Emirates Journal of Food and Agriculture

Emirates Journal of Food and Agriculture 36: 1–13
doi: 10.3897/ejfa.2025.126915

RESEARCH PAPER

Effect of seed priming and foliar application of organic liquid manure on germination, growth, yield and quality of late-sown wheat

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Academic editor: Giovanni Buonaiuto ♦ **Received** 6 May 2024 ♦ **Accepted** 11 December 2024 ♦ **Published** 7 February 2025

Abstract

The sub-optimal temperature during sowing results in delayed germination, poor crop establishment, and constrained vegetative development, which results in forced maturity, low yield, and wheat with poorer quality grains in north India. Thus, in 2020–21, a field experiment with fixed plots was carried out to analyze the impact of organic liquid manure herbal kunapajala as seed priming and foliar spray on the development and output of late-sown wheat. A total of 14 different treatments were tested in this thrice-replicated randomized block design study. Treatments consisted of $T_{1:}$ No seed priming + 100% RDN, $T_{2:}$ Hydropriming + 100% RDN, $T_{3:}$ 10% HK priming + 100% RDN+ foliar application of 10% HK, $T_{4:}$ 10% HK priming + 75% RDN+ foliar application of 10% HK, $T_{5:}$ 10% HK priming + 50% RDN+ foliar application of 10% HK, $T_{6:}$ 10% HK priming + no Fertilizer+ foliar application of 10% HK, $T_{7:}$ 25% HK priming + 100% RDN+ foliar application of 10% HK, $T_{8:}$ 25% HK priming + 75% RDN+ foliar application of 10% HK, $T_{9:}$ 25% HK priming + 50% RDN+ foliar application of 10% HK, $T_{10:}$ 25% HK priming + no fertilizer+ foliar application of 10% HK, $T_{11:}$ 50% HK priming + 100% RDN+ foliar application of 10% HK, $T_{12:}$ 50% HK priming + 75% RDN+ foliar application of 10% HK, $T_{13:}$ 50% HK priming + 50% RDN+ foliar application of 10% HK, $T_{14:}$ 50% HK priming + no fertilizer+ foliar application of 10% HK. The results revealed that T_7 (128.7 cm), T_2 (125.1 cm), T_1 (122.6 cm), and T_5 (119.9 cm) had much taller plants than the others. The highest number of grains per spike was found to in T_7, T_3, T_2 and T_8 shown at par with each other (49.90, 49.90, 48.67 and 47.67 grains/spike). Similarly, fertile spikelets per spike was shown significantly higher with T_7 (23.30) which was at par with T_3 and T_2 (21.67 and 21.20, respectively) as compared to other treatments. The maximum grain production was seen with T_7 (48.0 q/ha) and T_3 (47.90 q/ha), however these two treatments were at par. Higher harvest index was observed significantly from T_7, T_3, T_2, T_{12}, T_1 and T_{11} (40.6, 39.7, 39.0, 37.9, 37.8 and 37.6%, respectively) as compared with other treatments but at par with each other. The maximum α-amylase activity was observed with T_7 (27.9 mg of starch hydrolyzed/g of seeds) which was at par with T_3 and T_2 (25.1 and 24.7 mg of starch hydrolyzed/g of seeds, respectively). From the information presented above, it can be inferred that seed priming with 10% HK along with 100% of the recommended dose of nutrients, followed by foliar applications of 10% HK at various growth stages, increased the growth, productivity and enzyme activity of late sown wheat that priming with 10% HK and its foliar application under 100% RDN increased the growth, productivity, grain quality indices, enzyme activities, and economic profitability of late-sown wheat. From the current research, it can be concluded that HK is a successful and cost-efficient method that may be utilized to increase crop production under late-sown conditions.

Keywords

Kunapajala, nitrogen, seed priming, wheat

Introduction

Wheat is one of the most extensively produced cereal crops in the world today (Reyer et al. 2022) and the second-most significant food crop in India, which grows on around 31.6 million hectares and produced 103 million metric tonnes in 2016—or nearly 13% of the world's wheat crop (USDA 2022). Regardless of its high production, the productivity of wheat is declining in India due to many abiotic stresses such as heat stress. Among the crucial factors limiting productivity are the timing of planting, the quality of the seed, and the availability of the right nutrients for crop growth. These factors determine crop establishment, growth, and development, and consequently, the harvest's yielding capacity. Wheat has a wider planting window and is primarily planted during the rabi season. It is sown in the second fortnight of October as an early planting, in the first to third week of November as the ideal sowing season, and in the fourth week of November till the end of December in the north western plain zone of India (Singh et al. 2018). Achieving the desired production potential and grain quality in both regular and late planting conditions is never easy. In recent years, especially in India's Indo-Gangetic Plains of India, huge yield losses have resulted from the lengthy duration of basmati rice and sugarcane, which prevents farmers from growing wheat until early January.

Late sown wheat faces sub-optimal temperature at sowing time, causes delayed germination, poor crop establishment and restricts vegetative growth. In India, around 13.5 million hectare of wheat is grown under heat stressed (Basu et al. 2014). As a result, low yields are produced together with poor establishment and poor vegetative growth, endangering food security (Singh et al. 2014). Additionally, it results in forced maturity, poor yield, and low-quality grains in wheat, resulting in fewer grains per spike (Sharma et al. 2020). The current climate change scenario is expected to exacerbate this high temperature stress. With increase in population, there is also shrinkage on cultivable land. Unfavorable environmental factors have an impact on wheat's growth, development, and productivity, which lowers yield and lowers grain quality. Because of this, it is vital to carefully choose wheat types from the wide variety of possibilities offered by the domestic seed market that exhibit exceptional resistance, consistent production, and outstanding quality. Therefore, the main focus would be on increasing the productivity by adopting improved cultivation practices (Devi et al. 2023). To solve these problems, uniform crop establishment and balanced nutrient management practices may help to improve crop productivity under delayed condition.

Crop establishment, which is influenced by sowing timing and seed quality, as a significant factor. Although several soil fertility management technologies have been developed to maximize the crop establishment of robust seedlings, adoption of these technologies by resource-poor farmers is still low because they are either too costly or inappropriate for these farmers (Von Loeper et al. 2016). Farms with limited resources could greatly increase stand establishment and productivity by implementing low-risk, low-cost agronomic interventions (Harris et al. 2005). Seed priming is one such approach that can increase yields for low-resource farmers. Seed priming is a pre-sowing technique that involves the treating of seeds to initiate the germination process before planting to the field (Habibi et al. 2024). It is the most promising seed invigoration technique which quickens the germination process, enhances stand establishment of crop and promotes seedling vigour. Under both normal and stressful circumstances, seed priming—a promising technique—has been effectively utilized to address the issue of poor germination and the erratic crop stand that followed (Atique-ur-Rehman et al. 2013; Farooq et al. 2019a). This is especially crucial since, until root uptake begins to feed soil nutrients, seedling growth is sustained by seed mineral nutrient reserves (Muhammad et al. 2016). Research conducted in Bangladesh, Nepal, India, and Pakistan has demonstrated that nutrient seed priming can boost maize yields by as much as 70% when minerals like phosphate, zinc, boron, and molybdenum are added to priming water (Harris et al. 2001). Much work has been done recently on hydropriming to increase the rate of germination and growth uniformity of several field crops, including wheat and other crops.In addition, seed priming is effective on various physiological parameters, such as photosynthetic rate, stomatal conductance and transpiration rate (Habibi et al. 2023). Another seed priming method is using organic liquid manure "herbal kunapajala" (HK) to hasten the seed germination and crop establishment. The term "kunapa" in Sanskrit means "smelling like a dead body, stinking," and refers to the fermented liquid manure made from animal marrow, flesh, and urine (jala = water). It is also known as kunapambu (Kumar et al. 2020). Kunapajala made from herbs is now used to nurture soil, crops, and seeds. Its qualities of growth stimulation, nutrition, and antibacterial activity make it highly successful in nourishing plants at different stages through soil and foliar application (Sudhakar et al. 2010; Kavya and Ushakumari 2020). In addition, it is also an abundant source of plant growth-promoting bacteria that could offer various benefits to its host plants, including nutrient availability, plant growth promotion and control of pests and diseases

(Mukherjee et al. 2023). Hence, it can also be used as a seed priming approach. HK can be used as foliar nutrition, soil drenching and priming medium for many agricultural and horticultural crops because of its bio stimulant and antimicrobial properties (Jani et al. 2017). The breakdown of complex components into lower molecular weight simpler components during ingredient fermentation accounts for the efficiency of HK releasing nutrients for quick plant uptake makes suitable for foliar spray (Devi et al. 2024). This liquid organic comprises vitamins, growth hormones (IAA and GA_3), necessary amino acids and advantageous microorganisms such as bacteria that fix nitrogen, both symbiotic and free-living, and bacteria that solubilize phosphorus (Ankad et al. 2019; Chakraborty et al. 2019). Kunapajala is a potential and environmentally safe plant stimulant for safe agro ecosystems and sustained crop production (Erisman et al. 2007).

In addition, wheat production under intensive agricultural systems calls for substantial amounts of nitrogen fertilizer inputs, which is linked to the possibility of nitrogen loss. Nitrogen fertilization is thought to be very important for getting the best food growth. By applying nitrogen in two separate applications, farmers may maximize plant absorption of the nutrient and lessen the likelihood of wasteful leaching, according to research published in 2012 by Gaudin (Gaudin 2012). In most cropping systems, applying N fertilizer is a necessary crop and soil management strategy. Thus, recommendations for N fertilizer should take into account increasing crop yields and net returns while having the fewest possible adverse effects on the environment (Obour et al. 2024). The split application has been shown to increase wheat grain output and flour quality, according to many authors. In addition to using fertilizers, it is possible to enhance N efficiency by supplementing the soil with HK, a locally produced organic liquid nutrient supplement. Herbal medicine quality may be negatively impacted by the use of synthetic fertilizers, hence organic manures are in high demand. Organic manure also increases the soil's buffering ability and water-holding capacity, which helps to promote and preserve soil fertility (Das 2003). Application of organic liquid along with chemical fertilizers might enhances plant growth and yield due to improved mobilization and rapid availability of plant nutrients while lowering the nutrient losses. Many studies have shown that using HK on vegetable plants including chilli, mango, coconut, and kiwi fruit leads to great outcomes (Nene 2006). However, there have been little efforts to evaluate HK's effectiveness on wheat crop specially under delayed sowing. Therefore, a field appraisal of these priming techniques in early late sown wheat need to be tested. Therefore, a study entitled "Response of late sown wheat (*Triticum aestivum* L.) to seed treatment and foliar application of herbal kunapajala under different dose of nutrients" was conducted with the objective: To study the effects of herbal kunapajala seed priming followed by its foliar spray on crop establishment, growth and productivity of late sown wheat.

Materials and methods

Site description

The study was conducted at Udham Singh Nagar District formed in October 1995, Uttarakhand state of India. The Norman E. Borlaug Crop Research Centre at the G. B. Pant University of Agriculture and Technology is located in Pantnagar town of Udham Singh Nagar (Fig. 1). The University hosted the field research during the rabi season of 2020–21 at Pantnagar, at an elevation of 243.83 m above sea level. Weather data recorded during experimental period are given in Fig. 2. The average weekly high temperature during the duration of the trials varied from 16.6 °C to 37.5 °C, with an average of 27.1 °C, while the average weekly low temperature varied from 6.1 °C to 17.8 °C, with an average of 11.9 °C. The total quantity of precipitation was 42.5 mm, spread among 4 wet days throughout the crop season (Fig. 2). Humidity ranged from a high of 83% to a low of 43%, with a median of 83% and a standard deviation of 5%. There was a significant concentration of organic carbon in the soil in the experimental region (7.3 g/kg), the soil pH was 6.9 and the available nitrogen, phosphorus, and potassium levels were 201, 209, and 213 kilograms per hectare. On December 28, 2020, the UP-2526 type of wheat was drilled utilizing a seed rate of 125 kg/ha, a depth of 5 cm, and a row-to-row spacing of 20 cm. The crop was harvested on April 23, 2021.

Experimental details

A basic randomized block design with three replicates in a net plot size of 3.0 m × 2.2 m was used for the outdoor experiment. Table 1 lists all of the study's treatments in detail. The different concentrations of 10%, 25% and 50% of HK were taken based on the concentrations that shown better results in pre-sowing laboratory test.

Table 1. Treatments details of experiments undertaken in late sown wheat.

T_1	No seed priming + 100% RDN
T_2	Hydropriming + 100% RDN
T_3	Seed priming with 10% HK + 100% RDN+ foliar application of 10% HK
T_4	Seed priming with 10% HK + 75% RDN+ foliar application of 10% HK
T_5	Seed priming with 10% HK + 50% RDN+ foliar application of 10% HK
T_6	Seed priming with 10% HK + no Fertilizer+ foliar application of 10% HK
T_7	Seed priming with 25% HK + 100% RDN+ foliar application of 10% HK
T_8	Seed priming with 25% HK + 75% RDN+ foliar application of 10% HK
T_9	Seed priming with 25%HK + 50% RDN+ foliar application of 10% HK
T_{10}	Seed priming with 25% HK + no fertilizer+ foliar application of 10% HK
T_{11}	Seed priming with 50% HK + 100% RDN+ foliar application of 10% HK
T_{12}	Seed priming with 50%HK + 75% RDN+ foliar application of 10% HK
T_{13}	Seed priming with 50% HK + 50% RDN+ foliar application of 10% HK
T_{14}	Seed priming with 50% HK + no fertilizer+ foliar application of 10% HK

RDN: Recommended dose of nutrients; HK: herbal kunapajala.

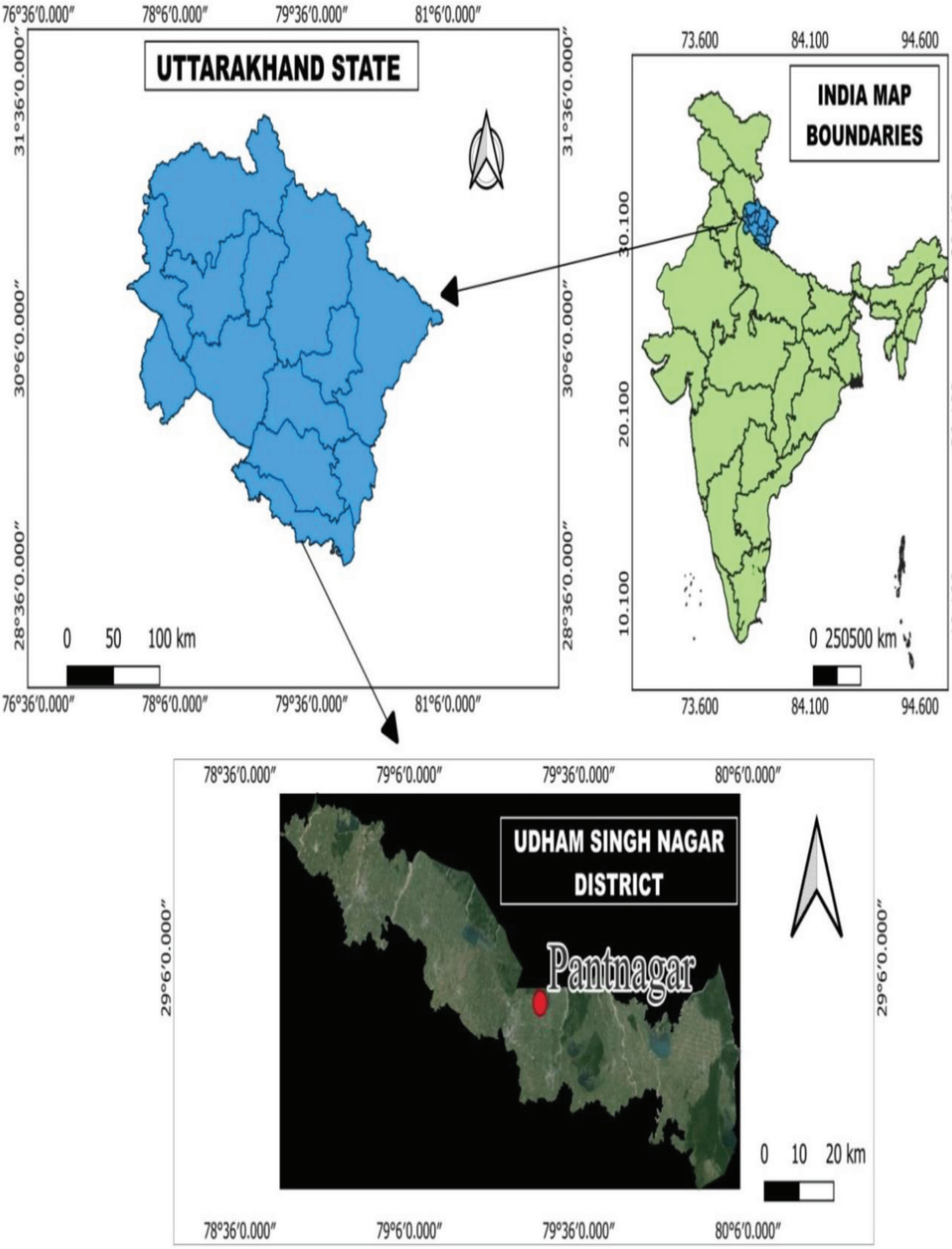

Figure 1. Location map of Study Area (Pantnagar, Udham Singh Nagar district).

Nutrient management

The recommended dose of nutrients (RDN) were 120–60–30 kg/ha N-P_2O_5-K_2O N, P, and K were supplied via urea, NPK fertilizers, and muriate of potash, respectively. In order to prepare the field, 50% N, 100% of the required P, and 100% of the recommended K were administered as basal fertilizer (as per treatments), and the remaining 50% N was top-dressed in a single split. Sprays of 10% HK were applied to the leaves at 25, 45, 65, 85, and 105 days following planting using hand-operated knapsack sprayers fitted with flat fan nozzles to ensure a uniform application. In order to avoid getting spray on the dewy leaves, we sprayed in the evening. All other practices such as irrigation were applied as for crop requirement

Preparation of Herbal kunapajala (HK) and seed priming

At the University Farm's Crop Research Center's organic block, 40 days before the trial, herbal kunapajala (HK) was prepared for the purpose of both seed priming and foliar application. All the ingredients as given in Table 2 as per

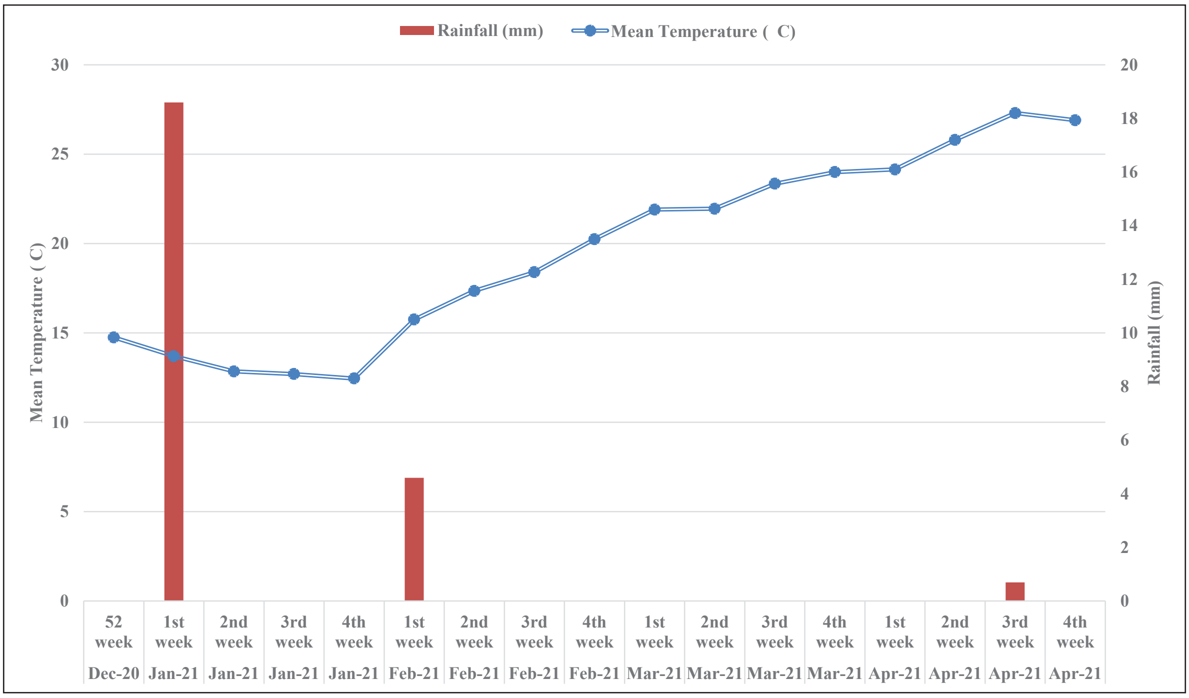

Figure 2. Weather data recorded during the experimental period (Dec-2020 to April-2021).

Table 2. Ingredients for the preparation of HK.

Ingredients	Quantity
Cow dung	10 kg
Cow urine	10 L
Sour butter milk	2 L
Jaggery	2 kg
Sprouted Urd	2 kg
Mustard cakes	2 kg
Rice bran water	3 L
Fresh milk	1 L
Kande	3–4 pieces
Nettle grass	10 kg
Leaves of other local grasses	10 kg

their concentrations were mixed into a plastic drum of 200 L capacity and 10 L of water was added. Then it was mixed properly with a thick stick. After shaken, the volume of water makes upto 200 L and the kept the container airtight. The contents of the drum were mixed properly with a thick stick twice a day (morning and evening) and kept for about 15–25 days. When the bubbles are invisible inside the drum, indicates the preparation is completed. Then, HK was used both for seed priming and foliar spray at different stages. For foliar application, 2–3 sieving was done 2–3 times with muslin cloth so that the sprayer nozzle is not blocked.

Then, the freshly prepared HK was then measured and made different concentrations for seed priming. Wheat variety UP-2526 type of wheat obtained from the G.B.U.A &T was used for the experiment. Seeds were primed with different concentration of HK viz, 10%, 25% and 50% and hydropriming (tap water) for 16 hours in the ratio of 1:2 (seed: priming media) (w/v) followed by shade drying to reach initial moisture (11.86%). Untreated dry seeds were used as control.

Field parameters

The field emergence was calculated as given by (Scott et al. 1984) as given below:

$$\text{Field Emergence}(\%) = \frac{(\text{Number of emerged seedlings})}{(\text{Total number of seeds sown in 2 meter row})} \times 100$$

The following yield characteristics such as: spike length (cm), number of grains per spike, number of fertile spikelets per spike, grain weight per spike (g), and 1000 grain weight; plant height (cm), number of tillers, dry matter accumulation (g/plant), at harvest; and spike length (cm) were measured. We determined the grain yield (q/ha) and straw yield (q/ha) from the net plot area. The harvest index (%) was calculated by using the formula given below:

$$\text{HI}(\%) = \frac{\text{Grain yield (kg/ha)}}{\text{Biological yeild (kg/ha)}} \times 100$$

The α-amylase and dehydrogenase activities were assessed by using the procedures given by Kittock and Law (1968) and Mazumdar and Majumdar (2017), respectively.Grain quality parameters such as hectoliter value and phenol test were also determined. For determination of hectoliter value, thoroughly cleaned grain samples were put into a funnel of the hectoliter instrument by keeping its outlet closed and levelled. Then the outlet was kept opened to allow free flow of grains in to the metallic cylinder below until completely filled, then levelled by sliding the shutter. Weight of the sample was taken from the cylinder. Then hectoliter weight was expressed as kg/hectoliter. For phenol test, any damaged kernels or foreign materials were cleaned and put in a Petri dish. Then 1% phenol solution was added to keep the seeds in the solution and kept for 2 hrs. Then the solution was drained and dried the seeds on a filter paper sheet. After complete drying, the color was graded on the scale of 1–10.

Statistical analysis

The data obtained from numerous observations was analyzed using the analysis of variance (ANOVA) method for a simple factorial randomized block design. The critical difference was determined using 5 percent significance level. To evaluate the connection between the characteristics, a correlation study was performed between them using the Origin Pro Software (USA) (https://www.originlab.com/getstarted). The significance threshold used in determining the crucial difference was 5%. Tukey's post hoc test was used to compare across different combinations of the treatments. Treatments denoted by different alphabetical letters represent the statistical significant difference among the treatment pairs.

Principal component analysis

Using the multivariate analysis tab in the Origin pro software (USA) (https://www.originlab.com/getstarted), Principal Component Analysis (PCA based on Pearson correlation) was done on the yield, quality traits and enzyme activity. To visualize the correlations and effects of the various factors on one another, we used Origin Pro software to generate PCA biplots.

Results

Field emergence (%)

The field emergence (%)and was significantly influenced by HK treatments under different nutrient doses (Table 3). The highest field emergence (%)was jointly recorded from T_7, T_3, T_2 and T_1 (93%, 91.2%, 87.7% and 85.6%, respectively) and the lowest from T6, T_{10}, T_{11} and T_{14} (66.3%, 68.3%, 70% and 70%, respectively) among all the treatments.

Growth parameters

According to Table 3, plant height, number of tillers, and dry matter accumulation all changed significantly throughout the range of HK treatments and nutrient levels tested. It was observed that T_7 (128.7 cm), T_2 (125.1 cm), T_1 (122.6 cm), and T_5 (119.9 cm) had much taller plants than the others. The T_{14}, T_{10}, T_9, T_6, T_{11}, and T_{12} plants all measured at their shortest at 101.3, 101.3, 101.5, 103.8, and 113.4 cms. Tiller number (m^2) also found highest at T_7 (333.3 tillers/m^2), T_2 (320.2 tillers/m^2), T_1 (315 tillers/m^2) and T_3 (313.2 tillers/m^2) than rest of the treatments but shown par with each other. Significantly, lower tiller numbers recorded from all the remaining treatments except T_4 (287 tillers/m^2). Significant increase in plant dry matter were also observed from T_3, T_2, T_1, T_7, T_4, T_{12} and T_{11} treatments (5.67, 5.50, 5.43, 5.40, 5.37, 5.10 and 5.03 g/plant respectively). The lowest dry matter accumulations were recorded from all the treatments T_5, T_6, T_9, T_{10}, T_{13} and T_{14} which was at par with each other.

Yield and yield attributes

The yield parameters assessed by treatments were significantly under the present study (Table 4). These comprised the number of fertile spikelets per spike, the number of grains per spike, the weight of 1000 grains, the spike length (cm), and the spike weight (g). With a spike length of 12.43 cm, T_7's was the longest among T_2, T_1, and T_3 (11.20 cm, 11.07 cm, and 10.83 cm, respectively). Treatment with T_6 resulted in the shortest spike (8.8 cm), which was comparable to those obtained with T_4, T_5, and T_{10} (10.33, 9.97, and 8.87 cm, respectively).

Table 3. Field mergence, plant stand and growth parameters of wheat as influenced by HK treatments under different dose of nutrients.

Treatments	Field emergence (%)	Plant height (cm)	Number of tillers (m^{-2})	Dry matter accumulation (g/plant)
T_1	85.6abc	122.6ab	315.0ab	5.43abc
T_2	87.7ab	125.1ab	320.2ab	5.50ab
T_3	91.2ab	118.0abc	313.2abc	5.67a
T_4	80.7 abcd	117.3abcd	287.0abcd	5.37abc
T_5	81.9abcd	119.9ab	279.0abcd	4.17cd
T_6	66.3d	103.8cde	244.0d	4.37abcd
T_7	93.0a	128.7a	333.2a	5.40abc
T_8	75.0 bcd	115.5	262.0bcd	4.87abcd
T_9	75.0bcd	101.5de	256.5bcd	4.57abcd
T_{10}	68.3d	101.3e	245.7cd	4.23bcd
T_{11}	70.0cd	103.8cde	264.0bcd	5.03abcd
T_{12}	76.7 abcd	113.4abcde	245.5cd	5.10abcd
T_{13}	76.7 abcd	110.7bcde	253.7bcd	4.47abcd
T_{14}	70.0cd	101.3e	244.0d	4.02d
SEm±	3.3	3.1	13.3	0.26
CD(p = 0.05) .06	9.7	9.1	38.7	0.75

The highest number of grains per spike also found to be in similar trend with spike length where T_7, T_3, T_2 and T_8 shown at par with each other (49.90, 49.90, 48.67 and 47.67 grains/spike). While the lowest number of grains were observed from T_6, T_{14} and T_{10} (32.05, 33.43 and 33.53, respectively) which was at par with each other.

Fertile spikelets per spike was shown significantly higher with T_7 (23.30) which was at par with T_3 and T_2 (21.67 and 21.20, respectively) as compared to other treatments. Whereas the lowest fertile spikelets were observed from T_{14}, T_{10} and T_6 (14.93, 16.23 and 16.27, respectively) but was at par with each other.

Grain weight per spike were observed maximum jointly from T_7, T_2, T_3, T_1 and T_4 (1.677, 1.620, 1.607, 1.550 and 1.527 g/spike) which was at par with each other as

Table 4. Yield and yield attributes of wheat as influenced by HK treatments under different dose of nutrients.

Treatments	Spike length (cm)	Number of grains per spike	Fertile spikelets per spike	Grain weight per spike (g)	1000 grain weight (g)	Grain yield (q/ha)	Straw yield (q/ha)	Harvest index (%)
T_1	11.07ab	47.67a	19.33abc	1.52ab	36.67ab	41.33bc	68.00ab	37.8a
T_2	11.20ab	48.67a	21.20ab	1.62a	40.22ab	45.23ab	70.77ab	39.0a
T_3	10.83ab	49.90a	21.67ab	1.60a	43.00a	47.90a	72.77a	39.7a
T_4	10.33ab	44.50a	19.00abcd	1.55ab	34.75ab	40.33c	68.63ab	37.0a
T_5	9.97ab	45.27a	19.20abcd	1.44abc	31.37b	38.70c	66.03ab	37.0a
T_6	8.80b	32.05c	16.23cd	1.10bc	29.60b	24.87d	64.83ab	27.7b
T_7	12.43a	49.90a	23.20a	1.67a	42.93a	48.03a	70.30ab	40.6a
T_8	10.50ab	42.30a	20.13abc	1.43abc	33.88ab	38.90c	71.13ab	35.4a
T_9	10.43ab	41.85ab	19.93abc	1.29abc	36.99ab	38.03c	68.70ab	35.7a
T_{10}	8.87b	33.53bc	16.27cd	1.07bc	31.67b	24.50d	62.33b	28.2b
T_{11}	10.47ab	41.45ab	19.93abc	1.37abc	33.37ab	42.43bc	70.30ab	37.6a
T_{12}	9.97ab	44.37a	19.93abc	1.34abc	33.73ab	38.30c	62.90ab	37.9
T_{13}	10.07ab	45.27a	17.73bcd	1.28abc	33.73ab	38.73c	65.20ab	37.3a
T_{14}	8.81b	33.43bc	14.93d	1.04c	29.67b	23.00d	67.70ab	24.5b
SEm±	0.56	1.47	0.85	0.076	2.22	0.93	1.97	1.0
CD($p = 0.05$)	1.62	4.29	2.50	0.223	6.49	2.71	5.75	3.1

compared with rest of the treatments. The lowest weight was found as same trend with fertile spikelets per spike i.e. T_{14}, T_{10} and T_6 (1.040, 1.073 and 1.107 g/spike) and was statistically similar with each other.

1000 grain weight (g) is found in similar trend with fertile spikelets per spike i.e. the highest 1000 grain weight were observed from T_3, T_7 and T_2 (43, 42.93 and 40.22 g, respectively) which was at par with each other while the lowest from T_6, T_{15} and T_{10} (29.60, 29.67 and 31.67 g, respectively).

The maximum grain production was seen with T7 (48.0 q/ha) and T3 (47.90 q/ha), however these two treatments were at par. The lowest grain yield was found in T14, T10, and T6, which were all the same (23, 24.8, and 24.45 q/ha). The higher straw yield was recorded from T_3 (72.77 q/ha) but was at par with all the treatments except T_5 (66.03q/ha), T_{13} (65.20 q/ha), T_6 (64.83 q/ha), T_{12} (62.93 q/ha) and T_{10} (62.33 q/ha). While the lowest straws were recorded jointly from T_{10} (62.33 q/ha), T_{12} (62.93 q/ha) and T_6 (64.83 q/ha) among all the treatments.

Higher harvest index was observed significantly from T_7, T_3, T_2, T_{12}, T_1 and T_{11} (40.6, 39.7, 39.0, 37.9, 37.8 and 37.6%, respectively) as compared with other treatments but at par with each other. The lowest harvest index was recorded from T_{14} (24.5%).

Grain quality indices

Hectoliter weight (kg/hL) and Phenol value

The results depicted in Fig. 3 shown that the varying seed priming treatments under different nutrient doses had significant effect on hectoliter weight. In our experiment,

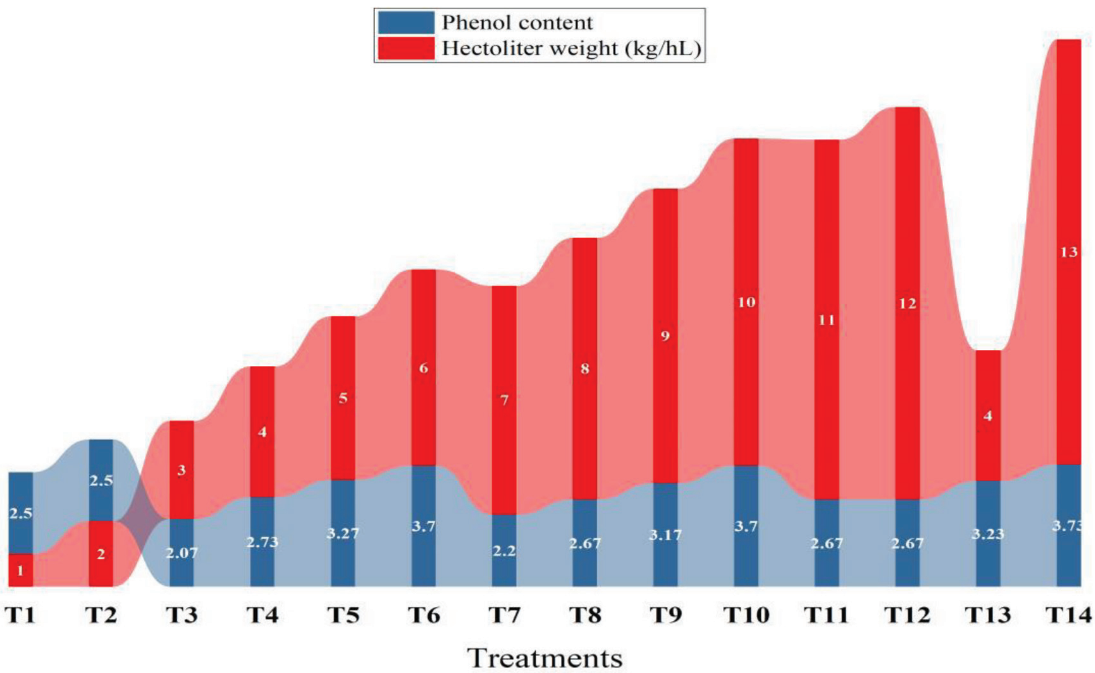

Figure 3. Hectoliter weight (kg/hL) and phenol value of wheat as affected by varying treatments.

highest hectoliter weight was observed from control T_1 (78.47) which was at par with T_2 (75.57 kg/hL) whereas T_3 (65.43 kg/hL) scored the lowest hectoliter weight which was at par with T_7 (66.63 kg/hL).

Phenol value was also significantly affected due to varying treatments (Fig. 3). Maximum phenol test value was observed in T_{14} where 50% of RDN were applied which was statistically at par with T_6 and T_{10} (3.70 and 3.70, respectively). The minimum phenol was recorded from T_3 (2.07) but statistically par with T_7 (2.20).

Enzyme activities

Alpha amylase enzyme

The α-amylase activity was significantly influenced by varying treatments in the study (Fig. 4). The maximum α-amylase activity was observed with T_7 (27.9 mg of starch hydrolyzed/g of seeds) which was at par with T_3 and T_2 (25.1 and 24.7 mg of starch hydrolyzed/g of seeds, respectively). The minimum α-amylase activity was recorded from T_{10} (18.3 mg of starch hydrolyzed/g of seeds) but shown at par with T_6 and T_{10} (18.6 and 19.4 mg of starch hydrolyzed/g of seeds, respectively).

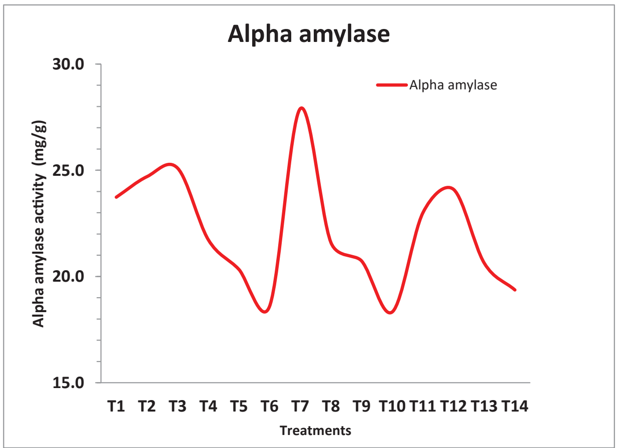

Figure 4. Alpha amylase activity (mg of starch hydrolyzed/g of seeds) of wheat as affected by varying treatments.

Dehydrogenase activity

Variations in therapy had significant effects on dehydrogenase activity (OD). In comparison to T_3 (0.63 OD), T_7 (0.68 OD) showed considerably greater dehydrogenase activity (Fig. 5). The minimum was measured at time point T_{14}, which was determined to be statistically equivalent to time point T_6 (0.39 and 0.39 OD, respectively).

Correlation studies

Correlation coefficient (r) calculated among various parameters of wheat is given in Fig. 6. It demonstrates that there is a significant and positive correlation between the field emergence percentage and other parameters except phenol content. It also shows positive correlation with plant height,

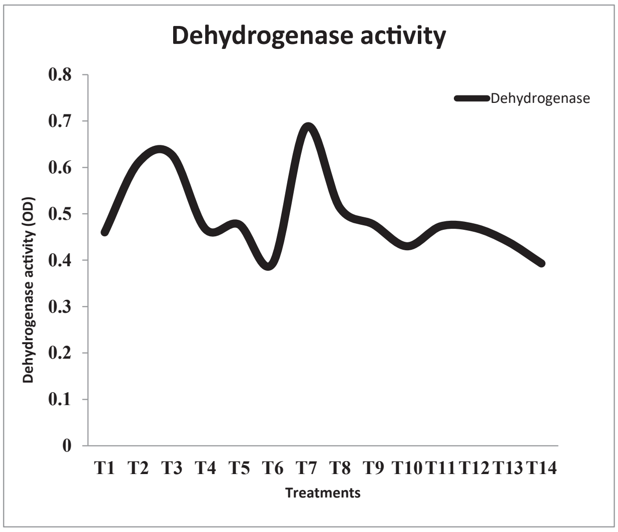

Figure 5. Dehydrogenase activity (OD) of wheat as affected by varying treatments.

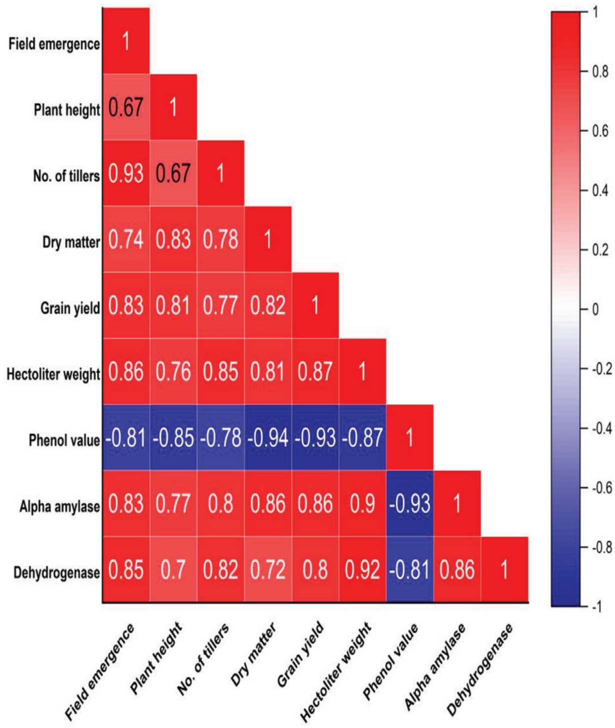

Figure 6. Correlation coefficient between field emergence (%), plant height (cm), No. of tillers (m^{-2}) grain yield (q/ha), hectolitre weight (kg/hL), phenol value and dehydrogenase activity (OD) under different treatments.

number of tillers, dry matter accumulation, grain yield, alpha amylase activity, and dehydrogenase activity, but a significant and negative correlation with the phenol value.

Principal Component Analysis (PCA)

The PCA was carried out to determine the level of correlation between grain yield with growth parameters, grain quality and enzyme activities of the plant. Fig. 7 displays the

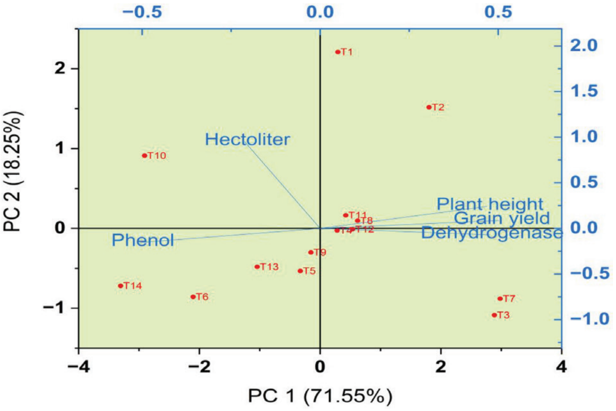

Figure 7. Principal component analysis between plant height, grain yield, hectolitre weight, phenol value and dehydrogenase activity.

percentage of variation in plant height (PH), grain yields (GY), hectoliter weight (HL), phenol value (P) and dehydrogenase activity (DH) that could be attributed to each factor's principal component (PC1 and PC2) (Table 5).

The main component analysis revealed a substantial association between plant height (PH), grain yield (GY), hectoliter weight (HL), phenol value (P) and dehydrogenase activity. Wheat vegetative features, yield attributes, grain quality and enzymatic parameters were all impacted by HK seed priming. According to PC1, there is a strong positive correlation between plant height, dehydrohydogenase activity and grain yield, which suggests that when taller the plant height and greater the dehydrogenase enzyme the grain yield will increase as a result. In contrast, the phenol content exhibited a negative correlation with grain yield indicating that an increase in the yield is likely to result in a decrease in the phenol content due to the treatment effects. The PCA results revealed that the plants under seed priming treatments specifically T_7, T_3, T_{12}, T_8, T_{11} and T_4 had higher growth, enzyme, grain yield and quality. Thus, in principal component analysis of the above parameters, PC1 explains 71.55% of the variance in all the data, hence PC1 is sufficient to contribute to the variance of all the data.

Table 5. Principal Component Analysis between different parameters.

Treatments	PC 1 (Score 71.55%)	PC 2 (Score 18.25%)
T_1	0.29572	2.2093
T_2	1.80489	1.51657
T_3	2.88634	-1.08693
T_4	0.28254	-0.02606
T_5	-0.32839	-0.53245
T_6	-2.10217	-0.53245
T_7	2.98142	-0.88081
T_8	0.62091	-0.09687
T_9	-0.15162	-0.30065
T_{10}	-2.90694	0.91067
T_{11}	0.42508	0.16404
T_{12}	0.5393	-0.01159
T_{13}	-1.04284	-0.48126
T_{14}	-3.30424	-0.71949

Discussions

In the present experiment, 10% and 25% kunapajala primed seeds jointly recorded maximum germination percentage (99.7%) which was statistically at par hydro-priming (99.3%). Fast translocation and the provision of food reserves to growing seedlings are facilitated by the rapid accumulation of germination metabolites and metabolic repair brought on by priming (Farooq et al. 2019b). As a result, the germination of primed seeds proceeds quickly. The 10% herbal kunapajala primed seeds may have improved seedling growth parameters because of the rapid start of enzyme activity and breakdown of stored food components. In other study, *Jatropha curcas* and *Pongamia pinnata* seeds that were fortified with 2% panchagavya showed a higher percentage of germination, which may have been caused by the activities of microorganisms and growth stimulants such GA_3 and IAA in a liquid mixture (Srimathi et al. 2013). Other findings reported that the percentage of kalamegha and ashwagandha seeds that germinated after being treated with 10% Kunapajala and Panchagavya exhibited a substantial increase above no priming (Ankad 2018). In a Zimbabwean study, primed cotton and maize seeds produced better germination percentages at low water potentials than non-primed seeds (Murungu et al. 2005). As a result, root and shoot length were seen significantly higher in seeds primed with HK than control.

The magnitude of difference in emergence % and plant stand in treatment T_7 and T_6 were up to the tune of 28.7% and 25.7%, respectively. This improvement in emergence per cent and plant stand might be due to the fact that enzyme activities were efficient during seedling emergence in case of T_7 as compared to untreated seeds and no fertilizer treatment i.e. T_6. Primed seeds make faster water uptake and greater activity of α-amylase which increased the breakdown of starch and supply the energy for seed germination. Vigorous root systems and robust seedlings are more resilient to biotic and abiotic stressors (Harris 2006; Dimkpa and Bindraban 2016). Additionally, the addition of vitamins, growth regulators such IAA and GA_3, and amino acids to kunapajala formulations may stimulate the -amylase activity in kunapajala primed seeds, resulting in better crop establishment and quicker seedling emergence. However, when the kunapajala content in the priming medium increased, both the percentage of plants that emerged from the soil and the total number of plants in the field decreased. This may have been caused by the priming media exceeding the appropriate dosage of the organic product, which is generally crop-specific, resulting in decreased water absorption and slow starch breakdown.

The increase in plant height and tiller number in T_7 than T_{14} were up to the tune of 21.3% and 26.8%, respectively than control. Taller plants and maximum tiller numbers were observed in 100% recommended dose of nutrients compared to lower doses because of more nutrient supplement (Borse et al. 2019). Usually, tiller production is directly proportional to the increasing rate of nitrogen dose. It helps in the production of greater number of tillers resulted to higher survival rate. Potassium is thought to activate several enzymes necessary for plant growth, while phosphorus is also a crucial dietary element for plant development and expansion. Due to this important role of nutrients in plant growth, the tiller number showed an enhancing trend with 100% recommended dose. Presence of macro and micro nutrients, beneficial microorganisms many vitamins, hormones, enzymes and growth promoters like IAA and GA_3 supplied through foliar application of KJ also improved the plant growth. Higher plant dry matter accumulation with 100% recommended dose of nutrient can be attributed to increased plant height coupled with a greater number of tillers.

In addition to minerals, plant growth regulators (such IAA and GA_3), and helpful bacteria (like *Rhizobium*, *Azotobacter*, *Pseudomonas*, etc.) that promote plant development, liquid manure also includes growth hormones, vitamins, and amino acids that are advantageous to plants (Devi and Laishram 2023). Spike length was found to be 21.4% more with T7 (11.20 cm) than T6 (8.8 cm). There was 35.8% increase in number of grains per spike in T7 treatment over T1 (control). Grain weight per spike and 1000 grain weight (g), two traits that affect yield, were both enhanced by priming with KJ seeds at doses of 10% and 25%. The T_3 increase in thousand grain weight was 31.16 percentage points more than the T6.

The optimal supplement of nutrients resulted in increased magnitudes of growth parameters and yield attributing features, leading to a rise in grain production at 100% of the prescribed dosage. The grain production rose as a consequence of receiving the full amount of nutrients prescribed. Consistent with the results of (Nehra et al. 2009) higher grain production was seen when the recommended amount of nutrition was increased to 100%. The decrease in grain yield of wheat caused by late spring stress primarily stems from the death of tillers during the green return and jointing stages, hindrance in young spikes development, and reduction (Zheng et al. 2024). The increase of grain yield in HK priming provided with foliar application of 10% HK might be due to availability of micronutrients in optimum quantities along that has a pronounced impact on plant growth. Grain weight per spike and thousand grain weight may have risen, contributing to this growth. Cow dung, urine, milk, urd sprouts, rice bran milk, kande, jaggary, and nettle grass are used to make HK, a concoction that promotes plant growth and yield by providing macronutrients, micronutrients, vitamins, amino acids, growth-promoting substances, and beneficial microorganisms. It might also be due to increase in the photosynthesis rate while also reducing leaf surface temperature and electrolyte leakage due to seed priming (Habibi et al. 2023).

Higher harvest index reveals that the increase in economic yield was more than that of straw yield which is mainly attributed to better partitioning of photosynthates due to optimum amount of nutrients in soil.

Physical and chemical properties are used to evaluate grain quality, and these in turn are affected by both genetic potential and environmental factors (Johansson et al. 2019). Milling companies place a premium on hectoliter weight, much as farming operations place a premium on grain production. A milling quality measure, the weight of wheat grain in hectoliters is connected to wheat milling yield. Agriculture inputs, crop diversity, and climate all have role. HectoL value was reduced in HK primed seeds followed by foliar application than control. This may be due to the sulphur content in HK, which was found to be 123.61 percent in a quantitative elemental analysis and assists in increasing plant growth and physiological functions (Jani et al. 2017). The essential amino acids methionine and cysteine, both of which are essential for starting the process of protein synthesis, include sulphur. This result is in line with that of (Hoel 2011) who observed a significant decrease in the weight of wheat grain per hectoliter after sulphur fertilisation. This result was also in conformity with the findings of are also reported by (Alemu et al. 2023), wherein they found that highest hectoliter was obtained from the control (no sulphur) (76.12 kg/hL) and lowest (76.12 kg/hL) was obtained from 60 kg S/ha. This might be due to the fact that the increasing nitrogen dose decreased the phenol values.

Endosperm α-amylase activity was increased thanks to GA_3 being delivered there and turning on the RAmy1A gene (Kaneko 2002). The amino acids, vitamins, and growth regulators (IAA and GA_3) found in HK may cause primed seeds' -amylase activity to be activated, causing the breakdown of endosperm starch and the release of energy for germination (Sudhakar 2010). Significant association between α-amylase activity and water absorption by seeds was observed by (Marambe et al. 1992). All of these findings were consistent with those of (Farooq et al. 2019). However, α-amylase activity was reduced with increasing the concentration levels of KJ seed priming. This may be due to negative impact on synthesis of gibberellic acid which eventually affected the starch hydrolysis. Similar results, reported that 25% KJ primed seeds at 12, 16, and 24 hours of priming durations exhibited the highest -amylase activity, with values of 24.1, 27.1, and 24.6 mg of starch hydrolyzed/g of seeds, respectively, which were statistically equivalent to those observed with 10% HK priming at 12 hours of priming duration (Devi et al. 2023).

In the embryonic axis, both catabolic and anabolic processes occur during seed germination, making it an amphibolic process. Catabolic process is controlled by dehydrogenase group of enzymes. Dehydrogenase enzyme activities indicate the level of viability in seed as its component of ETC system which facilitated the electron transport from a substrate to oxygen necessary for the respiratory process. The similar results are also in agreement in wheat that 25% KJ primed seeds recorded significantly higher dehydrogenase activity (0.68 OD) which was at par with hydroprimed seeds and 10% kunapajala primed seeds (0.63 and 0.62 OD, respectively) (Devi et al. 2023). Similar results reported hydropriming improved the dehydrogenase enzymes (20 µg/100 seeds) as compared with untreated seeds. In this way, dehydrogenase enzymes activate hydrolytic enzymes during seed priming, increasing the metabolism of seed reserves (Farooq et al. 2006).

India is, however, now on the verge of introducing chemical-free natural farming based on on-farm resource recycling and dairy excreta-based microbial formulations (Source: http://www.niti.gov.in/natural-farming-niti-initiative). The new Indian agricultural policy, no doubt, would offer a wider acceptance of Kunapajala technology as a regenerative input. On the other hand, according to the United Nations' Sustainable Development Goals (https://SDGs.un.org/goals), our planet would face the threat of almost 90% deforestation globally mainly triggered by crop agriculture and animal farming. It therefore results in exploitative use of natural resources; destruction of the facial features of the earth such as polluting our farms; deterioration of the bio diversity; unpredictable vulnerability of climate and ultimately, a very high and irreparable loss of crops and yield in the shorter-term and long-term detrimental effects that effects our environment and health. Thus, 'sustainable intensification' and 'ecosystem services' in Agriculture directly get the international attention required while making 'traditional knowledge and practices' further robust to sustain the 'agro biodiversity' and incorporating 'comprehensive' and 'strategic' approach towards the optimum utilization of natural resources and scientific enablement of innovations & technologies specific to niches (Jhariya et al. 2021). For instance, proper management practices in plant waste utilization as recycled manure will be more efficient for environment conservation to support sustainable agriculture. Hence, it is proposed that conventional innovations like Kunapajala technology could possibly be re-evaluated to contribute positively towards the sustainable intensification and concerning ecosystem services in a range of agro- ecological and socio-economic territories.

Conclusion

From the information presented above, it can be inferred that seed priming with 10% HK along with 100% of the recommended dose of nutrients, followed by foliar applications of 10% HK at various growth stages, increased the growth, productivity, quality, enzyme activity, and profitability of late sown wheat. This means that pre-sowing treatment with HK is a successful and cost-efficient method to increase crop production under late-sown conditions. Therefore, traditional innovations like the herbal kunapajala can be explore more on its suitability to crops with the aim of aiding in the sustainable intensification and supporting ecosystem services in various agro ecological and socio economic zones. Perhaps, in the subsequent years, application of herbal kunapajala either as seed treatment, soil treatment or foliar spray or their combinations in field crops widely may be an option to scaling-up the uses and awareness to the farmers.

Competing interest statement

The authors claim to have no conflicts of interest.

Funding

This research did not receive any specific funding.

Acknowledgements

The authors are very thankful to National Mission on Himalayan Studies under Ministry of Environment, Forest and Climate Change, Govt. of India for support and help us to make the product "herbal kunapjal" as a part of the project "Exploring livelihood potential of wild growing stinging nettle (*Utrica dioica*) in Uttarakhand, India".

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