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RESEARCH ARTICLE
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Seed priming with various chemical agents stimulates the germination and growth attributes synergistically in wheat (*Triticum aestivum* L.) varieties

Osmoacondicionamiento de semillas con diversos agentes químicos estimula sinérgicamente la germinación y los atributos de crecimiento en variedades de trigo (*Triticum aestivum* L.)

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Abstract

Seed priming is a pre-sowing technique that involves the soaking of seeds in water or other solutions to initiate germination and early growth. This study explores the impact of different seed priming solutions on both the germinate on rate and overall performance of the wheat varieties Banganga and Bijaya. The seeds were subjected to different treatments, including polyethylene glycol (PEG) (10 %), boric acid (0.1 %), urea (2 %), polyethylene glycol (PEG) (5 %), $ZnSO_4$ (2 %), MoP (2 %), DAP (2 %), $CaCO_3$ (2 %), and with untreated seeds serving as the control. There was significant variation among the seed priming agents and that they also had a significant effect on the germination percentage, speed of germination, and seedling growth of wheat. $CaCO_3$ (2 %), DAP (2 %), and untreated seeds were found to be the most effective priming solutions, showing superiority in all parameters measured, including shoot length, root length, and fresh weight. Furthermore, Bijaya exhibited higher germination parameters, while Banganga displayed better growth parameters. In conclusion, the findings suggest that using Bijaya with DAP (2 %) or $CaCO_3$ (2 %) as seed priming agents can significantly improve the germination and growth parameters of wheat seedlings. This research sheds light on the potential of various chemical agents applied during seed priming to enhance the germination and growth of two different varieties of wheat.

Keywords: *Priming; Wheat; Physiological and Morphological Characteristics; Chemical priming*

Resumen

El osmoacondicionamiento de semillas es una técnica previa a la siembra que implica remojar las semillas en agua u otras soluciones para iniciar la germinación y el crecimiento temprano. En este experimento, se investigaron los efectos de diversas soluciones de primado de semillas en la tasa de germinación y el rendimiento general de las variedades de trigo Banganga y Bijaya. Las semillas fueron sometidas a diferentes tratamientos,

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incluyendo glicol de polietileno (PEG) (10 %), ácido bórico (0.1 %), urea (2 %), glicol de polietileno (PEG) (5 %), $ZnSO_4$ (2 %), MoP (2 %), DAP (2 %), $CaCO_3$ (2 %), y se utilizaron semillas no tratadas como control. Hubo una variación significativa entre los agentes de osmoacondicionamiento de semillas y también tuvieron un efecto significativo en el porcentaje de germinación, velocidad de germinación y crecimiento de plántulas de trigo. Las soluciones de $CaCO_3$ (2 %), DAP (2 %) y las semillas no tratadas resultaron ser más efectivas, mostrando superioridad en todos los parámetros evaluados, incluyendo longitud del brote, longitud de la raíz y peso fresco. Además, Bijaya mostró parámetros de germinación más altos, mientras que Banganga presentó mejores parámetros de crecimiento. En conclusión, los hallazgos sugieren que el uso de Bijaya con DAP (2 %) o $CaCO_3$ (2 %) como agentes de *priming* de semillas favorece la germinación y crecimiento de las plántulas de trigo. Esta investigación arroja luz sobre el potencial de varios agentes químicos aplicados durante la osmoacondicionamiento de semillas para mejorar la germinación y el crecimiento de dos variedades diferentes de trigo.

Palabras clave: *Priming; Trigo; Características Fisiológicas y Morfológicas; Osmoacondicionamiento químico*

1 Introduction

Behind maize and rice crops, wheat is the third-fastest-growing cereal crop in the world, and it is regarded as a staple diet in South Asian nations where the population is constantly growing (Faisal et al., 2023). Wheat farming is tough despite the rising demand for its output because wheat is vulnerable to several abiotic stresses (Kanjevac et al., 2023). However, 91 % of the world's wheat-growing region is exposed to environmental pressures, with around 50 % of production losses attributed to diverse abiotic stresses such as drought (9 %), salinity (10 %), hot temperature (20 %), and low temperature (7 %) (Mickky, 2022). Environmental conditions have a direct impact on seed germination, a critical step that determines plant development and output (Iqra et al., 2020). Low osmotic potential caused by drought stress prevented seeds from germinating by inhibiting water intake (Alam et al., 2022). A simple method for reducing stress on farms is seed priming, which uses a small amount of the priming chemical and has minimal negative effects on soil fertility (Farooq et al., 2022). Farmers have been removing biotic and abiotic stress factors for a very long time thanks to a promising seed-priming technology that provided ground-breaking media that supports close monitoring (Bhusal & Thakur, 2020). Pre - treatments in wheat are therefore a successful method for reducing the negative consequences of drought stress (Günay et al., 2022). After being sowed, seeds spend a lot of time just soaking up moisture from the ground. Seed germination and seedling emergence are quicker if this period is reduced via immersing seeds in water before sowing (Chakma et al., 2020). A simple, affordable, and frequently used method for increasing drought tolerance in many crops, including wheat, is seed priming (Asaduzzaman et al., 2021). This pre-sowing seed treatment involves soaking the seeds in priming media up until the second stage of germination, which can vary from crop to crop, and then drying them in the shade (Devi et al., 2022).

Pre-germination alterations are typically induced by a variety of seed priming approaches, such as hydropriming, osmopriming, chemical priming, nutritional priming, hormone priming, and redox priming (Mim et al., 2022). Osmopriming is a specific term for soaking seeds in aerated low-water potential solutions, which is a sort of primed seed priming (Abdullahi et al., 2021). Different field crops, including cereals, have benefited from priming treatments such as hydro-priming, which are efficient in enhancing seed vigor (Bhusal & Thakur, 2020). According to several studies, seed priming boosts yield potential by accelerating the metabolism of maturing seeds, which results in longer leaves, more tillers, taller plants, and biochemical changes (Mutum et al., 2021). Priming primarily targets the delayed stage of seed germination and hastens gene expression, DNA repair rates, enzyme activation, and metabolite buildup (Ambreen et al., 2021). Plant establishment, allometric characteristics, yield-contributing factors, biological yield, grain yield, and harvest index were all improved by seed priming (Hussian et al., 2019; Kanjevac et al., 2023). Although seed priming increased emergence, stand establishment, tiller numbers, allometry, grain and straw yield, and harvest index (Liela et al., 2010), it had no effect in certain experiments on plant height, spikelet number, grain number, or weight per 1000 grains (Esatu et al., 2022; Zada et al., 2020). Faster emergence, better and more uniform stands, robust plants, improved drought tolerance, earlier flowering, and increased grain production in many crops are direct advantages of seed priming (Chakma et al., 2020; Yang et al., 2021). Increasing a plant's resilience to harsh climatic circumstances and reducing the impact of various types of abiotic stress on wheat plants are two additional advantages of seed priming (Khaing et al., 2020; Mickky, 2022). Additionally, seed priming has been discovered as a technology to reduce the time needed for germination and might enable the seedlings to escape from the worsening physical conditions of the soil (Sharma et al., 2022).

Physiologically, seed priming involves drying and hydrating seeds to speed up metabolic processes prior to germination (Günay et al., 2022). It significantly improved several elements of seed germination (Abdullahi et al., 2021). These priming methods are frequently used to synchronize and shorten the time between seed germination and seedling emergence (Liela et al., 2010). The priming method simulates the process of hydrating seeds with solutions of various osmotic potentials that start germination but prevent the development of radicles by inducing specific metabolic activities (such as protein synthesis, repair, or synthesis of new mitochondria) (Kanjevac et al., 2023). Wheat seeds have also been effectively primed with water in the past (Giri & Schillinger, 2003). Recent studies have found that seed priming treatments can improve germination and establishment in a variety of crops, including canola, maize, wheat, and rice. Treatments for seed priming include both controlled and uncontrolled water uptake systems (Abdullahi et al., 2021). For the early seedling establishment, enhanced growth in terms of more productive tillers, 1000-grain weight, and grains per spike, which ultimately led to higher grain yields under abiotic challenges, several researchers used different seed priming methods (Faisal et al., 2023). Wheat seedling vigour and germination have been demonstrated to be enhanced by primed seeds in solutions of macro- and micronutrients (Mim et al., 2022; Faisal et al., 2023).

This research aims to examine how various chemical agents used in seed priming affect the germination rate and growth parameters of wheat. It identifies the most effective seed priming agent for enhancing germination percentage, speed, and seedling growth. The study evaluates the performance of two wheat varieties, Banganga and Bijaya, under different seed priming agents. The goal is to contribute to knowledge about seed priming techniques for enhancing wheat seedling growth. Ultimately, the findings can guide the development of seed priming protocols to improve wheat cultivation efficiency and productivity.

2 Methods and Methodology

2.1 Experiment site

The study was carried out at GPCAR, Gothgaun Morang, between November 12, 2022, and December 12, 2022. The research site is characterized by a tropical climate, with an average annual temperature ranging between 22.81 °C to 32.46 °C. Detailed meteorological data throughout the research period are depicted in Figure 1.

2.2 Plant materials

Two local varieties of wheat, namely Banganga and Bijaya, were selected for this study. The wheat seeds were procured from Nepal Agricultural Research Council (NARC), Tarahara, Sunsari, and were used for the experiment.

2.3 Seed priming treatments

Eight different priming solutions and a control were used in the laboratory experiments as treatments. The specific seed priming agents used in the study are detailed in Table 1. Each treatment was prepared by adding the recommended dose of the respective priming solution to 500 ml of water, followed by soaking the seeds in the solution for 18 hours. The soaked seeds were then left to dry for 3 hours before sowing. For each replication, 50 seeds were sown on blotting paper, and 25 seedlings from each replication were randomly selected and transplanted into trays.

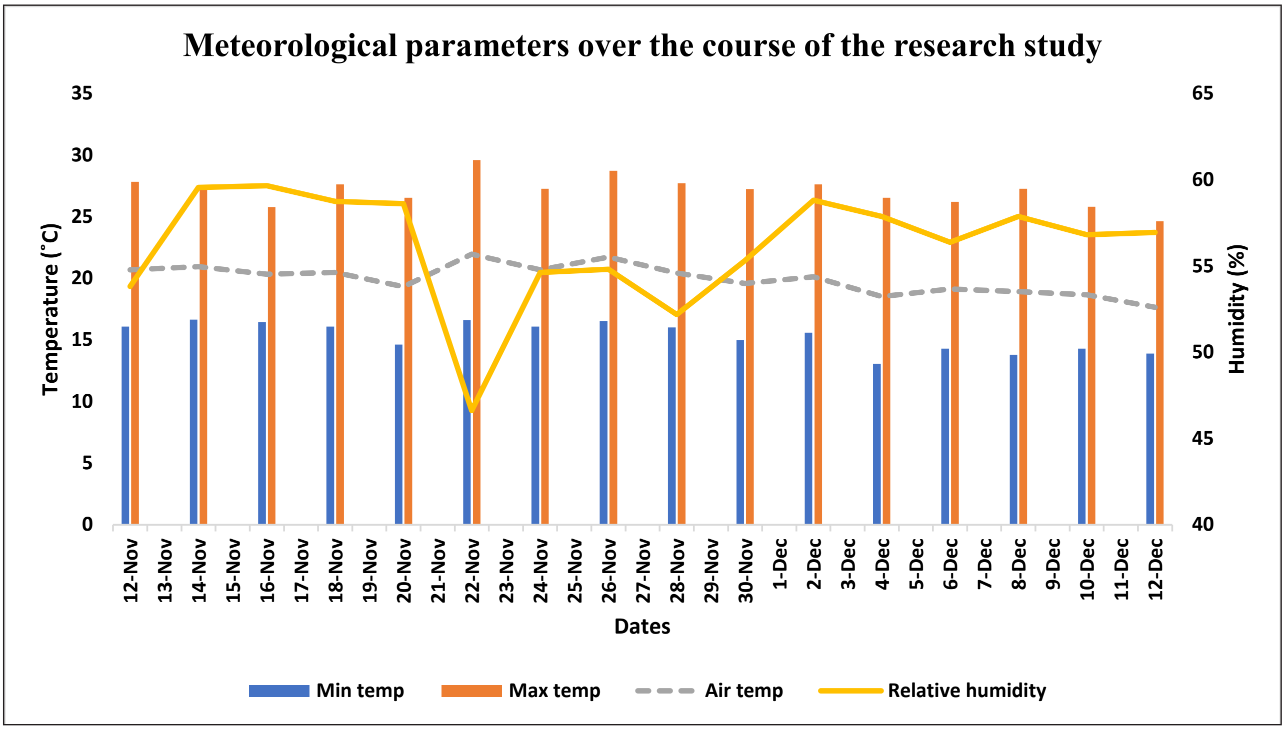

Figure 1. Meteorological parameters over the course of the research study.

Table 1. Various priming agents used in the study.

S. N.	Priming agents	Doses
1	Polyethylene glycol (PEG)	10 %
2	Boric acid	0.1 %
3	Urea	2 %
4	Polyethylene glycol (PEG)	5 %
5	Diammonium phosphate (DAP)	2 %
6	Calcium carbonate ($CaCO_3$)	2 %
7	Muriate of potash (MoP)	2 %
8	Zinc sulfate ($ZnSO_4$)	2 %
9	Control	-

2.4 Data collection and observation

The number of seed germinations was assessed daily for seven days following sowing. Twenty-five seedlings from each replication were randomly selected and transplanted into trays. After every 10-day interval, five seedlings were randomly uprooted, analysed, and destroyed. The growth and germination parameters were then recorded.

2.4.1 Germination parameters

In this study, the germination parameters that were assessed included germination percentage, germination speed, germination energy, and vigor index. Germination percentage refers to the ratio of viable seeds that successfully grow into plants under ideal growing conditions. Likewise, the total number of seeds that germinated each day was included in the computation of seed germination speed. The germination energy is defined as the percentage by which the number of seeds germinates within a definite period in a given sample. Further, the vigour index illustrates a seed's capacity to control its degree of activity and performance throughout germination and emergence.

$$\text{Germination Percentage} = \frac{\text{No. of seeds germinated}}{\text{Total no. of seeds sown}} \times 100 \quad \text{(Eq. 1)}$$

$$\text{Speed of Germination} = \frac{\text{No. of seeds germinated in 72 hours}}{\text{No. of seeds germinated in 168 hours}} \times 100 \quad \text{(Eq. 2)}$$

$$\text{Germination Energy} = \text{Percentage of seed germinated in 72 hours} \quad \text{(Eq. 3)}$$

$$\text{Vigor Index} = \text{Seedling length} \times \text{Germination Percentage} \quad \text{(Eq. 4)}$$

The formulas used to calculate these germination parameters are as follows: Eq. 1 for germination percentage (Mim et al., 2022), Eq. 2 for speed of germination (Rahman et al., 2019), Eq. 3 for germination energy (Koirala et al., 2019), and Eq. 4 for vigour index (Kandil et al., 2012; Yadav et al., 2023).

2.4.2 Growth parameters

Root and shoot length were determined by uprooting five randomly selected seedlings and measuring their roots and shoots using a measuring scale, respectively. The measurements were recorded at 10, 20, and 30 days after sowing (DAS). Similarly, fresh weight was determined by weighing five fresh plants using an electronic weighing machine, while dry weight was determined by weighing five dry seedlings that were dried using the air-dry method.

2.5 Statistical analysis

The research was conducted in a completely randomized design with two factors, namely the priming agent (consisting of nine levels) and priming wheat variety (consisting of two levels), and each treatment was replicated thrice. The data collected from the experiment were inputted into Microsoft Excel (2019) and analysed using Gen-stat (18th edition). To compare the means of the parametric data, the Duncan Multiple Range Test (DMRT) was used as a statistical method (Gomez & Gomez, 1984). Moreover, the R-studio software (4.2.2 Version) with the daewr, gvlma, and agricolae packages were employed to analyse the interaction effect between the landraces and treatments.

3 Results and Discussions

3.1 Effect of priming agents on germination parameters

The result showed that the effect of different priming agents on germination parameters is very highly significant for germination percentage, germination speed, and germination energy at ($p < 0.001$) and highly significant for vigour index at ($p < 0.01$) (Table 2). Among the different varieties of wheat, Bijaya shows the highest value of germination parameters such as germination percentage, germination speed, germination energy, and vigour index under different priming agents as compared to the Banganga. Further, the average germination percentage was found to be 74.59 % when different priming agents were used in wheat varieties. Additionally, the average germination speed, germination energy, and vigor index were found to be 87.47 %, 65.56 %, and 1992, respectively, in both wheat varieties. Among different treatments used in seed priming, Control (84), $CaCO_3$ (82.33) and DAP (82.33) show maximum germination percentage followed by PEG 5 %, PEG 10 % and Boric acid respectively. Urea (72) and $ZnSO_4$ (69.33) show moderate germination while MOP (53) shows

Table 2. Effect of different priming agents on germination parameters of wheat.

Variety	Germination (%)	Germination speed (%)	Germination energy (%)	Vigor index
Banganga	69.48	83.73	58.30	1893
Bijaya	79.70	91.21	72.81	2090
Grand Mean	74.59	87.47	65.56	1992
SEM±	1.758	1.205	1.773	71.1
$LSD_{0.05}$	3.565	2.444	3.596	144.1
F-test	***	***	***	**
Treatments				
Boric acid (0.1 %)	75.67^{ab}	85.15^{bc}	64.67^{cd}	2008^{ab}
$CaCO_3$ (2 %)	82.33^{a}	89.05^{abc}	73.67^{ab}	2230^{a}
DAP (2 %)	82.33^{a}	86.52^{abc}	71.33^{abc}	2113^{ab}
MoP (2 %)	53.00^{c}	83.33^{c}	44.33^{e}	1480^{c}
PEG (10 %)	76.33^{ab}	86.63^{abc}	66.33^{bcd}	2179^{a}
PEG (5 %)	76.33^{ab}	91.95^{a}	70.33^{abc}	1942^{ab}
Urea (2 %)	72.00^{b}	87.69^{abc}	63.33^{cd}	1948^{ab}
$ZnSO_4$ (2 %)	69.33^{b}	86.07^{abc}	59.67^{d}	1819^{b}
Control	84.00^{a}	90.81^{ab}	76.33^{a}	2204^{a}
SEM±	3.728	2.556	3.761	150.7
$LSD_{0.05}$	7.562	5.184	7.628	305.7
F-test	***	*	***	***

*Significant at 5 % level of significance, **Significant at 1 % level of significance, ***Significant at 0.1 % level of significance, ^{NS}Non-significant, LSD: Least significant difference, SEM: Standard error of the mean, CV: Coefficient of variation a minimum germination percentage. Similarly, PEG (91.95) at 5 % shows maximum germination speed followed by control (90.81), $CaCO_3$ (89.05), Urea (87.69), PEG (86.63) at 10 %, DAP (86.52), $ZnSO_4$ (86.07), Boric acid (85.15) and MOP (83.33) gives minimum germination speed respectively (Table 3). Control (76.33) provides maximum germination energy which is followed by $CaCO_3$ (73.67), DAP (71.33), PEG (70.33) at 5 % and MOP (44.33) gives minimum germination speed respectively. Alike, $CaCO_3$ (2230), Control (2204), and PEG (2179) at 10 % give the highest vigour index followed by DAP (2113), boric acid (2008), Urea (1948), PEG (1942) at 10 % and MOP (1480) shows the lowest value of vigour index respectively.

Seed germination is mostly interlinked with plant growth and overall productivity since different environmental factors are responsible for each stage of growth and germination affecting the physiology and botany of newly grown seedlings (Günay et al., 2022). For establishing healthy seedlings' tolerance to environmental stress, different pre-sowing treatments with priming agents in seeds are performed for a positive impact on germination, seedling growth and vigour in wheat crops (Khaing et al., 2020). In this study priming agents are found to force lower germination percentages than those when untreated in both wheat varieties. Contrary to this, the research from Mim et al. (2022) revealed that priming agents brought a positive impact on different germination parameters like seed germination and seedling vigour in wheat varieties. This may be due to genetic variability and differences in the concentration of priming solution being used for soaking seeds. Germination speed is enhanced by PEG 5 % solution in our experiment. This is supported by Abdullahi et al. (2021) who indicated a minimum time of 50 % germination when osmo-priming with PEG 8000 at - 0.6 MPa osmotic potential was performed. Our experiment is actually in line with Zada et al. (2020) who suggested that seed priming with a duration of more than 18 hours in any priming agent decreases the rate of seeds germination as well as other germination parameters. In support of this. Esatu et al. (2022) observed the highest germination percentage in wheat seeds primed with seed-soaked distilled water while lower germination and vigour in unprimed seeds. As indicated by different experiments, priming agents provided a suitable medium for wheat varieties serving as pre-sowing treatment with a wide range of tolerance against

Table 3. Interaction of different priming agents on germination parameters of wheat.

Interaction of treatment		Germination (%)	Germination speed (%)	Germination energy (%)	Vigor index
Variety	Seed priming				
Banganga	Boric acid (0.1 %)	71.33[de]	81.19[def]	58.00[fgh]	2027[abcd]
	$CaCO_3$ (2 %)	76.00[cde]	84.19[cde]	64.00[defg]	2255[ab]
	DAP (2 %)	78.00[bcde]	80.11[ef]	62.00[defgh]	2062[abcd]
	MoP (2 %)	50.67[g]	75.13[f]	38.00[i]	1437[f]
	PEG (10 %)	72.00[de]	83.35[cde]	60.00[efgh]	2124[abcd]
	PEG (5%)	67.33[e]	89.98[abc]	60.67[defgh]	1692[cdef]
	Urea (2 %)	66.00[ef]	84.87[bcde]	56.00[gh]	1786[bcdef]
	$ZnSO_4$ (2 %)	66.67[e]	84.28[cde]	56.00[gh]	1639[def]
	Control	77.33[bcde]	90.46[abc]	70.00[cdef]	2017[abcd]
Bijaya	Boric acid (0.1 %)	80.00[abcd]	89.12[abcd]	71.33[abcde]	1990[abcde]
	$CaCO_3$ (2 %)	88.67[ab]	93.92[a]	83.33[a]	2205[ab]
	DAP (2 %)	86.67[abc]	92.94[ab]	80.67[abc]	2165[abc]
	MoP (2 %)	55.33[fg]	91.54[abc]	50.67[h]	1523[ef]
	PEG (10 %)	80.67[abcd]	89.91[abc]	72.67[abcd]	2235[ab]
	PEG (5 %)	85.33[abc]	93.92[a]	80.00[abc]	2193[abc]
	Urea (2 %)	78.00[bcde]	90.51[abc]	70.67[bcde]	2110[abcd]
	$ZnSO_4$ (2 %)	72.00[de]	87.86[abcde]	63.33[defg]	1998[abcde]
	Control	90.67[a]	91.17[abc]	82.67[ab]	2391[a]
CV (%)		8.7	5.1	9.9	13.1
SEM±		5.273	3.615	5.319	213.2
$LSD_{0.05}$		10.694	7.331	10.788	432.3
F-test		NS	NS	NS	NS

NS: Non-significant, LSD: Least significant difference, SEM: Standard error of the mean, CV: Coefficient of variation external stress (Asaduzzaman et al., 2021; Faisal et al., 2023; Mim et al., 2022).

3.2 Effect of priming agents on growth parameters

3.2.1 Shoot length and root length

The result of our study gives non-significant results for shoot length (cm) at 10, 20 and 30 DAT while these agents give a very highly significant ($p < 0.001$) effect at 10 and 20 DAT where highly significant ($p < 0.01$) effect at 30 DAT for root length (Table 4). The overall mean value of shoot length gives a minimum value at 10 DAT and goes on increasing and attains a maximum value at 30 DAT. Similarly, the average value of root length provides minimum values at 10 DAT and maximum at 30 DAT. Due to Treatment, the result shows highly significant ($p < 0.01$) results at 10 DAT and Non-significant output at 20 and 30 DAT for shoot length respectively. Likewise, findings from our study provide very highly significant ($p < 0.001$) data for root length at 10 and 20 DAT and non-significant data at 30 DAT. Within shoot length, PEG (27.13) at 10 % gives the highest value followed by MOP (26.94), Urea (26.02), control (25.75), PEG (25.20) at 5 %, $ZnSO_4$ (24.61), $CaCO_3$ (24.35), Boric acid (23.81) and DAP (23.62) gives the lowest values at 30 DAT respectively. Under root length, the results show increasing trends from 10 DAT to 30 DAT. PEG (9.44), $CaCO_3$ (9.08), and Boric acid (8.88) give the maximum values of root length followed by MOP (8.39), $ZnSO_4$ (8.38), Urea (8.34), Control (8.14), DAP (8.13) and PEG (7.00) at 5 % gives the lowest value at 30 DAT respectively (Table 5).

3.2.2 Fresh weight and dry weight

The research in wheat priming reveals that the fresh weight of variety Bijaya is higher as compared to the variety Banganga at 10, 20 and 30 DAT respectively when different priming agents are used. The result showed that data were non-significant at 10 DAT, significant ($p < 0.1$) at 20 DAT and very highly significant ($p < 0.001$) at 30 DAT (Table 6). Similarly, the treatments used in research give a non-significant result at 10 and 20 DAT whereas, the result gives highly significant data at 30 DAT. $CaCO_3$ (0.355) gives the highest fresh weight at 30 DAT followed by DAP (0.325), and $ZnSO_4$ (0.313) and the lowest fresh weight was given by PEG (0.243)

Table 4. Effect of different priming agents on shoot and root length of wheat.

Variety	Shoot length (cm)			Root length (cm)		
	10 DAT	20 DAT	30 DAT	10 DAT	20 DAT	30 DAT
Banganga	13.11	21.21	24.96	5.930	7.468	8.89
Bijaya	13.29	20.28	25.58	5.326	6.465	7.96
Grand Mean	13.20	20.74	25.27	5.628	6.966	8.42
SEM±	0.320	0.780	0.668	0.1723	0.1731	0.336
$LSD_{0.05}$	0.648	1.581	1.354	0.3494	0.3510	0.682
F-test	NS	NS	NS	***	***	**
Treatments						
Boric acid (0.1%)	11.84^{bd}	21.03^{a}	23.81^{bc}	6.19^{ab}	7.94^{a}	8.88^{a}
$CaCO_3$ (2%)	14.14^{a}	19.87^{a}	24.35^{abc}	6.58^{a}	7.64^{ab}	9.08^{a}
DAP (2%)	13.39^{abc}	19.94^{a}	23.62^{c}	5.12^{cd}	6.50^{de}	8.13^{ab}
MoP (2%)	13.24^{abcd}	22.49^{a}	26.94^{ab}	5.46^{bcd}	7.10^{bcd}	8.39^{ab}
PEG (10%)	13.41^{ab}	21.84^{a}	27.13^{a}	6.55^{a}	7.47^{abc}	9.44^{a}
PEG (5%)	14.38^{a}	19.15^{a}	25.20^{abc}	4.67^{d}	5.86^{e}	7.00^{b}
Urea (2%)	13.18^{abcd}	21.90^{a}	26.02^{abc}	5.25^{cd}	6.46^{de}	8.34^{ab}
$ZnSO_4$ (2%)	12.92^{abcd}	20.54^{a}	24.61^{abc}	5.11^{cd}	6.94^{bcd}	8.38^{ab}
Control	12.30^{bcd}	19.91^{a}	25.76^{abc}	5.69^{bc}	6.76^{cd}	8.14^{ab}
SEM±	0.678	1.654	1.417	0.365	0.367	0.714
$LSD_{0.05}$	1.375	3.354	2.873	0.7413	0.7445	1.448
F-test	**	NS	NS	***	***	NS

**Significant at 1 % level of significance, ***Significant at 0.1 % level of significance, NS: Non-significant, LSD: Least significant difference, SEM: Standard error of the mean, CV: Coefficient of variation at 10 %. Same as the above, the study provides highly significant ($p < 0.01$) data at 10 DAT whereas, significant ($p < 0.1$) at 20 DAT and non-significant at 30 DAT. Alike, the variety Bijaya observed the highest dry weight as compared to the Banganga at 10, 20, and 30 DAT respectively. Similarly, because of the treatment the study showed non-significant data at 10 and 30 DAT whereas highly significant data at 20 DAT. At 20 DAT, variation in dry weight was observed where Boric acid (0.052) gives maximum dry weight followed by PEG (0.041) at 5 %, PEG (0.040) at 10 %, control (0.040) whereas lowest dry weight was observed in $CaCO_3$ (0.027). Similarly, at 30 DAT, no variation was observed (Table 7). The data were almost similar in all treatments.

Priming agents can significantly improve plant height, root length, and fresh and dried weight of seedlings in wheat varieties (Zada et al., 2020). Different studies have shown the positive impact of different priming agents on the growth of early seedlings due to reduction in imbition time, increased activation of the pre-germinative enzyme and enhanced production of metabolites which is well documented in experiments performed by Asaduzzaman et al. (2021). In this present study, the shoot length is maximum (14.38 cm) when primed with PEG 5 % than other priming agents and untreated seeds. This is in line with Mutum et al. (2021) and Singh et al. (2023) who reported higher plant heights in other priming agents than when seeds are not primed. The increase in plant height can be credited to different priming agents being used due to the efficient availability of ATP enabling early growth. The root length, shoot length, dry weight and fresh weight are significantly higher in different priming agents such as boric acid 0.1 %, $CaCO_3$ 2 %, DAP 2 %, MoP 2 %, PEG 10 %, PEG 5 %, Urea 2 % and $ZnSO_4$ 2 % than that of control in varying days after transplanting. This is due to differences in the availability of chemicals being used in seed priming. Priming duration take an important role in achieving a positive impact on growth and yield parameters. The results from Chakma et al. (2020) suggested that the best plant height and root length as well as fresh and dry weight were observed when seeds are primed in water for 9 hours. Our findings are also supported by Esatu et al. (2022), Khaing et al. (2020), and Zada et al. (2020).

Table 5. Interaction of different priming agents on shoot and root length of wheat.

Interaction of treatment		Shoot length (cm)			Root length (cm)		
Variety	Seed priming	10 DAT	20 DAT	30 DAT	10 DAT	20 DAT	30 DAT
Banganga	Boric acid (0.1 %)	12.51^{abcd}	22.48^{ab}	26.17^{abcd}	6.32^{abc}	8.03^{abc}	9.28^{abc}
	$CaCO_3$ (2 %)	14.19^{ab}	22.45^{ab}	25.60^{abcd}	7.44^{a}	8.73^{a}	10.60^{a}
	DAP (2 %)	12.38^{bcd}	20.73^{ab}	23.56^{bcd}	5.46^{bcdefg}	7.82^{abc}	8.87^{abc}
	MoP (2 %)	13.40^{abcd}	21.59^{ab}	25.41^{abcd}	6.25^{bc}	8.29^{ab}	9.70^{ab}
	PEG (10 %)	13.89^{abc}	23.40^{a}	27.70^{ab}	6.45^{abc}	8.00^{abc}	9.07^{abc}
	PEG (5 %)	13.95^{ab}	19.67^{ab}	24.06^{abcd}	4.76^{efg}	5.60^{gh}	7.16^{c}
	Urea (2 %)	13.71^{abc}	21.42^{ab}	25.13^{abcd}	5.94^{bcde}	6.92^{cdef}	8.08^{bc}
	$ZnSO_4$ (2 %)	12.37^{bcd}	19.07^{ab}	22.54^{cd}	4.86^{defg}	6.54^{defg}	8.48^{abc}
	Control	11.59^{cd}	20.03^{ab}	24.48^{abcd}	5.86^{bcdef}	7.26^{bcde}	8.67^{abc}
Bijaya	Boric acid (0.1%)	11.17^{d}	19.58^{ab}	21.45^{d}	6.06^{bcd}	7.86^{abc}	8.48^{abc}
	$CaCO_3$ (2 %)	14.10^{ab}	17.29^{b}	23.10^{bcd}	5.72^{bcdefg}	6.55^{defg}	7.51^{bc}
	DAP (2 %)	14.41^{ab}	19.16^{ab}	23.67^{abcd}	4.78^{efg}	5.18^{h}	7.39^{bc}
	MoP (2 %)	13.08^{abcd}	23.38^{a}	28.47^{a}	4.67^{fg}	5.92^{fgh}	7.07^{c}
	PEG (10 %)	12.93^{abcd}	20.29^{ab}	26.56^{abc}	6.66^{ab}	6.94^{cdef}	9.81^{ab}
	PEG (5 %)	14.81^{a}	18.63^{ab}	26.33^{abc}	4.58^{g}	6.12^{efgh}	6.84^{c}
	Urea (2 %)	12.64^{abcd}	22.37^{ab}	26.91^{abc}	4.55^{g}	6.00^{fgh}	8.60^{abc}
	$ZnSO_4$ (2 %)	13.47^{abc}	22.01^{ab}	26.69^{abc}	5.36^{cdefg}	7.34^{bcd}	8.28^{abc}
	Control	13.01^{abcd}	19.79^{ab}	27.04^{abc}	5.53^{bcdefg}	6.25^{defgh}	7.61^{bc}
CV (%)		8.9	13.8	9.7	11.2	9.1	14.7
SEM±		0.959	2.339	2.003	0.516	0.519	1.009
$LSD_{0.05}$		1.944	4.744	4.063	1.0483	1.0529	2.047
F-test		NS	NS	NS	*	***	NS

*Significant at 5 % level of significance, ***Significant at 0.1 % level of significance, NS: Non-significant, LSD: Least significant difference, SEM: Standard error of the mean, CV: Coefficient of variation

Table 6. Effect of different priming agents on fresh and dry weight of wheat.

Variety	Fresh weight (g)			Dry weight (g)		
	10 DAT	20 DAT	30 DAT	10 DAT	20 DAT	30 DAT
Banganga	0.173	0.214	0.256	0.026	0.036	0.055
Bijaya	0.187	0.237	0.325	0.030	0.041	0.060
Grand Mean	0.180	0.225	0.291	0.028	0.039	0.058
SEM±	0.011	0.010	0.011	0.0015	0.0022	0.0035
$LSD_{0.05}$	0.022	0.021	0.023	0.0030	0.0045	0.0072
F-test	NS	*	***	**	*	NS
Treatments						
Boric acid (0.1 %)	0.192^{a}	0.249^{a}	0.271^{bcd}	0.034^{a}	0.052^{a}	0.066^{a}
$CaCO_3$ (2 %)	0.167^{a}	0.22	0.355^{a}	0.023^{b}	0.027^{c}	0.054^{a}
DAP (2 %)	0.163^{a}	0.228^{a}	0.325^{ab}	0.028^{ab}	0.036^{bc}	0.062^{a}
MoP (2 %)	0.184^{a}	0.213^{a}	0.264^{cd}	0.027^{ab}	0.038^{b}	0.053^{a}
PEG (10 %)	0.175^{a}	0.218^{a}	0.243^{d}	0.028^{ab}	0.040^{b}	0.060^{a}
PEG (5 %)	0.186^{a}	0.211^{a}	0.289^{bcd}	0.029^{ab}	0.041^{b}	0.060^{a}
Urea (2 %)	0.191^{a}	0.230^{a}	0.270^{bcd}	0.025^{b}	0.037^{b}	0.052^{a}
$ZnSO_4$ (2 %)	0.181^{a}	0.231^{a}	0.313^{abc}	0.029^{ab}	0.038^{b}	0.060^{a}
Control	0.181^{a}	0.223^{a}	0.285^{bcd}	0.028^{ab}	0.040^{b}	0.052^{a}
SEM±	0.0237	0.0223	0.024	0.0032	0.0047	0.0076
$LSD_{0.05}$	0.047	0.045	0.050	0.0065	0.0095	0.0154
F-test	NS	NS	**	NS	**	NS

*Significant at 5 % level of significance, **Significant at 1 % level of significance, ***Significant at 0.1 % level of significance, NS: Non-significant, LSD: Least significant difference, SEM: Standard error of the mean, CV: Coefficient of variation

Table 7. Interaction of different priming agents on fresh and dry weight of wheat.

Interaction of treatment		Fresh weight (g)			Dry weight (g)		
Variety	Seed priming	10 DAT	20 DAT	30 DAT	10 DAT	20 DAT	30 DAT
Banganga	Boric acid (0.1 %)	0.189^{a}	0.244^{a}	0.248^{efg}	0.032^{ab}	0.046^{abcd}	0.066^{abc}
	$CaCO_3$ (2 %)	0.177^{a}	0.235^{a}	0.306^{bcdef}	0.024^{abcd}	0.030^{de}	0.060^{abc}
	DAP (2 %)	0.153^{a}	0.219^{a}	0.263^{cdefg}	0.027^{abcd}	0.032^{de}	0.060^{abc}
	MoP (2 %)	0.179^{a}	0.217^{a}	0.261^{defg}	0.027^{abcd}	0.036^{bcde}	0.055^{abc}
	PEG (10 %)	0.176^{a}	0.195^{a}	0.220^{g}	0.026^{abcd}	0.043^{abcd}	0.045^{bc}
	PEG (5 %)	0.159^{a}	0.190^{a}	0.253^{defg}	0.024^{bcd}	0.034^{bcde}	0.052^{abc}
	Urea (2 %)	0.184^{a}	0.204^{a}	0.232^{fg}	0.019^{d}	0.034^{bcde}	0.042^{c}
	$ZnSO_4$ (2 %)	0.175^{a}	0.210^{a}	0.282^{cdefg}	0.030^{abcd}	0.039^{bcde}	0.065^{abc}
	Control	0.169^{a}	0.214^{a}	0.237^{fg}	0.025^{abcd}	0.032^{cde}	0.053^{abc}
Bijaya	Boric acid (0.1 %)	0.195^{a}	0.253^{a}	0.295^{cdefg}	0.035^{a}	0.058^{a}	0.066^{abc}
	$CaCO_3$ (2 %)	0.157^{a}	0.216^{a}	0.404^{a}	0.021^{cd}	0.023^{e}	0.048^{bc}
	DAP (2 %)	0.173^{a}	0.238^{a}	0.386^{ab}	0.030^{abcd}	0.040^{bcd}	0.064^{abc}
	MoP (2 %)	0.189^{a}	0.210^{a}	0.266^{cdefg}	0.027^{abcd}	0.041^{bcd}	0.051^{abc}
	PEG (10 %)	0.175^{a}	0.242^{a}	0.266^{cdefg}	0.031^{abc}	0.037^{bcde}	0.075^{a}
	PEG (5 %)	0.214^{a}	0.232^{a}	0.326^{abcde}	0.034^{ab}	0.049^{ab}	0.069^{ab}
	Urea (2 %)	0.199^{a}	0.255^{a}	0.309^{bcdef}	0.031^{abc}	0.040^{bcd}	0.063^{abc}
	$ZnSO_4$ (2 %)	0.187^{a}	0.253^{a}	0.345^{abc}	0.028^{abcd}	0.037^{bcde}	0.056^{abc}
	Control	0.194^{a}	0.232^{a}	0.333^{abcd}	0.031^{abc}	0.048^{abc}	0.052^{abc}
CV (%)		22.4	17.4	14.8	19.8	20.9	22.7
SEM±		0.033	0.032	0.035	0.0048	0.0068	0.01077
$LSD_{0.05}$		0.067	0.064	0.071	0.0092	0.0135	0.0218
F-test		NS	NS	NS	NS	NS	NS

NS: Non-significant, LSD: Least significant difference, SEM: Standard error of the mean, CV: Coefficient of variation

3.3 Interaction effect of priming agents on germination and growth parameters

The interaction of variety and priming agents on germination parameters have a varying range of significance, shown in Figure 2, 3, 4 and 5. The maximum germination percentage was recorded in the Bijaya variety at control (90.67 %). Likewise, the lowest germination (50.67 %) was observed in the Banganga variety primed using MoP 2 %. This may be due to the low intake of nutrients and their utilisation during inhibition (Asaduzzaman et al., 2021). Other priming agents were noticed to have a wide range of fluctuating germination percentages in both varieties i.e., Banganga and Bijaya. Comparatively, the Bijaya variety is more dominant in almost all priming agents except boric acid 0.1 % and $CaCO_3$ 2 % than the Banganga variety of wheat in terms of germination percentage, germination speed percentage, germination energy and vigour index. The highest germination speed (93.92 %) was achieved in the Bijaya variety when priming is done in $CaCO_3$ 2 %. The germination energy and vigour index were maximum in the Bijaya variety when primed at $CaCO_3$ 2 % and control respectively. The positive impact of priming agents on germination parameters was well documented by Mim et al. (2022) and Zada et al. (2020), which is in line with our experiment. In the case of the interaction of variety and priming agent on growth parameters, the root length was highest (10.60 cm) treated with $CaCO_3$ 2 % in the Banganga variety at 30 DAT. The root length shows significant data at 10 DAT and 20 DAT with varying ranges of positive influx. The highest shoot length was 28.47 cm at 30 DAT when primed with MoP 2 % in the Bijaya variety. The maximum fresh and dry weight was observed in 30 DAT in the Bijaya variety when primed with $CaCO_3$ 2 % and PEG 10 % respectively. The insignificant data may be due to genetic variability and unavailability of specific nutrients directly by plants at lab conditions from our experiment required at the growth stage of wheat crop. Our findings also supported Abdullahi et al. (2021) and Zada et al. (2020) who noted the positive impact of priming agents on the growth and yield of wheat crops.

4 Conclusions

In conclusion, this study focused on evaluating the impact of various priming solutions on germination and growth parameters in two local wheat varieties, Banganga and Bijaya. The findings highlight that priming with calcium

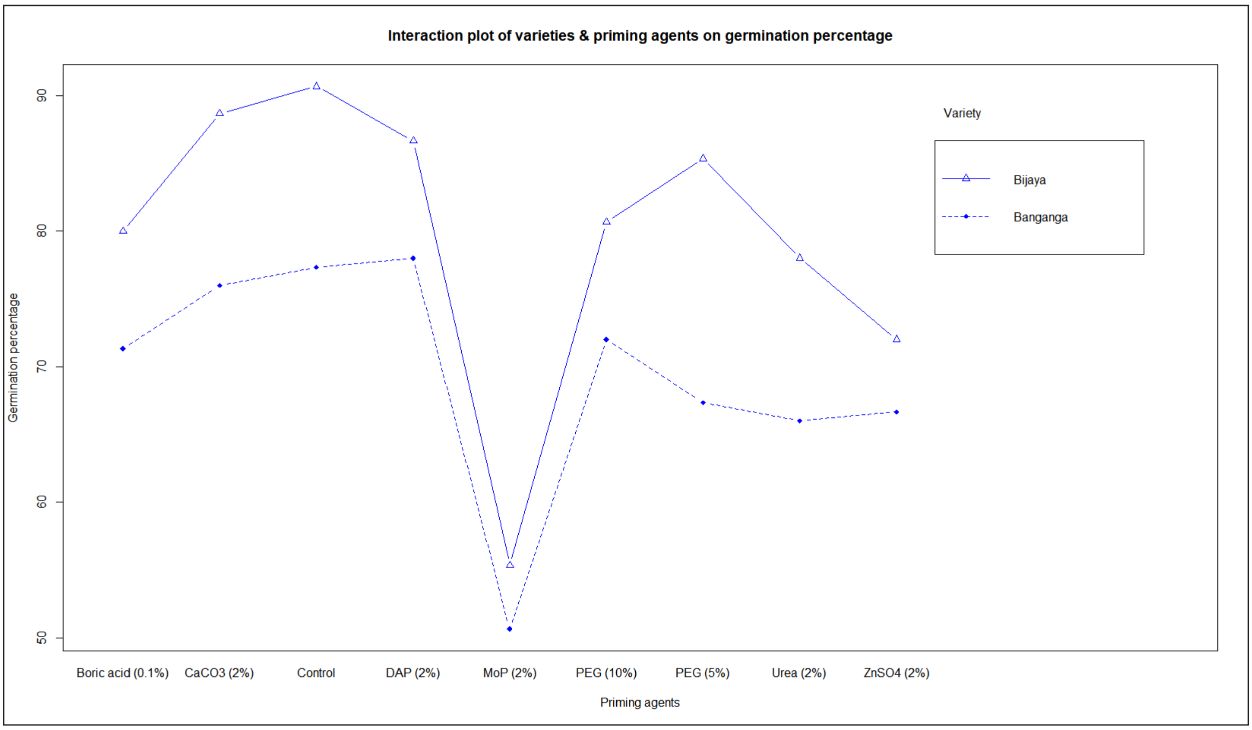

Figure 2. Interaction plot of varieties and priming agents on germination percentage.

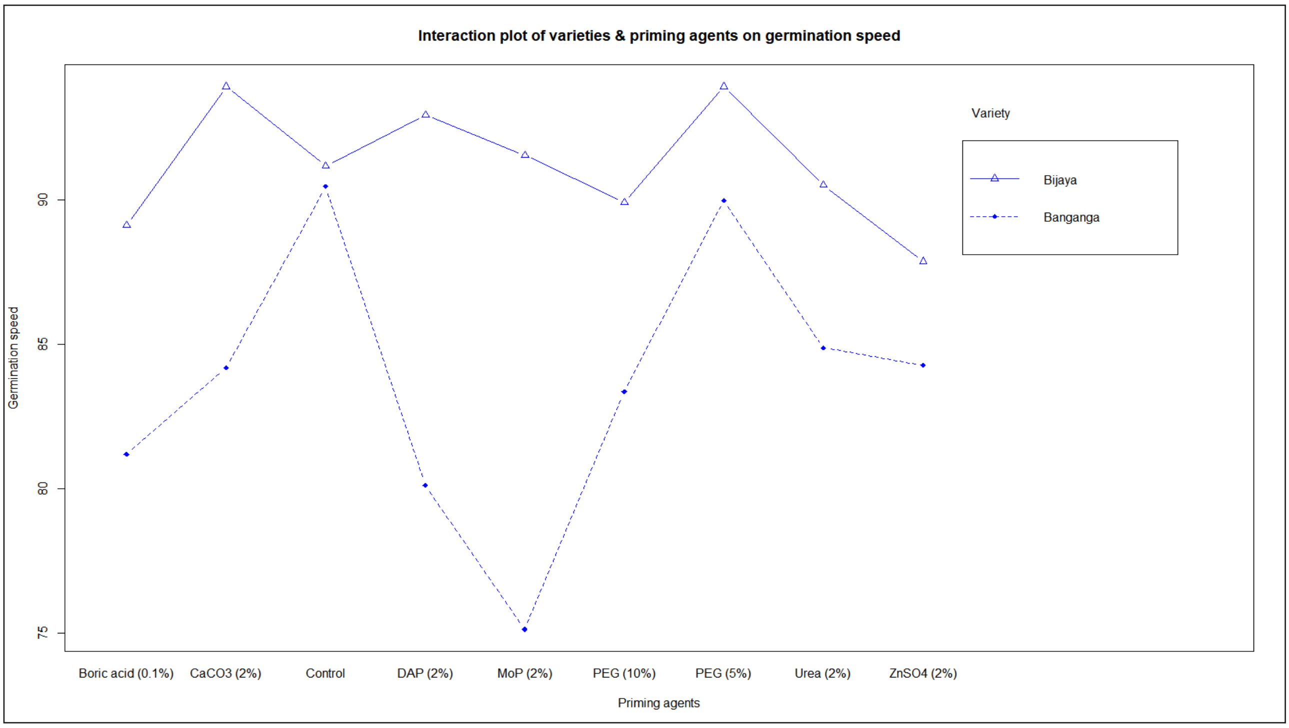

Figure 3. Interaction plot of varieties and priming agents on germination speed.

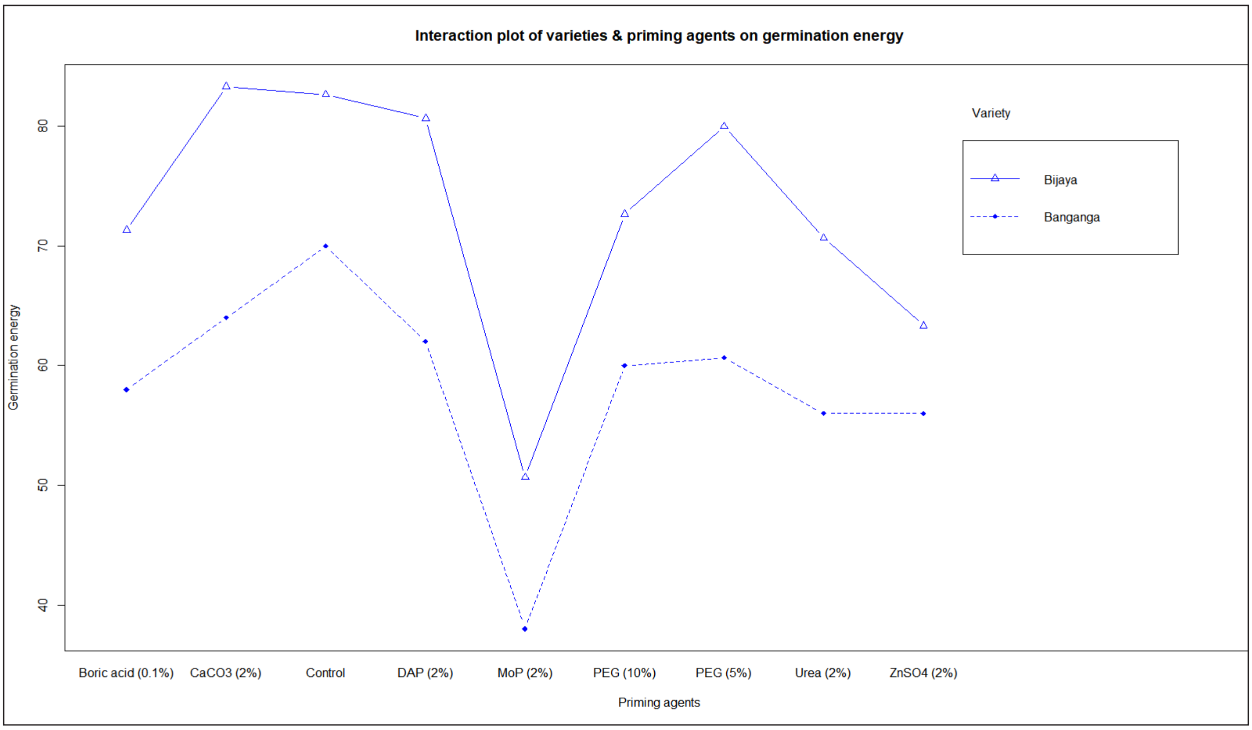

Figure 4. Interaction plot of varieties and priming agents on germination energy.

carbonate (2 %) exhibited the most favourable performance across several germination and growth parameters for the Bijaya wheat variety. However, it is evident that more comprehensive research is warranted to delve into the potential of seed priming in addressing abiotic challenges, such as heat and moisture, and their effects on the growth, physiology, and yield of wheat cultivars. This research underscores the existing gap and emphasizes the necessity for further investigations to thoroughly understand the advantages and limitations of seed priming in the context of wheat cultivation.

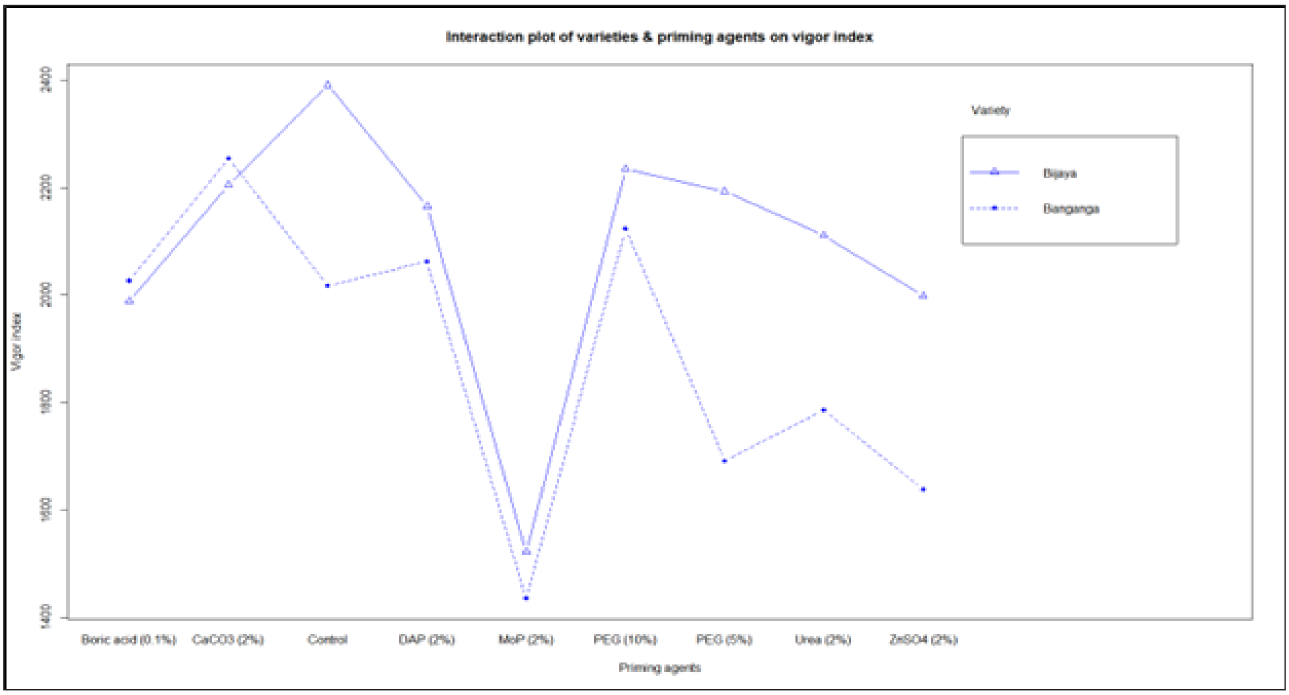

Figure 5. Interaction plot of varieties and priming agents on vigor index.

Conflicts of Interests

The authors declare no irreconcilable circumstances. Further, the final version of the manuscript was approved by all authors.

Author contribution statement

SPSY, NPG and SB: Conceived and designed the experiments. NPG, DKM, SPSY, SS, PP, PS, GP, and SB: Performed the experiments, interpreted the data, and wrote the paper. SPSY: Conducted the data analysis and visualization of the data. SB: Supervising the research.

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