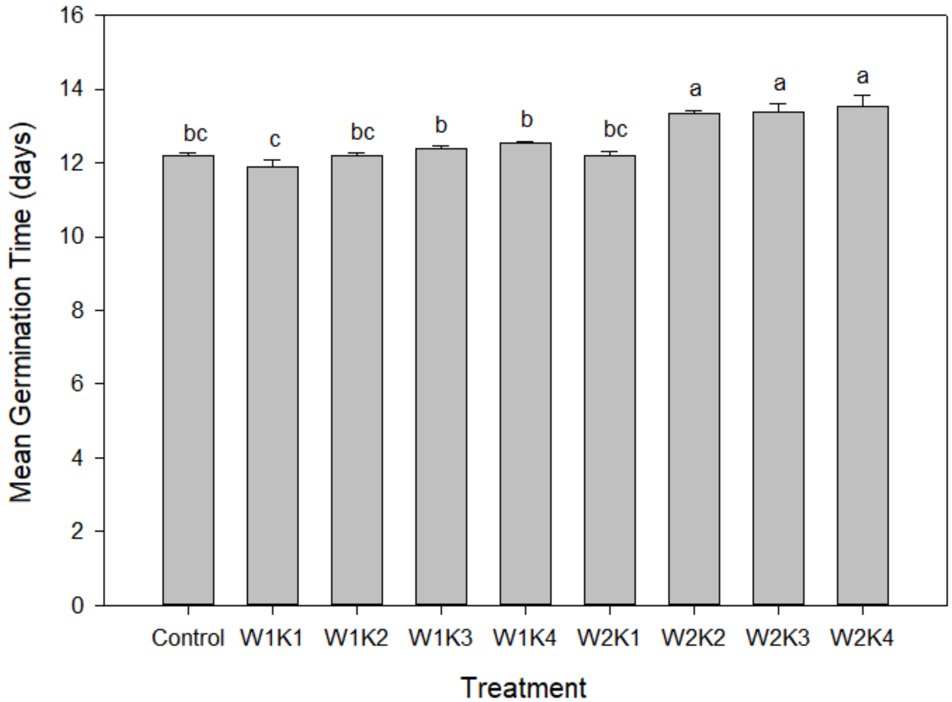

Figure 3. Differences in celery seed mean germination time under the interaction of soaking duration and red onion extract concentration compared to untreated seeds.

3.5 Vigor Indeks II and Seedling Length

Vigor Index II, which provides a comprehensive measure of early seedling vigor by combining seedling length and germination percentage, was not significantly affected by either soaking duration or red onion extract concentration (Table 5). Although the differences were not statistically significant, seeds soaked for 24 hours tended to show higher vigor index values (603.40) compared to those soaked for 48 hours. Similarly, treatment with 10% onion extract showed a slight tendency toward higher vigor index values (595.91), though this effect was also not significant. These trends suggest that shorter soaking durations and moderate extract concentrations may support early seedling development, but the effects are not strong enough to draw definitive conclusions.

Table 5. Vigor index II of celery seeds treated with red onion extract at various concentrations and soaking durations

Soaking Duration	Extract Concentration				
	K1 (0%)	**K2 (10%)**	**K3 (20%)**	**K4 (30%)**	**Mean**
W1 (24 hours)	458.33	743	565.11	647.15	603.40
W2 (48 hours)	541.96	448.81	578.19	512.15	520.28
Mean	500.15	595.91	571.65	579.65	(+)

Note: Values followed by the same letter within a column are not significantly different at $p < 0.05$ according to Duncan's Multiple Range Test (DMRT).

However, the interaction between soaking duration and onion extract concentration had a significant effect on the vigor index (Figure 4). The highest vigor index was observed in treatment K2W1 (10% onion extract, 24-hour soaking), which was not significantly different from the control, K3W2 (20% extract, 48 hours), and K4W1 (30% extract, 24 hours). In contrast, the lowest vigor index was recorded in K2W2 (10% extract, 48 hours), although it was not significantly different from several other treatments, including the control, K1W1, K1W2, K3W1, K3W2, and K4W2. These findings suggest that the benefits of certain extract concentrations on seedling vigor may depend on a shorter soaking duration, while longer durations may diminish these positive effects, even at the same concentration.

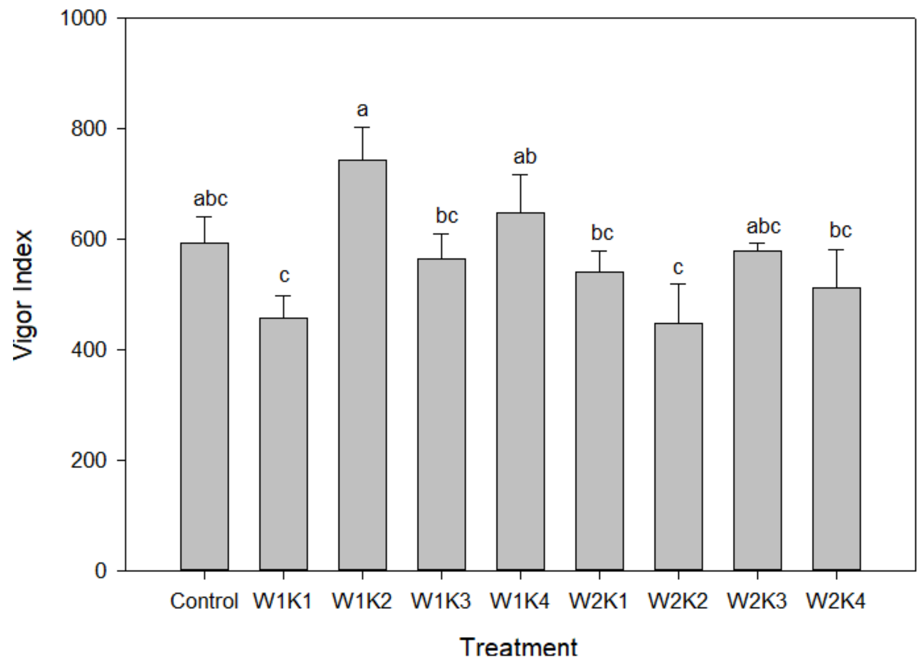

Figure 4. Differences in celery seed vigor index II under the interaction of soaking duration and red onion extract concentration compared to untreated seeds.

Seedling length is not only an important indicator of overall seed vigor but also a key measure for evaluating the early growth performance of seedlings. As shown in Table 6, neither soaking duration nor onion extract concentration alone had a significant effect on seedling length. However, the interaction between the two factors had a significant influence (Figure 5). This indicates that seedling length is affected more by the specific combination of soaking time and extract concentration than by either factor individually. Some combinations may create favorable conditions for early seedling growth, while others may impose stress or inhibitory effects, underscoring the need to optimize both variables when using onion extract for seed treatment.

Table 6. Seedling length (cm) of celery seeds treated with red onion extract at various concentrations and soaking durations

Soaking	**Extract Concentration**				
Duration	**K1 (0%)**	**K2 (10%)**	**K3 (20%)**	**K4 (30%)**	**Mean**
W1 (24 hours)	5.02	8.07	6.27	7.24	6.65
W2 (48 hours)	6.34	5.49	6.59	5.64	6.015
Mean	5.68	6.78	6.43	6.44	(+)

Note: Values followed by the same letter within a column are not significantly different at $p < 0.05$ according to Duncan's Multiple Range Test (DMRT).

The best interaction resulting in the highest seedling length in this experiment was observed in K2W1 (10% onion extract, 24-hour soaking). However, this treatment was not significantly different from the control, K3W2 (20% extract, 48 hours), and K4W1 (30% extract, 24 hours). The lowest seedling length was recorded in K1W1 (0% extract, 24 hours), which was not significantly different from all other treatments except K2W1 and K4W1. These findings suggest that moderate concentrations of onion extract combined with shorter soaking durations may support better early seedling growth, whereas the absence of treatment (K1W1) does not necessarily promote seedling elongation. The variation in seedling length across combinations further confirms that the interaction between soaking duration and extract concentration plays a key role in determining early seedling performance.

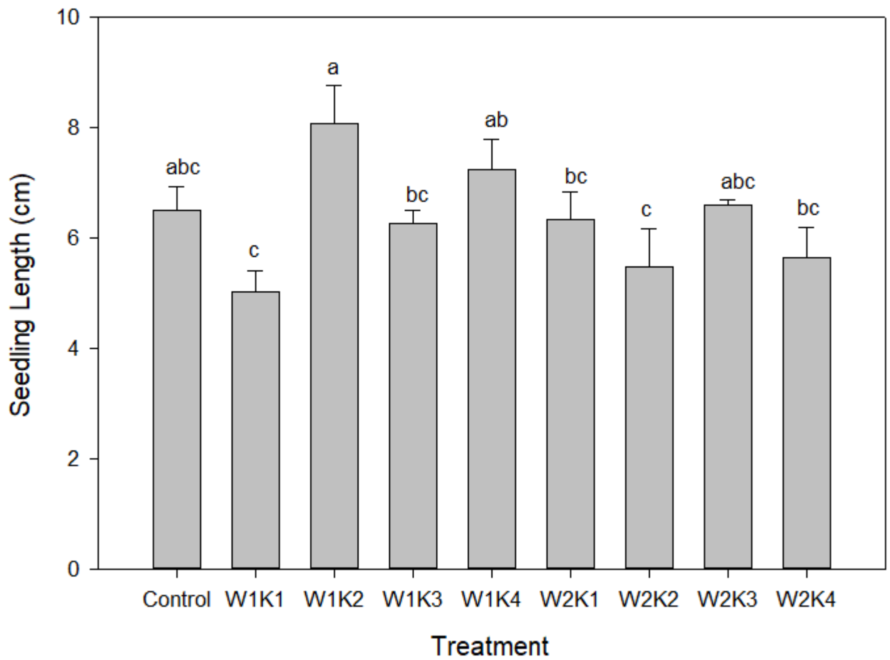

Figure 5. Differences in celery seedling length under the interaction of soaking duration and red onion extract concentration compared to untreated seeds.

4. Discussion

4.1 The Effect of Soaking Duration to the Celery Seed

This study showed that the treatment of celery seeds with various concentrations of red onion extract and soaking durations did not significantly affect the germination percentage. However, it had a significant effect on improving germination power. Soaking the seeds for 24 hours resulted in better germination power compared to 48 hours, suggesting that prolonged soaking may even impair the germination process. Soaking is known to cause temporary oxygen deficiency around the seed. According to Corbineau (2022), oxygen is a key factor in seed germination, as it enables the resumption of respiration and the reactivation of metabolism during seed imbibition, leading to the production of reducing power and ATP. Therefore, hypoxic conditions during prolonged soaking may affect physiological processes and metabolite accumulation in seeds.

Similar results were observed for germination speed index and mean germination time. Soaking for 24 hours consistently resulted in higher values, particularly for the germination speed index, indicating that seeds soaked for 24 hours initiated and progressed through germination more quickly. In addition, seeds soaked for 24 hours also had a lower mean germination time compared to those soaked for 48 hours. This result may be related to compounds leaching out of the celery seed coat and into the soaking solution. As reported by Yan *et al.* (2022), celery contains coumarin, a compound beneficial to human health but potentially harmful to seed germination. Coumarin may leach out from the seed coat during soaking and reduce germination performance if seeds are exposed for too long (Gupta *et al.,* 2024).

Coumarin has previously been tested on rice seeds and was found to suppress seed germination by significantly inhibiting the expression of OsABA8'ox2/3 in the ABA catabolic pathway. Reduced expression of these genes led to decreased OsABA8'ox activity, resulting in slower ABA degradation and increased ABA accumulation compared to water-imbibed seeds (Chen *et al.,* 2019). This increased ABA accumulation is believed to be the reason for the inhibited germination in coumarin-treated seeds. Similarly, Ye *et al.* (2014) reported that copper and glucose inhibit seed germination by interfering with ABA catabolism. It is well established that ABA (abscisic acid) is a plant hormone that promotes dormancy and inhibits seed germination (Jamil *et al.,* 2024). However, Vigor Index II and seedling length were not significantly affected by soaking duration. This could be due to the fact that even 24 hours of soaking may already be considered prolonged for celery seeds. According to Gupta *et al.* (2024), soaking for 12 hours is already sufficient to negatively impact celery seed germination.

4.2 The Effect of Red Onion Extract to Celery Seed Germination

In this study, the treatments involving soaking duration and varying concentrations of red onion extract applied to celery seeds did not show a significant effect on germination percentage. However, these treatments had a significant impact on germination power, germination speed index, and mean germination time. It was found that the seeds with the highest germination power and germination speed index were those not soaked in red onion extract. This suggests that these seeds had better germination performance and initiated the germination process more quickly, as indicated by their lower mean germination time.

In contrast, seeds soaked in 10%, 20%, and 30% concentrations of red onion extract did not show significant differences in germination power, germination speed index, or mean germination time. This may be due to the possibility that these concentrations were too high for celery seeds. Although onion *Allium ascalonicum* L, *Allium cepa*, just like garlic extract, is known as a natural plant growth regulator containing auxins and gibberellins, both beneficial for seed germination, it also contains other compounds, one of which is allicin (Ankri & Mirelman, 1999; Dorrigiv *et al.,* 2021). Allicin can have both positive and negative effects on seed germination performance. It is also commonly used as a natural fungicide. Parello *et al.* (2013) reported that allicin in garlic juice improved poor wheat seed germination caused by the grain's natural mycoflora. However, when seeds are exposed to allicin in excessively high concentrations, it may become phytotoxic, disrupt hormonal balance, and damage cell membranes. In plants, allicin has been shown to inhibit seed germination and suppress root development (Borlinghaus *et al.,* 2014).

Furthermore, red onion also contain allelopathic compounds that can inhibit the growth of other plants. When red onion extract is used in high concentrations during seed imbibition, it may trigger negative allelopathic effects that ultimately reduce germination performance. El Gith (2016) found that onion extract activates allelopathic compounds that significantly affect pea seedlings' germination, growth, and metabolic activity. The allelopathic effects of red onion extract also influenced tomato seed germination, where increasing the extract concentration (to 1%) resulted in lower germination rates compared to lower concentrations (0.1% and 0.3%). This finding aligns closely with the results of the current study, where the 10% extract concentration tended to produce higher germination power and germination index than the 20% and 30% concentrations, with the opposite trend observed in the mean germination time parameter.

Finally, regarding the parameters of vigor index and seedling length, no significant effects were observed from the red onion extract treatments. This further supports the hypothesis that the concentrations of red onion extract used in this study might be useful to enhance the germination of chilli seeds (Dzakwan *et al.,* 2023), but were too high for celery seeds.

4.3 The Effect of Interaction between Soaking Duration and Onion Extract Concentration to Celery Seed Germination

No significant interaction was found between soaking duration and various concentrations of red onion extract on germination percentage. However, the combination of 0% red onion extract and a 24-hour soaking duration resulted in the highest seed germination power, as well as the highest germination speed index, while also producing the lowest mean germination time, eventhough in fact, the result did not significantly different with control (directly sowing the seed withour treatment). The study also found that all concentrations of red onion extract combined with a 48-hour soaking duration led to the lowest germination power and germination index, along with the highest mean germination time.

A different trend was observed for the vigor index and seedling length. The highest vigor index and seedling length were obtained from the interaction treatment of 10% red onion extract and a 24-hour soaking duration. This result was not significantly different with control but significantly different from the interaction treatments using 0% extract at both 24 and 48 hours of soaking. These findings suggest that while onion extract may inhibit germination performance, it could enhance seedling growth at lower concentrations (10%) and with shorter soaking durations. This effect has also been observed in microgreen studies using onion biowaste, where moderate enhancement in growth was reported in *falooda* and *garden cress* seeds treated with onion extract (Patil *et al.,* 2021).

5. Conclusions

The optimal soaking duration for celery seeds was found to be 24 hours, as compared to 48 hours. The concentration of red onion extract used as a natural growth regulator to enhance germination should ideally be lower than 10%. Interestingly, control seeds (untreated) tended to produce results comparable to the best-performing interaction—namely, 0% extract with 24-hour soaking—for parameters such as germination power, germination speed index, and mean germination time. For vigor index and seedling length, the best outcome was observed at a concentration of 10% red onion extract with 24-hour soaking which also comparable with control.

6. References

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