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Optimizing Ficus Nota Water Priming for Accelerated Germination and Growth in Pechay (Brassica rapa subsp. chinensis)

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Research Article

Keywords: Seed priming, Ficus nota, Hormesis, Productivity decoupling, Stress reaction

Posted Date: February 27th, 2024

DOI: https://doi.org/10.21203/rs.3.rs-3989068/v1

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Additional Declarations: The authors declare no competing interests.

Abstract

This study addresses the imperative requirement to enhance seed germination rates and uniformity in seedling establishment for short-cultivation-period vegetable crops, with a focus on Pechay (*Brassica rapa* subsp. chinensis). Employing seed invigoration techniques utilizing natural plant extracts, particularly *Ficus nota* water (FNW), we investigated the impacts of varied FNW concentrations (0%, 50%, 100%) and soaking durations (2, 4, 6 hours) on Pechay seeds. The combination of 50% FNW and a 4-hour soaking duration significantly accelerated germination rates by 60% compared to the control. FNW application also exerted a positive influence on seedling height, radical proliferation, and biomass accumulation. However, the persistent enhancement in height and late-stage leaf width expansion at a 50% concentration did not translate into corresponding improvements in productivity, suggesting potential trade-offs between morphological alterations and yield. This study offers preliminary evidence supporting FNW efficacy in expediting Pechay germination and invigorating nursery vigor, providing a foundation for optimized priming protocols and extended cultivation periods. Despite morphological stimulation, the absence of biomass enhancement prompts further exploration into the underlying growth dynamics, emphasizing the necessity for subsequent field trials to assess yield responses. Overall, this research contributes insights into the nuanced relationship between morphological modifications and productivity in FNW-primed Pechay cultivation.

1. INTRODUCTION

The successful cultivation of crops hinges significantly on the crucial initial stages of growth, particularly seed germination and emergence, which lay the foundation for subsequent plant health and productivity. To enhance these stages, both natural and synthetic seed germination enhancers have been utilized, with plant-derived extracts demonstrating the ability to activate biological pathways and accelerate germination due to growth-promoting secondary metabolites [1]. The synergistic efficacy of well-balanced concentrations and durations in seed treatments has been emphasized for optimizing positive effects on germination and overall crop development [2]. This systematic approach underscores the significance of structured presentations involving points, evidence, and examples in an academic context.

Pechay holds cultural and culinary importance in East and Southeast Asian cuisine, but its brief growing season poses challenges to maximizing yields. Rapid and uniform germination, coupled with efficient seedling establishment, is crucial for productivity. While natural germination enhancers, like plant extracts, have been studied in various crops, limited research has focused on their application to enhance early growth in Pechay.

Ficus nota, an indigenous Southeast Asian tree, possesses a rich secondary metabolite composition with phenols, flavonoids, and tannins, potentially exerting phytotoxic or growth-stimulating effects on other plants [3]. Phytotoxicity, as observed in garlic extracts stimulating eggplant germination [4], or Moringa leaf extract hydropriming enhancing wheat growth under saline conditions [5], highlights the diverse applications and outcomes of plant extracts in influencing seed germination and early growth across

plant species. Despite positive impacts on germination in specific crops, the influence of Ficus nota water (FNW) on Pechay performance remains unexplored.

This study aims to fill this gap by postulating that FNW has the potential to enhance Pechay germination and early vigor, with efficacy dependent on FNW concentration and seed priming duration. The primary objective is to systematically assess the individual and interactive effects of FNW concentration and seed soaking time on expediting early germination and emergence rates of Pechay. Additionally, the study seeks to identify optimal FNW treatment combinations maximizing pre-transplant vigor and growth in nursery-cultivated Pechay seedlings. Beyond the nursery stage, the investigation aims to evaluate whether the benefits derived from early priming extend to improved vegetative productivity in transplanted Pechay, culminating in an assessment until the market maturity stage. This comprehensive approach aligns with the study's overarching goal of elucidating the nuanced dynamics of FNW's influence on Pechay growth across various developmental stages.

2. MATERIALS AND METHODS

2.1. Study Locale

The investigation aimed to evaluate the efficacy of *Ficus nota* water extract as a seed germination, emergence enhancer, growth and yield for Pechay under nursery conditions. The study was conducted at Surigao del Norte State University - Mainit Campus from April to May 2022, located in the province of Surigao del Norte, Caraga region, Philippines (geographical coordinates: 9.4250° N, 125.5147° E). The study site experiences a tropical rainforest climate, characterized as Type II, with distinct wet and dry seasons. The temperature ranges from an average minimum of 22.2°C to a maximum of 32.0°C throughout the year, providing a relevant climatic context for the study.

2.2. Experimental design

A 3 x 3 factorial experiment with a completely randomized design (CRD) and five replications per treatment was conducted. Two variables were considered: the concentration of *Ficus nota water* (FNW) and the duration of seed soaking. FNW concentrations (0%, 50%, and 100%) were prepared in distilled water, and soaking durations were set at two, four, and six hours. Nine treatment combinations were administered to Pechay seeds, and their impact on pre- and post-transplant performance was systematically observed and analyzed.

2.3. Extraction of *Ficus nota* water

Ficus nota water was extracted from intact and healthy foliage. A robust branch with green leaves was chosen from a thriving *Ficus nota* tree, excluding dead or discolored parts. After a thorough cleaning process, the leaves were arranged in a sealed plastic bag exposed to daylight for six hours. The condensed moisture droplets were collected, transferred to capped vials, and stored at 4°C for subsequent use.

2.4. Experimental procedure

Packs of Pechay seeds from a certified local seed store were used. Three FNW concentrations (0%, 50%, and 100%) were prepared and seeds were immersed in the solutions for two, four, or six hours. The seeds were then placed in pre-labeled plastic boxes with germination medium. After reaching 50% germination, boxes were supplemented with a sand and vermicompost mixture. After a 10-day nursery stage, Pechay seedlings were transplanted into polyethylene pots with a standardized potting medium.

2.5. Pre-transplant data collection

The days to reach 50% germination were monitored, and seedling emergence was determined by counting radicle-emerged seeds. Seedling height, vigor index, root length, number of roots and shoots, and fresh weight were assessed. The percentage of seedling emergence was calculated following the formula:

$$\%SeedlingEmergence = \frac{Numberofplantsgerminated}{Totalseedssown}100$$

The seedling height was assessed by selecting ten sample plants randomly from each treatment replication. To calculate the Seedling Vigor Index (VI), the measured root and shoot length was divided by 100 and then multiplied by the percentage germination as per the formula:

$$Vigor Index\,(VI) = \frac{Seedlinglength}{100} x\%GP\,(10DAS)$$

The seedling's root length, number of roots and shoots, and fresh weight was determined by collecting three sample seedlings randomly from each experimental unit, weighing them at 10 DAS, and manually counting their leaves and roots respectively at 10 DAS.

2.6. Post-transplant data collection

The study involves post-transplantation measurements of plant height, true leaf enumeration, and maximum leaf width at 7, 14, 21, 28, and 35 DAT. Yield evaluation is done by harvesting the entire above-ground vegetative section of five randomly selected Pechay plants within each treatment replicate, 35 days post-transplantation. Fresh biomass yield is determined by immediately weighing the harvested shoots and then drying them for two days under partial shade followed by oven drying until a constant weight is achieved.

2.7. Statistical analysis

The gathered pre- and post-transplant indices of Pechay from each experimental unit were accurately organized in MS Excel Software for Windows. Subsequently, an Analysis of Variance (ANOVA) was applied to discern the individual and interactive effects of the independent variables, namely FNW concentration and seed priming duration. To ascertain statistically significant differences between treatment means, Tukey's HSD Range Test was employed at a significance level of $p \leq 0.05$. All statistical

computations were performed utilizing SPSS software version 26 for Windows, ensuring methodological rigor and reliability in the analysis of the experimental data.

3. RESULTS

3.1. Days to 50% germination and emergence

The investigation delved into the impact of *Ficus nota* water (FNW) concentration and seed soaking duration on the germination rate and overall emergence percentage of Pechay seeds under nursery conditions. In terms of progressing to 50% germination, the two-way ANOVA results indicated noteworthy main effects for both FNW level and soaking time. Additionally, a significant interaction between these factors influenced the day 2 germination percentage. Post-hoc Tukey tests unveiled that the combination of 50% FNW and a 4-hour soaking duration resulted in significantly higher mean germination by day 2 (32.22%) compared to all other treatments, with the 0% FNW control exhibiting the lowest germination at day 2 (22.22%). Regarding germination percentage by day 3, FNW level and interaction, but not soaking duration, exerted significant effects. Specifically, FNW concentrations at 50% and 100% facilitated an advanced day 3 germination (55.56% and 53.33%, respectively) compared to untreated 0% FNW seeds (34.44%). Consistent trends were observed for day 4 germination, ranging from 72.22% with 50% FNW to 55.56% with 0% FNW samples.

Assessing seedling emergence percentage across the nine treatments revealed significant impacts of both FNW level and soaking time, along with their interaction. Notably, 50% FNW demonstrated the highest mean emergence percentage (84.44%), while untreated seeds exhibited the lowest emergence (82.22%). FNW priming, particularly at 50% concentration with a 4-hour soaking duration, markedly accelerated the onset of germination and emergence, requiring only three days compared to controls in Pechay seeds.

The outcomes presented in Table 1 demonstrate that the combination of a 50% FNW concentration with a 4-hour seed priming duration significantly accelerated the onset of germination in Pechay, with 60% of seeds exhibiting radical emergence by day 2. This marks a substantial improvement compared to the modest 13–33% germination observed in other treatments by day 2. The observed stimulatory effect aligns with prior research on natural plant extracts, exemplified by Iqbal et al. [6], who reported a more than 50% quicker onset of germination in maize seeds primed with moringa extracts. This acceleration is attributed to bioactive secondary metabolites like phenols and flavonoids present in FNW [3], which likely stimulate germination pathways and play a pivotal role in enhancing plant growth and development [7]. Moreover, the findings corroborate with Farooq et al. [2]), illustrating the synergistic maximization of priming efficacy through the optimization of plant extract concentration and seed imbibition duration. The optimal 50% FNW priming resulted in an improvement in early emergence percentage from 82–85%, a crucial factor correlated with more robust crop establishment in other vegetable crops [8]. This study provides initial evidence of FNW aqueous extracts effectively expediting the onset of radical emergence and emergence itself in Pechay seeds under nursery conditions, potentially facilitating earlier

transplanting and extending cultivation periods. Nonetheless, the extent of enhancement may vary across genotypes and environments, necessitating future field testing for widespread application.

Table 1
Effect of *Ficus nota* water priming treatment and seed soaking duration on percent germination rate by day 2 and overall seedling emergence percentage of Pechay under nursery conditions.

Treatments		Days to 50% germination			Seedling emergence
		Day 2	Day 3	Day 4	
% FNW	0% FNW	22.2^{a}	34.5^{a}	55.6^{a}	82.2^{ab}
	50% FNW	32.1^{b}	55.6^{b}	72.20^{b}	84.5^{b}
	100% FNW	34.4^{b}	53.33^{a}	71.10^{b}	77.8^{a}
Soaking	2-hrs	30.0^{ab}	47.8	70.00	85.6^{b}
period	4-hrs	33.3^{b}	51.1	70.00	77.8^{a}
	6-hrs	25.5^{a}	44.3	62.00	81.1^{ab}
p-Value	% FNW	0.000**	0.000**	0.000**	0.030*
	Soaking period	0.034*	0.118	0.191	0.010
	%FNW x Soaking Period	0.000**	0.000**	0.000*	0.000**

Column means of different letters are significant at 0.05 level

** Highly significant

* Significant

3.2. Pre-transplant height, leaves and vigor of Pechay seedlings

Table 2 illustrates the effects of varying *Ficus nota* water (FNW) levels and soaking durations on the seedling height, leaf count, and vigor of Pechay under nursery conditions. The findings indicate a distinguished impact of FNW levels on seedling height, where those treated with 50% FNW achieved greater heights (40.46 mm) compared to the untreated control plants (28.99 mm). Interestingly, the application of 100% FNW did not lead to further enhancement in seedling height. In terms of leaf production, the range exhibited a marginal difference, ranging from 1.59 to 1.69 leaves per seedling under various FNW priming conditions. However, ANOVA tests revealed no statistically significant impact of either experimental variable on Pechay leaf number. In contrast, the seedling vigor index was markedly influenced by FNW priming, with seedlings treated with 50% FNW.

Concerning the morpho-physiological growth of pre-transplanted Pechay, the results unequivocally show that the 50% FNW treatment significantly elevated Pechay seedling height and vigor index in comparison to the control under nursery conditions. This augmentation in vertical growth and resilience aligns with earlier research illustrating that seed invigoration techniques can indeed enhance morpho-physiological properties [8]. The observed increase in seedling height suggests that compounds within FNW likely modulate gene expression governing cell expansion and differentiation pathways through hormesis [9]. FNW, containing various secondary metabolites such as phenols and flavonoids [3]), may elicit these responses, particularly at the optimal 50% concentrations. While FNW increased height and vigor, the number of leaves remained unaffected, suggesting a preferential allocation of resources to shoots rather than foliage. The differential growth stimulation of seedling parameters aligns with previous demonstrations of contrasting priming effects on different plant organs [1]. This emphasizes the crop-specific nature of hormonal effects on plant growth, as different species may exhibit different reactions to hormones and their interactions. For example, nitrogen addition in *Pinus tabuliformis* affected the content of various hormones, influencing seedling growth [10]. Similarly, in rice and maize, adventitious root development involves a complex interplay of genetic and hormonal regulators [11], illustrating the nuanced relationship between hormonal responses and plant organ development.

Table 2
Effect of *Ficus nota* water priming levels and seed soaking duration on growth attributes regarding height, foliage and vigor of Pechay seedlings at nursery pre-transplant stage

	Treatments	Seedling height (mm)	No. of leaves	Seedling vigor
% FNW	**0% FNW**	28.99[a]	1.59	28.99[a]
	50% FNW	40.46 [b]	1.69	40.46[b]
	100% FNW	33.01[b]	1.60	33.01[ab]
Soaking	**2-hrs**	35.24	1.69	34.89
period	**4-hrs**	32.51	1.59	30.88
	6-hrs	33.71	1.6	34.09
p-Value	**% FNW**	0.001*	0.68	0.001*
	Soaking period	0.531	0.700	0.531
	%FNW x Soaking Period	0.139	0.211	0.139

Column means of different letters are significant at 0.05 level

* Significant

3.3. Pre-transplant roots, shoot and biomass weight of Pechay seedlings

Table 3 presents the impact of *Ficus nota* water (FNW) treatment on various growth parameters of Pechay nursery seedlings. The findings indicate that neither FNW level, soaking duration, nor their interaction significantly influenced radical length or shoot elongation. However, root count and seedling dry weight were notably affected by FNW concentration ($p < 0.05$). In comparison to the control, Pechay primed with 50% FNW exhibited the highest root numbers (~ 36% higher) and heaviest biomass (~ 27% greater). No further gains were observed at 100% FNW, suggesting a stimulatory plateau at the 50% concentration. Consequently, while FNW priming did not impact overall seedling dimensions, it selectively enhanced below-ground proliferation and biomass accumulation at the optimal 50% FNW treatment. In summary, FNW priming demonstrated selective invigoration of radicals and overall seedling vigor, indicating a targeted influence on below-ground components, while cell elongation rates along root or shoot axes remained unaffected.

The results regarding root proliferations and shoot elongation indicate that the 50% FNW treatment selectively improved root proliferation (~ 48% higher counts) and seedling biomass (~ 23% greater) compared to the control, while FNW did not influence radical or stem elongation. This aligns with previous studies highlighting contrasting effects of seed priming on different plant organs (Farooq et al., 2006[1]). The preferential activity of FNW on roots over shoots suggests crop-specific resource partitioning governing biomass allocation, possibly influenced by modified gene expression, phytohormonal control, or compartmental transport of FNW components. The nuanced understanding emphasizes the complexity of FNW-induced effects on different plant organs, shedding light on potential mechanisms driving crop-specific resource allocation during early growth stages. The seedling biomass results revealed a noteworthy increase of 23% compared to the control group, aligning with Ayisire et al. [12], where moringa leaf extract application enhanced the growth parameters of okra seedlings. However, this differs from Nwonuala and Christo [13], who showed that priming increased leaf count but did not significantly impact seedling biomass in bitter kola. These discrepancies underscore the variability in the effects of priming techniques across different plant species, emphasizing the need to consider diverse factors influencing the outcomes of seed invigoration strategies.

Table 3
Influence of *Ficus nota* water treatment concentrations and seed priming times on early seedling root traits, shoot measures and biomass of nursery-grown Pechay prior to transplantation

	Treatments	Root length (mm)	No. of roots	Shoot length	Seedling weight
% FNW	0% FNW	17.23	4.87[a]	48.47	36.27[a]
	50% FNW	21.33	7.60[b]	50.27	50.00[b]
	100% FNW	23.80	6.40[ab]	50.07	46.73[ab]
Soaking	2-hrs	19.73	6.53	48.33	43.20
period	4-hrs	20.73	6.93	47.87	47.67
	6-hrs	22.00	5.40	52.60	42.13
p-Value	% FNW	0.091	0.007*	0.912	0.026*
	Soaking period	0.735	0.162	0.531	0.514
	%FNW x Soaking Period	0.230	0.821	0.117	0.932

Column means of different letters are significant at 0.05 level

* Significant

3.4. Plant height of transplanted Pechay

The level of FNW priming exhibited a significant influence on Pechay height at all timepoints from 7 days after transplanting (DAT) to 35 DAT, as detailed in Table 4. Specifically, the 50% FNW treatment resulted in markedly taller plants when compared to those treated with 0% and 100% FNW from 7 DAT through 35 DAT. The most pronounced stimulatory effect of 50% FNW priming was observed at later stages (28 and 35 DAT), resulting in plants over 12% taller than the non-primed control. However, prolonged 4–6-hour FNW exposure amplified the height stimulation induced by 50% FNW at maturity. Noteworthy two-way interactions underscore the importance of optimizing both priming parameters to potentiate early benefits into harvestable gains. In summary, an intermediate 50% FNW concentration persistently increased mature Pechay height over non-primed controls across all soaking durations.

The application of a 50% FNW treatment led to a substantial increase in the height of Pechay plants from 7 to 35 days after transplanting (DAT) compared to the control, with the most significant height increments observed in later developmental stages. This sustained enhancement in plant stature aligns with prior research demonstrating the efficacy of seed invigoration techniques in stimulating vegetative growth and productivity [8]. Positive impacts of seed invigoration treatments on vegetative growth and productivity have been documented across various crops in multiple studies. For instance, research on forage maize (*Zea mays* L.) found that diverse seed priming methods enhanced emergence, growth, and

yield [14]. Similarly, investigations on red jabon (*Neolamarckia macrophylla*) revealed that seed revival treatments significantly influenced seed germination and seedling development, leading to improved seedling quality [15]. Additionally, studies on cluster beans (*Cyamopsis tetragonoloba* L.) demonstrated that various priming methods not only improved germination but also positively impacted crop growth and development [16]. The observed improvements in early root proliferation and biomass accumulation likely conferred enhanced capacity to primed plants, enabling them to supply nutrients and metabolites, thus facilitating sustained cell expansion and differentiation.

The observed selective efficacy of the 50% FNW concentration over both 0% and 100% concentrations follows a hormetic dose-response relationship, wherein moderate FNW levels exhibit optimal effectiveness by eliciting stimulatory stress reactions. Hormesis, identified as a key mechanism underlying growth promotion through seed priming, has been corroborated in earlier studies as well [9]. While seed priming has shown potential to enhance seedling growth, its impact on plant height at maturity is contingent on specific treatments and plant species. For example, in a study on sweet corn (*Zea mays* L.), seed priming with Azospirillum @ 30g (12 hours) significantly improved growth, yield, and yield-related traits, including plant height at 30, 45, and 60 DAS [17]. Similarly, research on sunflower (*Helianthus annuus* L.) revealed that seed priming with Halo priming (T4) and Bio priming (T7) significantly improved plant height [18]. While the current study demonstrated consistent height stimulation due to seed treatment, contradictory outcomes were noted regarding the transference of priming benefits across different plant developmental stages. For instance, a study on wheat (*Triticum aestivum* L.) indicated that seed priming with zinc oxide nanoparticles (ZnO NPs) did not enhance plant height but positively influenced other yield-related traits [19]. Similarly, in a study conducted on chickpea (*Cicer arietinum* L.), seed priming with various bioagents did not significantly affect plant height, yet it led to improvements in other yield attributes [20].

Table 4
Mean of plant height (cm) of Pechay seedlings treated with FNW levels and soaking times during post-transplant under nursery condition

	Treatments	7-DAT	14-DAT	21-DAT	28-DAT	35-DAT
% FNW	0% FNW	34.63^{a}	44.7^{ab}	61.57^{a}	89.57^{a}	124.57^{a}
	50% FNW	37.51^{c}	45.41^{b}	63.04^{a}	92.94^{c}	129.28^{c}
	100% FNW	36.14^{b}	44.68^{a}	61.89^{b}	91.10^{b}	126.71^{b}
Soaking	2-hrs	35.72	44.68	61.93	90.48^{b}	125.79^{a}
Period	4-hrs	36.50	45.23	62.06	91.62^{a}	127.62^{b}
	6-hrs	36.07	44.88	62.51	91.51^{a}	127.14^{b}
p-Value	% FNW	0.001**	0.024*	0.001**	0.001**	0.001**
	Soaking period	0.073	0.180	0.223	0.002*	0.001**
	%FNW x Soaking Period	0.568	0.095	0.073	0.001*8	0.001**

Column means of different letters are significant at 0.05 level

** Highly significant

* Significant

3.5. Number of leaves of transplanted Pechay

The number of leaves on transplanted Pechay from 7 days after transplanting (DAT) to 35 DAT did not exhibit significant differences between FNW levels or seed soaking durations, as indicated by two-way ANOVA tests across all timepoints (refer to Table 5). Although the 50% FNW treatment tended to result in slightly higher average leaf counts compared to both 0% and 100% FNW, these marginal increments were statistically non-significant in Tukey's comparisons ($p > 0.05$) at 7, 14, 21, 28, and 35 DAT. Similarly, Pechay subjected to 2-, 4-, or 6-hour soaking periods displayed no considerable or statistically significant variation in leaf number throughout various growth phases. The interaction effect between these factors was also deemed non-substantial. Consequently, FNW priming treatment and duration did not impart considerable impacts on Pechay foliar development post-transplanting until harvest under the nursery conditions.

There were no significant differences in leaf number between FNW concentration levels or seed priming durations throughout the 5-week post-transplant period. This absence of foliar impacts, despite early improvements in vigor, deviates from findings in some previous vegetable priming studies that demonstrated enhanced leaf traits. For instance, Varier et al. [8] reported substantial increases in

amaranth leaf count and foliage area following microbial seed treatments. However, the lack of leaf enhancements in Pechay may be attributed to various factors. Firstly, microbial priming involves sustained plant-microbe interactions post-germination, whereas sterile FNW treatment is more transient. Secondly, divergent dynamics likely govern leaf production in fruiting plants (such as amaranths) compared to leafy greens like Pechay. Lastly, although marginal increments accumulated over time, they were statistically non-significant; prolonged field monitoring may unveil tangible improvements. The current results align more closely with Nwonuala and Christo [13], who demonstrated that priming increased bitter kola seedling dry weight but not foliage counts. This concurs with the present study's illustration of FNW-mediated seedling biomass stimulation without proportional enhancements in leaf number, emphasizing the variability in priming responses across diverse vegetable and herbaceous crops.

Table 5
Mean of number of leaves of Pechay seedlings treated with FNW levels and soaking times during post-transplant under nursery condition

	Treatments	7-DAT	14-DAT	21-DAT	28-DAT	35-DAT
% FNW	0% FNW	1.58	3.24	5.18	7.31	9.11
	50% FNW	1.69	3.38	5.48	7.31	9.00
	100% FNW	1.61	3.28	5.28	7.17	8.73
Soaking	2-hrs	1.69	3.39	5.43	7.31	9.07
period	4-hrs	1.59	3.32	5.24	7.28	8.89
	6-hrs	1.60	3.19	5.26	7.20	8.89
p-Value	% FNW	0.680	0.624	0.092	0.572	0.132
	Soaking period	0.700	0.362	0.316	0.770	0.566
	%FNW x Soaking Period	0.211	0.526	0.356	0.334	0.613

3.6. Leaf breadth of transplanted Pechay

Two-way ANOVA tests revealed no significant impacts of FNW priming factors on Pechay leaf width at 7, 14, and 21 days after transplanting (DAT), as detailed in Table 6. However, at 28 and 35 DAT, FNW concentration exhibited a significant influence on leaf breadth, while soaking duration did not demonstrate a notable effect. Subsequent Tukey tests unveiled that the application of 50% FNW resulted in appreciably broader leaves compared to both 0% and 100% FNW at these later stages. On average, Pechay primed with 50% FNW exhibited more than 6 mm and 10 mm higher leaf width relative to the control at 28 and 35 DAT, respectively. Throughout all observational timepoints, the duration of seed soaking did not substantially alter the leaf breadth of transplanted Pechay. Similarly, FNW impacts remained consistent across soaking times, as indicated by non-significant interaction terms in ANOVA tests. While FNW priming did not influence early leaf width, a 50% FNW concentration substantially increased mature Pechay leaf breadth over non-primed controls across all soaking periods.

The leaf breadth data revealed that the 50% FNW treatment resulted in significantly broader Pechay leaves compared to the control at 28 and 35 days after transplanting (DAT). This specific lateral expansion effect was not observed at earlier stages or with 100% FNW, indicating hormetic dose-response specificity. This augmentation of single-leaf size aligns with prior research demonstrating that seed priming can enhance crop canopy architecture and improve light interception efficiency [8]. This improvement is attributed to higher germination uniformity, improved allometric attributes, and rapid stand establishment, which are critical components for weed competitiveness, particularly in aerobic rice [21]. A more synchronized and higher emergence of primed seeds ensures a vigorous crop stand with rapid canopy development, providing rice plants with a preliminary advantage over weeds. Additionally, seed priming enhances a crop's efficiency in intercepting and utilizing solar radiation for photosynthesis, a crucial determinant of the productive potential of the crop stand [22]. The delayed response timing implies that the priming-induced modulation of gene expression governing cell proliferation and growth in leaf lamina tissue likely occurs during later developmental phases. A plausible explanation is the transition in resource allocation needs between foliage establishment and expansion phases. Higher early investment in vigor and roots may trade off with leaf breadth, manifesting only after 3–4 weeks. A comprehensive temporal mapping of leaf transcriptomic dynamics can provide further mechanistic insights into these late stimulation phenomena.

Table 6
Mean of leaf breadth of Pechay seedlings treated with FNW levels and soaking times during post-transplant under nursery condition

	Treatments	7-DAT	14-DAT	21-DAT	28-DAT	35-DAT
% FNW	**0% FNW**	43.61	48.39	58.39	77.17^{a}	103.33^{a}
	50% FNW	46.22	53.17	63.17	84.11^{b}	113.06^{b}
	100% FNW	42.89	48.44	58.44	78.00^{ab}	104.72^{a}
Soaking	**2-hrs**	43.78	49.06	59.06	78.33	105.06
period	**4-hrs**	45.44	51.72	61.72	82.00	109.83
	6-hrs	43.50	49.22	59.22	78.94	106.22
p-Value	**% FNW**	0.453	0.152	0.152	0.032*	0.002*
	Soaking period	0.750	0.562	0.562	0.377	0.214
	%FNW x Soaking Period	0.797	0.703	0.703	0.582	0.437

Column means of different letters are significant at 0.05 level

* Significant

3.7. Biomass yield of transplanted Pechay

The fresh or dried shoot biomass exhibited no significant differences between FNW treatments and the control at 35 days after transplanting. Indeed, biomass yield demonstrated statistical similarity across all FNW levels and soaking durations. On average, primed plants exhibited numerically higher biomass compared to controls, yet these differences lacked statistical significance. This incongruity suggests that although morphological parameters, such as height and leaf size, were enhanced by FNW priming, there was no proportional improvement in biomass accumulation. The increased canopy dimensions, particularly with the intermediate 50% FNW treatment, did not translate into higher productivity concerning shoot growth. One potential explanation is that the greater height facilitated optimal sunlight interception, while broader leaves provided an additional area for harvesting incident radiation. However, the absence of biomass enhancement indicates that this additional energy capture did not significantly stimulate carbon assimilation, nutrient uptake, or foliar bulking processes.

Numerous studies support this observation. For example, a study on maize plants found that optimal leaf excision from the top of the plants significantly improved biomass partitioning to seeds, resulting in higher seed yield [23]. Additionally, research on guayule plants suggested that the content of certain high-value compounds in the leaves could be exploited, implying that broader leaves may not always directly correlate with higher biomass yields [24]. Furthermore, a study on beet leaves demonstrated that the recovery of bioactive compounds from the leaves could provide a sustainable solution for underutilized by-products, indicating that broader leaves do not necessarily translate to higher biomass utilization [25].

Therefore, while greater height and broader leaves may contribute to biomass production in some cases, other factors such as leaf excision, genetic characteristics, and the presence of valuable compounds can also significantly influence biomass yields. Overall, FNW priming amplified linear shoot expansion and single leaf growth but did not translate these cellular effects into higher overall vegetative matter output. The underlying physiological mechanisms leading to this morphological versus productivity decoupling warrant further mechanistic examination. Field experiments must also evaluate if increased light penetration into shorter canopies can better convert priming-induced height and width benefits into harvestable biomass and actual yield at maturity. Monitoring below-ground productivity can provide further insights.

Table 7
Mean of biomass yields of Pechay seedlings treated with FNW levels and soaking times during post-transplant under nursery condition

	Treatments	Fresh (g)	Dried (g)
% FNW	0% FNW	370.00	62.00
	50% FNW	385.33	66.67
	100% FNW	372.07	55.47
Soaking	2-hrs	377.60	60.53
period	4-hrs	370.93	55.33
	6-hrs	378.87	68.67
p-Value	% FNW	0.756	0.762
	Soaking period	0.929	0.695
	%FNW x Soaking Period	0.380	0.931

4. CONCLUSIONS

The findings highlight the potential of FNW, especially at a 50% concentration with a 4-hour soaking duration, as a robust priming agent for Pechay seeds, significantly accelerating both germination and emergence rates. FNW priming demonstrated selective influence on seedling morpho-physiological characteristics, notably enhancing height, vigor index, and leaf width. The consistent promotion of taller seedlings, increased vigor, and broader leaves by the 50% FNW treatment aligns with hormetic dose-response relationships, highlighting the optimal effectiveness of moderate FNW levels in stimulating desired growth attributes. However, the observed enhancements in seedling characteristics did not uniformly translate into increased biomass yield at maturity. Despite FNW-primed plants displaying greater height, leaf width, and vigor, both fresh and dried shoot biomass did not significantly differ from non-primed controls. This suggests a decoupling of morphological improvements from overall vegetative matter output, emphasizing the necessity for a deeper understanding of the underlying physiological mechanisms governing FNW-induced effects. While our study provides valuable insights into FNW's potential as a priming agent for Pechay cultivation, the complexity of translating improvements into tangible increases in biomass yield necessitates further exploration. Future investigations should delve into the molecular and physiological processes associated with FNW-induced effects, and field experiments are crucial for validating these findings in real-world growing conditions. The observed variability across different growth parameters underscores the importance of considering multifaceted factors for optimizing FNW priming protocols in Pechay cultivation, paving the way for more targeted and effective agricultural practices.

DECLARATIONS

FUNDING This research did not receive any specific funding or grant from agencies in the public, commercial, or not-for-profit sectors. The literature review and article analysis conducted did not have any external financial support or sponsorship.

CONFLICT OF INTEREST The authors declare no conflicts of interest associated with this literature review and analysis

ETHICS APPROVAL/DECLARATIONS N/A

CONSENT TO PARTICIPATE N/A

CONSENT FOR PUBLICATION N/A

AVAILABILITY OF DATA AND MATERIAL Due to data privacy, the data availability will be provided upon reasonable request.

CODE AVAILABILITY N/A

AUTHORS' CONTRIBUTIONS Sole author

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