Effect of Priming on Seed Germination, Seedling Vigor and Yield of Bread Wheat (*Triticum aestivum* L.) under Moisture-Stress Conditions

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Abstract

Uniform stand establishment of wheat is considered one of the most important yield-contributing factors in semi-arid areas. An experiment evaluated how different priming media and durations impact germination, vigor, and yield. The experimental design involved a bread wheat variety (Hidase), four priming media (distilled water, 0.1% KNO3, 2% Mannitol, 0.06% Salicylic acid, and a non-primed control), and two priming durations (12 and 24 hours), under laboratory and field conditions, using factorial CRD and CRBD, respectively. The results revealed that the priming media had a significant ($P<0.05$) effect on germination, vigor, the number of fertile spikes, yield, and year. The highest germination percentage was achieved with distilled water (93.58%), followed by 0.1% KNO_3 (92.62%). The vigor index-I was not enhanced by priming, with the control exhibiting the highest value (1803.8%cm). The highest Vigor index-II (1069%mg) was observed in seeds primed with 0.1% KNO_3 for 24 hours. Priming with 0.1% KNO_3 for 12 hours resulted in a higher number of spikes (487 m^{-2}) and yield (5.12 t ha^{-1}) compared to the control. However, the same priming medium resulted in the lowest yield (4.03 t ha^{-1}) at a priming duration of 24 hours. A priming duration of 12 hours with 0.1% KNO_3 resulted in a 19% yield increase compared to the unprimed control. In conclusion, 0.1% KNO3 contributed to the enhancement of germination, early seedling establishment, and yield of wheat under moisture-stress conditions.

Keywords: Bread wheat; Priming-media; Priming-duration; KNO_3; Yield

Introduction

Wheat (*Triticum aestivum* L.) is a staple food crop, providing a significant portion of daily caloric intake for many populations worldwide (Itam *et al.*, 2022). The crop contributes 19.4% of protein and 18.2% of kilocalories in the global food supply (FAOSTAT, 2022). As per the data from FAOSTAT (2022), the global annual yield in 2022 was around 808 million tons, harvested from 219 million ha of land. In the same year, Ethiopia produced 7 mill tons of yield from 2.3 million ha (FAOSTAT, 2022). Despite its role as a primary nutritional source for a significant proportion of the global population, the yield of this crop is threatened by various abiotic stresses like drought (Ashraf and Foolad, 2007), thereby

intensifying food insecurity, particularly among vulnerable demographics (Pörtner *et al.*, 2022).

Ethiopian wheat production is impeded by diseases, soil issues, terminal moisture stress, heat, and certain agricultural practices (Tadesse *et al.*, 2022). Even though Ethiopia has introduced many different types of bread wheat varieties to suit different agro-ecologies, there is still not enough information on how to protect the seeds from moisture stress during germination and early growth. This includes using priming substances externally. Abiotic stresses like salinity, drought, flooding, heat, cold, excess light, UV radiation, and heavy metal toxicity significantly reduce seed germination, seedling growth, and yield across different crops worldwide (Zhao, *et al.*, 2007). Moreover, abiotic stress like water stress is a significant threat to farming, particularly in reducing crop productivity in dry and semi-dry regions worldwide (Arun *et al.*, 2022). Conventional breeding for drought stress in crop plants is complex, but alternative technologies such as seed priming and genetic engineering could help combat these stresses and increase yield in agriculture (Arun *et al.*, 2022).

Rapid and uniform field emergence is essential to achieve high yield in quantity and quality in annual crops (Yari *et al.*, 2010) During periods of abiotic stress, the physiological and biochemical changes in plant cells reduce growth and development, ultimately decreasing wheat yield (Hossain *et al.*, 2021). Water stress is the most important abiotic stress adversely affecting wheat productivity through its influence on nitrogen uptake, mineralization, and losses through leaching, denitrification, and volatilization (Ali and Akmal, 2022). Therefore, innovative approaches are necessary for sustainable wheat production in the face of changing climate conditions, in order to guarantee the food and nutritional security of the ever-growing global population (Hossain *et al.*, 2021).

Seed priming is a pre-soaking of seed in different solutions that allows controlled hydration of seed, followed by re-drying the seed, and goes through the first stage of germination but does not allow radicle protrusion (McDonald, 2000). Seed priming eases germination even under adverse conditions, lifts crop performance, and enhances yield potential (Marthandan *et al.*, 2020). Priming benefits germination by activating biochemical mechanisms that repair cell damage, resuming metabolic activity, synthesizing nucleic acids (DNA and RNA) and proteins, and improving the antioxidant defense system in dry seeds (Arun *et al.*, 2022). The total performance of seed priming is more prominent under adverse conditions (Parera and Cantliffe, 1994). Seed priming is a low-cost, feasible technique that improves abiotic stress tolerances in seed production (Arun *et al.*, 2022). For most crops, the mean yield increases due to priming range from zero to more than 200% with an overall average increase of 30% (Harris *et al.* 2001).

Salicylic acid, a plant growth–regulating substance, affects plant growth and development and is known to improve plant stress tolerance depending on its

concentration, the type of plant, the stage of plant growth, and environmental conditions; thus it can have beneficial or inhibitory effects (Ashraf *et al.* 2010). Soaking seeds in the solution with inorganic salt (halopriming) such as KNO_3 stimulates the crop to raise robust even under soil salinity. Several studies have shown that the application of potassium nitrate can improve wheat growth and development. Tanin *et al.*, (2023) found that the application of potassium nitrate and salicylic acid improved grain yield and related traits by delaying leaf senescence in advanced wheat genotypes. Mannitol (osmopriming) improves crop performance in saline and non-saline conditions (Devika *et al.* 2021). Afrin, (2021), reported that wheat seeds primed with 2% Mannitol for 9 hours exhibited the highest germination and vigor index. In contrast, seeds that were not subjected to osmo priming or hydropriming displayed lower results in these parameters.

Osmopriming, KNO_3, and KH_2PO_4 improved the germination and seedling vigor of wheat seeds (Salehzade *et al.* 2009; Hamidi *et al.*, 2013). Wheat seeds primed with 10 g L^{-1} KNO_3 solution improved germination performance, early growth, and vigor index of wheat seedlings in salt stress conditions (Steiner *et al.* 2018). This seed priming improved emergence, stand establishment, tiller numbers, allometry, grain and straw yield, and harvest index. Priming with 50 mM KNO_3 enhanced uniform and improved seed germination and the vigor of *Gerbera jamesonii* and *Zinnia elegans* (Ahmad *et al.*, 2017). However, there is limited information available on the potential benefits of priming wheat seeds under moisture-stressed field conditions in Ethiopia. Therefore, this study was conducted to assess the effects of different priming methods (hydro-priming, KNO3 @0.1%, Mannitol @2%, Salicylic acid @0.06%) at 12 and 24-hour durations on seed germination, vigor, and yield-related traits of bread wheat under both laboratory and sub-optimal field conditions.

Materials and Methods

Experimental site description

The experiment was conducted at the Kulumsa Agricultural Research Center in the Seed Technology Laboratory and under field conditions at the Dhera sub-station in Ethiopia during the main cropping seasons of 2019 and 2020. The location is at 08°21"04' N, 39°18"18' S, and an altitude of 1604 m.a.s.l. The main growing season is between July and November. In both growing seasons, planting was done at the end of July and harvested on the first of November. The total precipitation from the first July to the end of October was 503 mm in 2019 and 541 mm in 2020. The soil type at the Dhera experiment station is Andosols. The average minimum and maximum temperatures from the first of July to the end of November were 25.5°C and 15.1°C in 2019, and 25.5°C and 14.7°C in 2020, respectively.

Experimental design and treatment setup

Seeds were primed in four different priming media solutions for 12 and 24 hours, with unprimed seeds used as a control. The experiment consisted of a total of nine treatments (eight treatment combinations and one control). A completely randomized design (CRD) for laboratory experiments and a Randomized Complete Block Design (RCBD) for the field experiments, with three replications for both conditions were used.

The field experiment consisted of plots measuring 1.2 m * 2.5 m (3 m^2) with a spacing of 1 m between replications, 0.4 m between plots, and 0.2 m row spacing. The seeds were planted in rows at a rate of 125 kg ha^{-1}. Nitrogen and phosphorus fertilizers were applied in the form of Urea (46% N) and diammonium phosphate (18% N and 46% P_2O_5) at the rate of 100 kg ha^{-1} each, as per recommendations. Herbicides and fungicides were used for weed and fungi control. Harvesting was done by plot harvester.

Treatments and priming media preparation

Initially, uniform-sized seeds were surface-sterilized with 1% sodium hypochlorite for 2 minutes, followed by washing four times with distilled water to sterilize the seeds. Then, the following treatments were made and applied:

i. **Distilled Water Treatment (hydropriming):** Bread wheat seeds (324 g) were soaked separately in 324 ml of distilled water for 12 and 24 hours.
ii. **KNO_3 (0.1%) Treatment**: A solution was prepared by dissolving 0.324 g of potassium nitrate (KNO_3) in 324 ml of distilled water. Seeds (324 g) were soaked separately in this solution for 12 and 24 hours.
iii. **Mannitol (2%) Treatment**: A solution was prepared by dissolving 6.48 g of mannitol in 324 ml of distilled water. Seeds (324 g) were soaked separately in this solution for 12 and 24 hours.
iv. **Salicylic Acid (0.06%) Treatment**: A solution was prepared by dissolving 0.1944 g of salicylic acid in 324 ml of distilled water. Seeds (324 g) were soaked separately in this solution for 12 and 24 hours.
v. **Unprimed Seeds (Control):** Seeds that were primed with neither of the priming medium.

After completing the required seed treatments, primed seeds were thoroughly rinsed three times with distilled water and re-dried on blotter paper under shade approximately to their initial moisture content for planting.

Data collection

Laboratory data

Standard germination (%): For each treatment, 400 seeds were sown on moistened germination paper in a plastic bowl (13 cm diameter) covered with glass, and kept at 20 ℃ in the germination room for eight days. Normal seedlings were counted according to rules for testing seeds (ISTA, 2014) and expressed as Standard Germination Percentage **(SGP)**;

$$SGP = \frac{Normal\ seedling\ germinated}{Total\ seeds\ planted} * 100$$

Seed vigor index I **(VI)** and Seed vigor index II **(VII)** were determined as per (ISTA, 2014) by taking ten randomly selected normal seedlings at the final counting date from each treatment during the standard germination test, following formulae of Abdul-Baki and Anderson (1973);

$$VI = Seedling\ length\ (cm) * SGP\ (\%)$$

and

$$VII = Seedling\ dry\ weight\ (mg\%) * SGP\ (\%)$$

Seed vigor index I (%cm): is calculated by multiplying standard germination percentage by the mean seedling length in centimeters. During the final count, the number of normal seedlings is evaluated, and the length of ten randomly selected seedlings (including shoot and root length) is measured using a standard ruler.

Seed vigor index -II (%mg):- is calculated by multiplying standard germination (%) by the mean seedling dry weight (mg). The same ten randomly selected seedlings were used for measuring the seedling dry weight. The process involved removing seeds attached to the germinated seedlings, oven-drying them at 105°C for 24 hours, cooling them down in a desiccator for 45 minutes, and then weighing them on a sensitive balance.

Field data

Phenological, yield, and yield-related data like plant height, day to heading, fertile spikes per square meter, grain yield, hectoliter weight, and thousand seed weight were collected as follows:

Plant height (cm): Measured from ground level to the top of the spike excluding the awns from randomly taken ten plants from middle rows at maturity time.

Heading date (day): Recorded from the date of planting to 50% of the heads that emerged.

Fertile spikes per square meter (number): Determined by counting the total number of productive spikes/heads in the square meter area at maturity.

Grain yield (t ha^{-1}): Determined after harvesting, threshing, and cleaning of seed from whole plots, and seed was weighed and expressed in t ha^{-1} after its MC was determined and adjusted to 13%: using the formula;

$$Yield\ (t\ ha^{-1}) = PYLD * \left(\frac{100\% - Actual\ MC\%}{100\% - Standard\ MC\%\%}\right) * \left(\frac{10}{net\ plot\ area\ in\ m^2}\right)$$

Where; PYLD = plot yield in kilograms and MC=moisture of the grain (the units are not considered).

Hectoliter weight (kg/hl): This is the bulk density or mass per unit volume, and it was measured in kilograms per hectoliter (kg/hl) from the bulk of thrashed seed.

Thousand seed weight (g): Computed by measuring the weight of 1000 kernels in grams after the moisture content of the seed was adjusted to 13% by using the formula;

$$Adjusted\ TSW\ (g) = Measured\ TSW(g) * \left(\frac{100 - Actual\ MC\%}{100 - Standard\ MC\%}\right)$$

Data analysis

The data were subjected to ANOVA for a significance test using SAS software version 9.3. The ANOVA was performed to determine the significance of differences between years, priming media, duration, and their interaction. Mean separations were conducted using the least significant difference (LSD) test at a 5% level of significance. The homogeneity of variances among different priming media and duration was tested using Levene's test.

Results and Discussion

Analysis of variance revealed significant effects of the year on the measured parameters ($P < 0.05$). Additionally, a significant impact of priming media was observed for germination and vigor index I (Table 1). Conversely, no significant effects of priming media or priming duration were found for days to heading (DH), plant height (PH), thousand seed weight (TSW), and hectoliter weight (HLW) (Table 2). Notably, there were significant interaction effects between priming media and duration for vigor index-II, fertile spikes per square meter (FSPSM), and grain yield (Table 3 and Figure 1).

Germination and vigor index-I

Wheat seed produced in the 2020 cropping season showed a higher germination percentage of 91.9% than in the 2019 cropping season of 89.0%. Similarly, the vigor index-I gained 1774.6% cm in 2020 and 1547% cm in 2019. The observed performance differences in germination percentage and vigor index I between the years are likely attributed to variations in seed lots used each year. Although the seed lots were sourced from the same production site annually, distinct environmental conditions (such as rainfall distribution and temperature) may have influenced maternal plant performance and subsequently impacted these parameters (Table 1).

Germination was enhanced from 90.5% (unprimed control) to 93.6% in distilled water and 92.7% in KNO_3 at 0.1% (Table 1). The positive impact of priming wheat seeds in distilled water aligns with the findings of Tania *et al.* (2021), while the effect of KNO_3 is consistent with reports by (Salehzade *et al.* 2009; Sarlach *et al.* 2013 and Hamidi *et al.* 2013). Ruttanaruangboworn *et al.* (2017) also observed improved germination and vigor in rice seeds soaked in 1.0% KNO_3 for 28 hours.

Similarly, Steiner *et al.* (2018) demonstrated that KNO_3-primed seeds exhibited enhanced germination performance, early growth, and vigor index in wheat seedlings. The improvement in germination of primed seeds may be attributed to increased RNA and protein synthesis (Fu *et al.*, 1988). In contrast, germination decreased to 84.9% in seeds treated with Salicylic acid at 0.06% and remained unchanged in Mannitol at 2% (90.6%) compared to the unprimed control (Table 1). Tania *et al.* (2021) reported that wheat seeds primed with 2 mM Salicylic acid for half an hour exhibited lower germination under non-saline stress compared to the unprimed control. Similarly, Bousba *et al.* (2021) found that Mannitol reduced germination in durum wheat seeds primed with 5 g L^{-1} of Mannitol, with the negative effect becoming more pronounced as the concentration increased. Notably, there was no significant variation in wheat seed germination between 12 and 24 hours of soaking time across different priming media (Table 1).

Vigor Index I

Unprimed seed (1803.8%cm) and seed primed in KNO_3 @ 0.1% (1741.10%cm) showed higher vigor index I (Table 1). However, none of the tested priming media positively contributed to the improvement of vigor index I under optimal laboratory conditions. Besides, Salicylic acid @ 0.06% and Mannitol @ 2% negatively affect vigor index I by decreasing it from 1803.8 (control) to 1487.30 and 1555.3% cm, respectively. However, Tania *et al.* (2021) reported pretreating wheat seed with 1 mM Salicylic acid promoted the germination percentage, seedling growth, and seed vigor index under salt stress (150 mM NaCl).Vigor index I was not also affected by priming duration between 12 and 24 hours (Table 1).

Vigor Index II

The vigor index II was highest in seeds treated with KNO_3 at a concentration of 0.1% and lowest in those treated with Salicylic acid at 0.06% (Figure 1). Although no statistical differences were observed between primed and unprimed seeds for vigor index II, the priming treatment involving KNO_3 at 0.1% and distilled water with a 24-hour duration showed greater vigor than the unprimed control (Figure 1). Sarlach *et al.* (2013) reported that priming wheat seeds with 1% KNO_3 led to a higher vigor index. This effect could be attributed to the involvement of potassium ions in root and shoot growth (Sustr *et al.*, 2019) as well as increased RNA and protein synthesis (Fu *et al.*, 1988). Additionally, the vigor index II, which reflects seedling dry weight, may be influenced by K^+ ions participating in auxin-induced cell expansion in hypocotyls and leaves, contributing to root and shoot development (Sustr *et al.*, 2019). There was no significant difference in the vigor index II between 12 and 24 hours of priming duration within each priming medium. Notably, relatively vigorous seedlings were observed after 24 hours of priming with KNO_3 at 0.1% (1069% mg) and Mannitol at 2% (1046% mg) compared to the 12-hour treatment. Salicylic acid @ 0.06% exhibited the lowest

vigor index II of 930 and 943% mg for 12 and 24 h. Mannitol @ 2% also demonstrated a lower vigor index-II at 12 h of priming time but, a small improvement was shown as the priming time increased from 12 to 24 h. However, priming the wheat seed in distilled water for not more than 24 hours is economical for better vigor index II (Figure 1).

Table 1: Main effects of year, priming media, and priming duration for germination and vigor index-I of bread wheat seed.

	Germination percentage (%)	Vigor index-I (%cm)
2019	89.0b	1547.4b
2020	91.9a	1774.6a
Mean	**90.5**	**1661.0**
CV (%)	**4.8**	**13.1**
LSD	**2.2**	**112.3**
$F_{ydf, edf}$	**1, 56**	**1, 56**
KNO_3 @ 0.1%	92.7ab	1741.1a
Mannitol @ 2%	90.6b	1555.3bc
Salicylic acid @ 0.06%	84.9c	1487.3c
Distilled water	93.6a	1717.2ab
Unprimed	90.5b	1803.8a
Mean	**90.5**	**1661.0**
CV (%)	**3.8**	**13.2**
LSD	**2.8**	**179.9**
$F_{mdf, edf}$	**4, 53**	**4, 53**
12h	90.7	1663.2
24h	90.2	1658.7
Mean	**90.5**	**1661.0**
CV (%)	**5.1**	**14.9**
LSD	**2.4**	**127.7**
$F_{ddf, edf}$	**1, 56**	**1, 56**

Note: Means in the same column followed by the same letters are not significantly different at a 5% level of significance according to the least significant difference (LSD) test for Germ=Germination percentage and vigor indices at laboratory conditions.

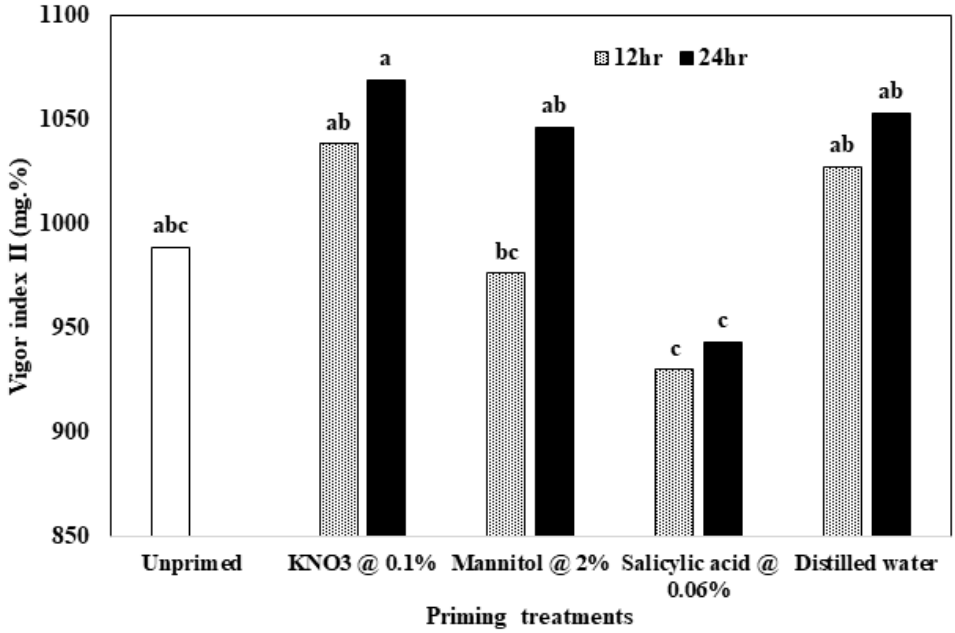

Fig 1. Mean vigor index-II of wheat seed primed in different media for 12 and 24 h. Means followed by different letters are significantly different at a 5% significance level. Note: Coefficient of variation = 7.06 %; LSD (5%) = 83.5 mg. %.

Days to heading and Plant height

The days to heading and plant height in wheat were influenced by the growing seasons (years). In 2019, plants took relatively longer days to head (51.1 days), while relatively taller plants were observed in 2020 (81.5 cm) (Table 2). These differences in plant performance may be attributed to varying weather conditions between the two growing seasons, including differences in rainfall distribution and heat waves. Notably, in 2020, there was better rainfall distribution during the grain-filling stage, despite the total amount being lower than in 2019.

Regarding priming effects, all tested priming media did not significantly impact the days to heading in wheat crops, with a range of 48.2 to 49.8 days (Table 2). Similarly, priming media had no significant effect on plant height, ranging from 75.6 cm in the unprimed control to 80.1 cm in seed primed in KNO_3 at 0.1%. The consistent plant height and day-to-heading across different priming treatments suggest that the contribution of various priming media to wheat plant height and day-to-heading was negligible. Previous studies have also reported that seed priming does not significantly affect plant height, the number of spikelets, grain count, or 1000-grain weight in wheat (Farooq *et al.*, 2008). Furthermore, neither the 12-hour nor the 24-hour priming duration altered the height and heading date of the wheat crop (Table 2).

Table 2: Main effects of year, priming media, priming duration for days to heading, plant height, thousand seed weight, and hectoliter weight of bread wheat at Dhera sub-station

	Days to heading (day)	Plant height (cm)	Thousand seed weight (g)	Hectoliter weight (kg/L)
2019	51.1a	75.6b	32.2b	76.0b
2020	46.5b	81.5a	46.1a	77.7a
Mean	48.8	78.6	39.2	76.8
CV (%)	5.3	5.9	4.7	3.0
LSD	1.3	2.4	0.95	1.19
$F_{ydf, edf}$	1, 56	1, 56	1, 56	1, 56
KNO_3 @ 0.1%	48.8	80.1	39.7	77.1
Mannitol @ 2%	48.8	77.7	39.7	76.9
Salicylic acid @ 0.06%	49.8	79.8	37.8	76.0
Distilled water	48.2	79.7	39.1	76.7
Unprimed	48.5	75.6	39.5	77.5
Mean	48.8	78.6	39.2	76.8
CV (%)	7.3	7.0	19.3	3.3
LSD	2.9	4.5	6.2	2.1
$F_{mdf, edf}$	4, 53	4, 53	4, 53	4, 53
12h	49.1	78.8	39.2	77.0
24h	48.5	78.3	39.1	76.7
Mean	48.8	78.6	39.2	76.8
CV (%)	7.2	7.1	18.9	3.2
LSD	1.8	2.9	3.8	1.3
$F_{ddf, edf}$	1, 56	1, 56	1, 56	1, 56

Means in the same column followed by the same letters are not significantly different at a 5% significance level according to the least significant difference (LSD) test for Days to heading, plant height, thousand seed weight, and hectoliter weight at the Dhera sub-station.

Thousand seed weight (TSW) and Hectoliter weight (HLW)

Thousand seed weight and HLW of seed were affected by the growing season and higher in 2020. However, both were not affected by priming media. The average of 39.2 g and 76.8 kgL^{-1} were the results for TSW and HLW, respectively (Table 2).

A higher thousand seed weight of 46.1 g was obtained from wheat grown in 2020 compared to 2019. However, any of the priming treatments did not affect the thousand seed weight of wheat seed (Table 2). Our finding is in agreement with that of (Farooq *et al.* 2008), who reported that wheat seed priming did not affect the 1000-grain weight of wheat. Similarly, Sarlach *et al.* (2013) found that priming wheat seed in KNO_3 did not contribute to the improvement of thousand seed weights.

A higher mean value of hectoliter weight of 77.7 kg L^{-1} was shown from wheat seed harvested in the 2020 growing season. These may be due to better rainfall distribution in a season, particularly during the grain filling period, that resulted in the plump seeds and increased bulk weight. However, the effect of priming media and priming duration were not significant for the hectoliter weight of wheat seed.

Fertile spikes per meter square

Seeds primed with KNO_3 at 0.1% for 12 hours exhibited the highest spike density, with 487 spikes per square meter. Notably, this result was not statistically different from seeds primed in mannitol at 2% or distilled water for 12 and 24 hours, as well as seeds primed in salicylic acid at 0.06% for 24 hours. However, seeds primed with 0.1% KNO_3 for 12 hours exhibited a greater number of fertile spikes compared to a 24-hour soaking time. Except for salicylic acid @ 0.06% for 12 hours and KNO3 @ 0.1% and distilled water for 24 hours, all other priming media and duration combinations significantly improved the number of fertile spikes. Unprimed seeds recorded the lowest number of fertile spikes (408). These findings suggest that priming wheat seeds with any of the tested priming media enhances spike production by either increasing tiller numbers or improving tiller fertility. For instance, seed priming with KNO_3 at 0.1% for 12 hours resulted in 16% more fertile spikes compared to the unprimed control (see Table 3).

Table 3: Mean interaction of priming media and duration on fertile spike population and yield components of bread wheat over two years at Dera sub-station

Priming duration (hrs)	Priming media	Fertile spikes per m^2 (no.)	Yield (t ha^{-1})
0	Unprimed/control	408d	4.17e
12	KNO_3 @ 0.1%	487a	5.12a
12	Mannitol @ 2%	456abc	4.58bc
12	Salicylic acid @ 0.06%	439bcd	4.20de
12	Distilled water	456abc	4.32cde
24	KNO_3 @ 0.1%	416cd	4.03e
24	Mannitol @ 2%	451abc	4.48bcd
24	Salicylic acid @ 0.06%	469ab	4.72b
24	Distilled water	448abcd	4.60bc
Mean		447.8	4.47
CV (%)		7.8	5.87
LSD (0.05)		40.8	0.31

Note: Means in the same column followed by the same letters are not significantly different at 5% level of significance according to the least significant difference (LSD) test for, fertile spikes per square meter and yield at Dhera sub-station.

Grain yield

The highest grain yield of 5.12 t ha^{-1} was obtained in seeds primed with 0.1% KNO_3 for 12 hours (Table 3). The observed effects may be attributed to the role of KNO_3 in enhancing wheat plant root system development during early stages. Additionally, the influence of K+ on photosynthesis and carbohydrate transport from source leaves via the phloem could contribute to these effects (Xu *et al.,* 2020). Similarly, Sarlach *et al.* (2013) reported that 12 hours of wheat seed priming with 2.0% KNO3 gave higher grain yield as compared to the unprimed control. Nevertheless, the use of the same priming medium (0.1% KNO_3) led to a comparable and reduced grain yield of 4.03 t ha^{-1} when compared to the unprimed control after 24 hours of priming. This outcome could be attributed to potential toxicity resulting from the extended priming duration. There was a 21% yield gap between 12 and 24 h priming duration in seed primed with KNO3 @0.1%. In contrast to the 0.1% KNO_3, an increase in yield was observed as the priming

duration extended from 12 hours to 24 hours using 0.06% salicylic acid (Table 3). Additionally, priming with distilled water resulted in a similar yield regardless of the priming duration. Harris *et al.* (2001) reported a 13% yield advantage when seeds were primed with water for eight hours. The tested priming media enhanced yield compared to the unprimed control for both 12 and 24-hour priming duration, except for 0.1% KNO3 at 24 hours.

Conclusion

Priming the wheat seed in distilled water and KNO3 at a [0.1%] for 12 to 24 hours enhanced the germination. Soaking the wheat seed in distilled water, KNO3 @ 0.1%, and Mannitol @ 2% for 24 hours resulted in better Vigor index II. Priming media and priming duration did not have any effect on plant height, days to heading date, thousand seed weight, and hectoliter weight of bread wheat: but these parameters were affected by growing seasons. Priming wheat seed in KNO3 @ 0.1% for 12 hours resulted in higher fertile spikes compared to 24 hours of soaking time. There were 16% more fertile spikes in seeds primed with KNO_3 at 0.1% for 12 hours compared to the unprimed control. All the tested priming media positively enhanced the yield, compared to the unprimed control, for both priming durations (12 and 24 hours), except KNO_3 at 0.1% for 24 hours. Priming duration between 12 and 24 hours did not result in any variation in germination, vigor index I, days to heading, plant height, thousand seed weight, and hectoliter weight for the tested priming media. The higher vigor index II (1069% mg), fertile spikes per square meter (487 m^{-2}), and yield (5.12 t ha^{-1}) were obtained when using KNO_3 at 0.1% for 24, 12, and 12 hours, respectively. However, better grain yield and more fertile spikes are obtained if the seed is not soaked for more than 12 hours in KNO_3 @ 0.1%. Salicylic acid @ 0.06% hindered the germination of wheat seed, and it did not contribute to the desired improvement in yield and yield component of wheat in our study. In conclusion, KNO_3 at 0.1% proved to be the most effective medium among those tested in enhancing the germination, vigor, yield, and yield-related traits of wheat. This study has limitations as it only studied priming media for some specific concentrations. Therefore, further studies should be conducted using different concentrations of the tested media.

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References

Abdul-Baki, A. A., & Anderson, J. D. (1973). Vigor determination in soybean seed by multiple criteria 1. *Crop science*, *13*(6), 630-633.

Afrin, m. S. (2021). Enhancement of germination, seedling growth, water relation behavior of

wheat through osmo and hydro priming under drought stress condition.

Ahmad, I., Saleem, A. M., Mustafa, G., Ziaf, K., Afzal, I., & Qasim, M. (2017). Seed halopriming enhances germination performance and seedling vigor of gerbera jamesonii and zinnia elegans. *Sarhad Journal of Agriculture*, *33*(2), 199-205.

Ali, N., & Akmal, M. (2022). Wheat growth, yield, and quality under water deficit and reduced nitrogen supply. A review. *Gesunde Pflanzen*, *74*(2), 371-383.

Arun, M. N., Hebbar, S. S., Senthivel, T., Nair, A. K., Padmavathi, G., Pandey, P., & Singh, A. (2022). *Seed priming: The way forward to mitigate abiotic stress in crops* (Vol. 11, p. 173). London, UK: IntechOpen.

Ashraf, M., Akram, N. A., Arteca, R. N., & Foolad, M. R. (2010). The physiological, biochemical and molecular roles of brassinosteroids and salicylic acid in plant processes and salt tolerance. *Critical Reviews in Plant Sciences*, *29*(3), 162-190.

Ashraf, M. F. M. R., & Foolad, M. R. (2007). Roles of glycine betaine and proline in improving plant abiotic stress resistance. *Environmental and experimental botany*, *59*(2), 206-216.

Bousba, R., Bounar, R., Sedrati, N., Lakhal, R., Hamla, C., & Rached-Kanouni, M. (2021). Effects of osmotic stress induced by polyethylene glycol (peg) 6000 and mannitol on seed germination and seedling growth of durum wheat. *Journal of Bioresource Management*, *8*(3), 6.

Devika, O. S., Singh, S., Sarkar, D., Barnwal, P., Suman, J., & Rakshit, A. (2021). Seed priming: a potential supplement in integrated resource management under fragile intensive ecosystems. *Frontiers in Sustainable Food Systems*, *5*, 654001.

FAOSTAT, (2022). Wheat Production Statistics. Available at: FAOSTAT https://www.fao.org/faostat/en/#data/QCL/visualize. (Accessed: February 18, 2024).

Farooq, M., Basra, S. M. A., Rehman, H., & Saleem, B. A. (2008). Seed priming enhances the performance of late sown wheat (Triticum aestivum L.) by improving chilling tolerance. *Journal of Agronomy and Crop Science*, *194*(1), 55-60.

Fu J. R.; Lu S. H.; Chen R. Z.; Zhang B. Z.; Liu Z. S. and Cai D. Y. (1988). Osmoconditioning of peanut (Arachis hypogaea L.) seed with PEG to improve vigor and some biochemical activities. *Seed Sci. Tech*. 16 : 197-212.

Hamidi, R., Pirasteh-Anosheh, H., & Izadi, M. (2013). Effect of seed halo-priming compared with hydro-priming on wheat germination and growth. *International Journal of Agronomy and Plant Production*, 4(7), 1611-1615.

Harris, D. B. S. R., Raghuwanshi, B. S., Gangwar, J. S., Singh, S. C., Joshi, K. D., Rashid, A., & Hollington, P. A. (2001). Participatory evaluation by farmers of on-farm seed priming in wheat in India, Nepal and Pakistan. *Experimental Agriculture*, *37*(3), 403-415.

Hossain, A., Skalicky, M., Brestic, M., Maitra, S., Ashraful Alam, M., Syed, M. A., ... & Islam, T. (2021). Consequences and mitigation strategies of abiotic stresses in wheat (Triticum aestivum L.) under the changing climate. *Agronomy*, *11*(2), 241.

ISTA. 2014. International rules for seed testing. Page International Rules for Seed Testing. The International Seed Testing Association (ISTA) Zürichstr. 50, 8303 Bassersdorf, Schweiz ©2014 par l'Association Internationale d'Essais d.

Itam, M. O., Mega, R., Gorafi, Y. S., Yamasaki, Y., Tahir, I. S., Akashi, K. & Tsujimoto, H. 2022. Genomic analysis for heat and combined heat–drought resilience in bread wheat under field conditions. *Theoretical and Applied Genetics*, Publication**,** 1-14.

Marthandan, V., Geetha, R., Kumutha, K., Renganathan, V. G., Karthikeyan, A., & Ramalingam, J. (2020). Seed priming: a feasible strategy to enhance drought tolerance in crop plants. *International journal of molecular sciences*, *21*(21), 8258.

McDonald, M. B. (2000). Seed priming. *Seed technology and its biological basis. Sheffield Academic Press, Sheffield*, 287-325.

Parera, C. A., & Cantliffe, D. J. (2010). Presowing seed priming. *Horticultural reviews*, *16*, 109-141.

Pörtner, H. O., Roberts, D. C., Adams, H., Adler, C., Aldunce, P., Ali, E., Begum, R. A., Betts, R., Kerr, R. B. & Biesbroek, R. 2022. Climate change 2022: Impacts, adaptation and vulnerability. IPCC.

Ruttanaruangboworn, A., Chanprasert, W., Tobunluepop, P., & Onwimol, D. (2017). Effect of seed priming with different concentrations of potassium nitrate on the pattern of seed imbibition and germination of rice (Oryza sativa L.). *Journal of Integrative Agriculture*, *16*(3), 605-613.

Salehzade, H., Shishvan, M. I., Ghiyasi, M., Forouzin, F., & Siyahjani, A. A. (2009). Effect of seed priming on germination and seedling growth of wheat (Triticum aestivum L.). *Res. J. Biol. Sci*, *4*(5), 629-631.

Sarlach, R. S., Sharma, A., & Bains, N. S. (2013). Seed Prim Ing in Wheat: Ef Fect on Seed Ger Mi Na Tion, Yield Parameers and Grain Yield. *Progress. Res*, *8*, 109-112.

Steiner, F., Zuffo, A. M., da Silva Oliveira, C. E., Honda, G. B., & Machado, J. S. (2018). Potassium nitrate priming mitigates salt stress on wheat seedlings. *Revista de Ciências Agrárias*, *41*(4), 989-1000.

Sustr, M., Soukup, A., & Tylova, E. (2019). Potassium in root growth and development. *Plants*, *8*(10), 435.

Tadesse, W., Zegeye, H., Debele, T., Kassa, D., Shiferaw, W., Solomon, T., Negash, T., Geleta, N., Bishaw, Z. & Assefa, S. 2022. Wheat production and breeding in Ethiopia: retrospect and prospects. *Crop Breeding, Genetics and Genomics*, 4.

Tania, S. S., Rahaman, M. M., Rauf, F., Suborna, M. A., Humayun Kabir, M., Hoque, M. A., & Rhaman, M. S. (2021). Seed priming with salicylic acid (SA) and hydrogen peroxide (H2O2) improve germination and seedling growth of wheat (Triticum aestivum) under salt stress. *Asian Journal of Research in Crop Science*, *6*(4), 60-69.

Tanin, M. J., Sharma, A., Ram, H., Singh, S., Srivastava, P., Mavi, G. S., . & Sohu, V. S., (2023). Application of potassium nitrate and salicylic acid improves grain yield and related traits by delaying leaf senescence in Gpc-B1 carrying advanced wheat genotypes. *Frontiers in Plant Science*, 14, 1107705.

Xu, X., Du, X., Wang, F., Sha, J., Chen, Q., Tian, G., ... & Jiang, Y. (2020). Effects of potassium levels on plant growth, accumulation and distribution of carbon, and nitrate metabolism in apple dwarf rootstock seedlings. *Frontiers in Plant Science*, *11*, 904.

Yari, L., Aghaalikani, M., & Khazaei, F. (2010). Effect of seed priming duration and temperature on seed germination behavior of bread wheat (Triticum aestivum L.). *ARPN Journal of Agricultural and Biological Science*, *5*(1), 1-6.

Zhao, T. J., Liu, Y., Yan, Y. B., Feng, F., Liu, W. Q., & Zhou, H. M. (2007). Identification of the amino acids crucial for the activities of drought responsive element binding factors (DREBs) of Brassica napus. *FEBS letters*, *581*(16), 3044-3050.