Biological and Clinical Sciences Research Journal
eISSN: 2708-2261; pISSN: 2958-4728
www.bcsrj.com
DOI: https://doi.org/10.54112/bcsrj.v2024i1.1443
Biol. Clin. Sci. Res. J., Volume, ***2024****: 1443*
Original Research Article

NITROGEN PRIMING SOURCES AFFECT THE SEED GERMINATION, GROWTH AND FRUIT ATTRIBUTES OF BITTER GOURD

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(Received, 17th September 2024, Revised 9th December 2024, Published 15th December 2024)

Abstract *The production of bitter gourd is often hampered by low seed germination rates due to its hard seed coat, which leads to sluggish seed germination, poor stand establishment, and yield losses. Nutrient seed priming has emerged as a promising technique to overcome these challenges by enhancing seed vigor and germination performance, hence explored in bitter gourd. The study pursued a thorough assessment of the effects of seed priming with nitrogen sources (Urea and KNO3) on germination, growth, fruit characteristics, and shelf life of bitter gourd cultivars (Fighter and Palee). The treatments included unprimed seeds (Control), seed priming with tap water, seed priming with urea solution (1% and 2%), and seed priming with KNO3 solution (1% and 2%). The results revealed that priming with KNO3 at 2% concentration emerged as the superior treatment across multiple growth parameters, yielding the highest germination rate (85.40%), longest vine length (179.34 cm), and most abundant leaf count vine-1 (298.89). This priming also led to a significant reduction in days to flowering and enhanced the fruiting phase, resulting in earlier fruit development (59.53 days), increased fruit length (22.80 cm), and the highest single fruit weight (104.87 g). The priming with KNO3 at 2% also showed promising results for fruit shelf-life characteristics and improved shelf life (6.07 days) and minimal weight loss (4.61%). Between the two varieties, 'Palee' consistently outperformed 'Fighter,' showcasing superior performance for all the attributes observed in the study. These findings highlight the significant role of priming in enhancing the germination, fruit characteristics and shelf life of bitter gourd.*

Keywords: *Priming; Urea; KNO_3; Seed germination; Growth; Bitter gourd*

Introduction

Bitter gourd (*Momordica charantia* L) is a tender, edible fruit pod in the Momordica genus of climbing vines. Botanically, it belongs to the Cucurbitaceae family, in the genus, Momordica. The center of bitter gourd domestication likely lies in eastern Asia, possibly eastern India or southern China (Ashraf et al., 2019; Miniraj et al., 2016). The plant requires a warm and hot climate and grows well on sandy loam soil with pH 6.0 to 6.7 (Basra et al., 2005) and altitude ranges up to 1000 m with optimal germination and growth at the temperature range of 24–27°C (Baig et al., 2020. The bitter gourd is very useful for the health of its disease-preventing and health-promoting phytochemical compounds (Grover & Yadav, 2017). Bitter gourd is generally consumed cooked in the green or early yellowing stage. Bitter gourd is very popular throughout South Asia; it is often prepared with potatoes and served with yogurt (Krawinkel & Keding, 2006). In Pakistan and Bangladesh, bitter gourd is often cooked with onions, red chili powder, turmeric powder, salt, coriander powder, and a pinch of cumin seeds (Begum et al., 2017).

Bitter gourd is eaten as a vegetable and used as a folk medicine for managing Type 2 diabetes in Asia and some African countries. Studies with animals and humans suggest bitter gourd (whole fruit, juice, or extract) has a role in diets for glycemic control of diabetes. The anti-diabetic effect of bitter gourd results from the complex action of multiple compounds in the fruit (Krawinkel & Keding, 2006). Nutritionally, bitter gourd is a valuable source of essential vitamins and minerals, making it a nutritious addition to the diet. It is particularly rich in vitamin C, an antioxidant that supports immune function and skin health, as well as vitamin A, which promotes vision and overall eye health (Ahmad et al., 2019). Likewise, it also has anti-carcinogenic

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properties and can be used against multiple cancer forms as a cytostatic agent (Abbas et al., 2024ab; Arshad et al., 2024; Haroon et al., 2024; Baig et al., 2020).

Germination and seedling establishment are critical stages in the plant life cycle (Ziaf et al., 2021; Ahmed et al., 2021; Sarwar et al., 2017). In crop production, stand establishment determines plant density, uniformity, and management options (Cheng & Bradford, 2018). A method to improve the rate and uniformity of germination is the priming or physiological advancement of the seed (Halmer., 2016). Seed priming is the soaking of seeds in a solution of any priming agent followed by the drying of seeds that initiates germination-related processes without radicle emergence (Jie et al., 2018). The beneficial effects of seed priming are mediated by various physiological and biochemical mechanisms. Priming treatments activate the repair and synthesis of cellular components, including DNA, proteins, and membranes, which are essential for seed viability and vigor (Bailly et al., 2019). Additionally, priming induces the synthesis and accumulation of protective compounds such as antioxidants, osmolytes, and stress-related proteins, which enhance the seed's capacity to withstand environmental challenges (Junaid and Gokce, 2024; Rehman et al.,2024; Sami et al., 2023; Finkelstein et al., 2021). Numerous studies have demonstrated the positive impact of seed priming on germination parameters and early seedling growth across different crop species. For instance, research by Khan et al. (2019) observed significantly higher germination percentages and quicker emergence in primed maize seeds compared to untreated ones. Similarly, primed rice seeds exhibited enhanced germination rates and uniform seedling emergence under both normal and stress conditions (Farooq et al., 2019). These improvements in germination and seedling establishment contribute to better stand establishment and ultimately higher crop yields. The research conducted by Ahmad et al. (2021) demonstrated that primed wheat seeds resulted in higher grain yields compared to untreated seeds, attributed to better root development, increased nutrient uptake, and improved photosynthetic efficiency. Similarly, primed soybean seeds exhibited enhanced yield components, including an increased number of pods per plant and higher seed weight, leading to greater overall productivity (Ehsanfar et al., 2020). These findings underscore the potential of seed priming as a sustainable approach to augmenting crop yields and ensuring food security.

Faster and consistent seed germination is crucial to productivity, quality, and eventually the profit to the growers related to vegetable farming (Jamil et al., 2016). Due to the thick and hard seed coat, the consumption of the water in the seed occurs gradually and therefore the emergence of the seed in the soil is always an issue in bitter gourd, even with the seed having high viability (Asna et al., 2020). To overcome this issue, numerous approaches have been applied and priming is one of them. Seed priming is a simple, low-cost, and effective strategy for enhancing crop performance (Farooq et al., 2019). The diverse horticultural and field crops have been proven to benefit from it in terms of rapid and uniform germination and eventually yield efficiency (Adhikari *et al*.,2021; Lamichhane et al., 2021; Ahmad et al., 2021).

Nutri-priming is one of the most popular seed priming techniques to enhance rapid germination, stand establishment, and higher yields of diverse crop species (Aboutalebian et al., 2012; Faruk. 2015; Guzman & Olav et al. 2006). Nutrient priming, which involves soaking seeds in any nutrient solution has been demonstrated to improve seedling vigor and early growth parameters (Ashraf, 2016) The production of bitter gourd is often hampered by low seed germination rates, which can lead to poor stand establishment and yield losses. The priming of the seed with any nutrient has emerged as a promising technique to overcome these challenges by enhancing seed vigor and germination performance (Chandrasekaran et al., 2018; Mahboob et al., 2015). Baig et al., (2020) concluded that seed priming in phosphorus solution has the potential to overcome the problem of poor germination, delayed emergence, and less survival of seedlings after emergence. Seed priming in neutralized SSP solution for 24 hours, followed by DAP solution effectively enhanced emergence, seedling vigor, survival percentage (%), number of branches plant^{-1}, fruit weight, number of fruits per plant, and finally fruit yield ha^{-1} of bitter gourd. Moreover, seed priming in DAP solution improved the fruit length (cm) and increased the number of seeds fruit^{-1}. Similarly, Tania et al., (2020). reported that priming of bitter gourd seeds has the potential to enhance seed germination, seedling growth, and eventually yield.

In the light of above discussion, the present investigation attempted to explore the potential of priming with nitrogen sources on the germination, growth, fruit characteristics, and shelf-life traits of bitter gourd.

Material and methods

Experimental site

The field trial was carried out at the experimental land of the Horticulture Department, Sindh Agriculture University Tandojam. The experimental trial area lies at 28°35'N to 81°37'E.

Experimental design

The study was executed by applying a Randomized complete block design (factorial) with three replications

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Genetic Material

The seeds of two famous commercial varieties of bitter gourd (Palee and Fighter) were studied. The acquisition of seed was made from a local agricultural shop.

Seed priming

Seeds were primed according to the plan of the experiment, Seed priming was done in the postgraduate laboratory, Department of Horticulture, Sindh Agriculture The seeds of studied varieties were primed by applying six priming treatments that included P1=Un-primed seeds (Control), P2=Seed primed with fresh tap water, seeds primed with urea @ 1%, seeds primed with urea @ 2%, seed primed with KNO_3 @ 1%, seeds primed with KNO_3 @ 2%, After priming seeds were subjected to drying for five hours before sowing.

Land preparation for sowing of seed and crop husbandry

The land was prepared thoroughly by three ploughings followed by clod crushing and land leveling for uniform distribution of irrigation water. The bunds were prepared to separate the sub-plots and feeding channels and paths were prepared according to the plan of work.

Seed sowing

Sowing was made on raised beds. Before sowing, seeds were treated with any suitable fungicide to protect the seedlings from damping off disease. The bed about 1.5 m wide was made. Seeds were sown on both sides of raised beds at the rate of 4-6 seeds per hill, the hills being 0.5 m apart. Just before the seedlings crowd and about three weeks after sowing when the danger of beetle infestation is almost over, the plants were thinned to two plants per hill.

Fertilizer application

The nitrogen, phosphorus, and potassium were applied at recommended doses of 100, 60, and 50 kg ha^{-1} in the form of Urea, Single Super Phosphate (SSP), and Sulphate of Potash (SOP), respectively. The full dose of SSP and SOP were applied at the time of land preparation. Nitrogen (N) was added to the soil in three splits (at the sowing, flowering, and fruit development stages of the crop).

Irrigation application

The irrigation was applied according to the conditions of the soil.

Intercultural practices/ Weed management

The crop was kept clean, and a periodical weed removal practice was carried out. All the cultural practices were performed uniformly in all the plots, keeping in view the crop requirement.

Plant protection

Plant protection measures were kept in operation and crop was sprayed when it was felt that the pest population was crossing the economic injury level. For the identification of insect pests, diseases and spraying recommendations, help was acquired from the research supervisor and entomologists and plant pathologists.

Harvesting

Harvesting was done when the fruits were still young and tender. Picking was done every other day.

Data Collection and Analysis

The data for seed germination, growth, yield, and quality related traits were recorded. For data collection and recording ten plants from each treatment were randomly selected and tabulated. For data analysis, analysis of variance (ANOVA) was done by the statistical software Statistix version. 8.1. Means of different treatments were divided by employing the least Significant Difference (LSD) test at alpha 0.05.

Results

Seed Germination

There is a statistically significant *($p<0.05$)* improvement in the germination percentage of bitter gourd seeds treated with various priming agents and types as compared to the control (table 1). Germination percentages varied across priming treatments, with seeds primed with urea at 2% (P4) showing 83.53% success, KNO_3 at 1% (P5) showing 83.16% success, and seeds primed with KNO_3 at 2% (P6) showing 85.40% success. Priming is important for enhancing germination rates since the lowest germination percentage was seen with unprimed seeds (P1), which had 76.47%. The germination rate of seeds primed with tap water (P2) was 79.80%, and when treated with 1% urea (P3), the rate of improvement reached 82.41%. Both varieties of bitter gourd responded to priming treatments differently. In terms of total germination percentage, the Palee (V2) variety achieved 84.56%, which is greater than the germination recorded in Fighter (V1) 79.03%. Palee seeds may have increased germination potential and may be more receptive to priming treatments. The interaction between seed priming treatments and varieties (P × V), provided further perception of how priming affects each variation differently. Among all treatment interactions, the combination of 2% KNO_3 and Palee (T12) had the best germination percentage at 88.28%. Subsequently, urea at 2% with Palee (T8) produced 86.35%, while KNO_3 at 1% with Palee (T10) produced 85.97% germination. According to these findings, the Palee variety shows the best germination rates when primed with KNO_3 or urea. On the other hand, under control (T1), the Fighter variety had the lowest germination rate of 73.88%, suggesting that unprimed Fighter seeds are the least effective. The germination rate was likewise quite low at 77.10% when tap water priming was combined with Fighter (T3).

Vine length

There is a significant development in the vine length of the bitter gourd when exposed to various seed priming treatments, regardless of the technique or variety. In comparison to unprimed seeds, priming seeds with different agents generally promoted vine development. Vine length was maximum for seeds primed with 2% KNO_3 (P6), with an average of 179.34 cm, compared to the control (P1) at 158.26 cm, the shortest of the priming treatments. The next best were seeds treated with 2% urea (P4) and 1% KNO_3 (P5), which produced vines that were 175.42 cm and 174.64 cm long, respectively (table 1). After priming with 1% urea (P3), the average vine length was 173.06 cm, which was significantly better than the control. In contrast, priming with fresh tap water (P2) produced a modest vine length of 167.59 cm, which was nevertheless better than the control. Priming seeds with nutrients, such as urea and KNO_3, obviously promotes vine development more effectively than priming seeds with water. Among varieties, Palee (V2) was superior to Fighter (V1), with an average of 177.58 cm compared to 165.19 cm vine length. This indicates that Palee produces greater vegetative development and is more receptive to treatments than priming seeds. The treatment interaction showed that priming Palee seeds with 2% KNO_3 (T12) resulted in the greatest vine length (185.40 cm); whereas priming seeds with 2% urea (T8) caused a reduction in vine length (181.35 cm). Most notably for the Palee type, findings demonstrated the substantial advantage of KNO_3 and urea treatments. Fighter vines, on the other hand, were consistently shorter (150.50 cm) in the control group (T1). The vine length improved significantly, reaching 173.27 cm, after priming Fighter seeds with 2% KNO_3 (T11). Prioritizing treatment effectiveness, 2% KNO_3 and 2% urea were the two most successful seed priming methods for both varieties.

Number of leaves vine^{-1}

There were substantial improvements across different priming techniques and tested types in the data (Table 1) regarding the number of leaves vine-1 in bitter gourd, with a p-value of less than 0.05. However, there was no significant impact of their interaction (P>0.05). In terms of average leaves vine^{-1}, the seeds primed with 2% KNO_3 (P6) produced the most, at 298.89 leaves. The seeds primed with 2% urea (P4) and 1% KNO_3 (P5), on the other hand, gave 292.36 and 291.06 leaves, respectively. Based on these findings, bitter gourd plants are much more productive when primed with nutrient-rich substances as KNO_3 and urea. When compared to the control treatment (P1), which only produced 265.90 leaves, priming with 1% urea (P3) likewise significantly increased the number of leaves (288.44), while priming with fresh tap water (P2) produced 279.31 leaves, which was a modest improvement. This proves that priming with nutrients is far more effective in encouraging vegetative growth than priming with water, although the latter does provide some advantage. When looking at the variations, Palee (V2) always produced more leaves than Fighter (V1). The average number of leaves vine-1 for Palee was 295.97, while for Fighter it was 276.02. In control, Palee leaves grow more rapidly because it is more susceptible to priming stimuli. Priming treatments and varieties (P × V) interacted to highlight the two kinds' distinct responses even more. After priming Palee seeds with 2% KNO_3 (T12), the maximum number of leaves was 309.00. Priming the seeds with 2% urea (T8) resulted in 302.24 leaves while priming the seeds with 1% KNO_3 (T10) produced 300.91 leaves, just behind. According to these findings, KNO_3 and urea work wonders for the Palee variety when it comes to improving leaf development. However, these treatments also affected Fighter seeds; the results for Palee were higher, with 288.79 leaves, while the largest number of leaves was seen with 2% KNO_3 priming (T11). Priming with 2% KNO_3 is the most successful approach for both kinds, followed by 2% urea, according to treatment rankings.

Number of days to flowering

Table 1, regarding the impact of seed priming treatments on bitter gourd flowering time, it can be seen that there are significant differences depending on the priming agents, varieties, and their interactions (P<0.05). On average, it took 38.33 days for the unprimed seeds (P1) to flowering. Primed seeds with fresh tap water (P2) took 38.81 days longer to bloom than the control, which is a modest but discernible difference. Priming agents based on nutrients lengthened the time it took for plants to bloom. Priming seeds with 1% urea (P3) took 40.50 days and 2% urea (P4) took an even longer time, 41.51 days, to produce flowers. Similar to how priming with KNO_3 delayed flowering, seeds treated with 1% KNO_3 (P5) lasted 41.00 days to blossom, whereas seeds treated with 2% KNO_3 (P6) took the longest at 42.52 days. The two bitter gourd varieties have noticeably different flowering times. On average, it took 48.98 days for Fighter (V1) to attain flowering in all treatments, but Palee (V2) took flowering quicker, on average, after 40.90 days. The treatment interaction revealed that out of all the seeds tested, the unprimed Palee seeds took the longest time to flowering at 38.77 days, followed by the unprimed Fighter seeds (T1) at 37.89 days. A total of 38.37 days and 39.25 days were required for Fighter (T3) and Palee (T4) seeds, respectively when they were primed with fresh tap water. A 40.04-day delay for Fighter (T5) and a 40.96-day delay for Palee (T6) was seen with seeds primed with 1% urea, for instance. The flowering time for Fighter (T7) and

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Palee (T8) when primed with 2% urea was 41.04 and 41.98 days, respectively. The same was true for Palee (T10) and Fighter (T9) seeds primed with 1% KNO_3; the latter exhibited a delay of 40.54 days. Priming seeds with 2% KNO_3 resulted in the longest flowering time; Fighter (T11) took 42.04 days and Palee (T12) took 43.01 days. Seeds treated with greater concentrations of KNO_3 and urea showed the most significant delay in bitter gourd flowering time when nutrient-enriched priming agents were used.

TABLE 1 GERMINATION, VINE LENGTH, NUMBER OF LEAVES VINE^{-1} AND NUMBER OF DAYS TO FLOWERING OF BITTER GOURD VARIETIES UNDER THE INFLUENCE OF VARIOUS SEED PRIMING TECHNIQUES

TREATMENTS	GERMINATION (%)	VINE LENGTH (CM)	NO. OF LEAVES VINE^{-1}	NO. OF DAYS TO FLOWERING
SEED PRIMING (P)				
P_1=Un-primed seeds (Control)	76.47 F	158.26 F	265.90 E	38.33 F
P_2=Seed primed with fresh tap water	79.80 E	167.59 E	279.31 D	38.81 E
P_3=Seeds primed with urea @ 1%	82.41 D	173.06 D	288.44 C	40.50 D
P_4=Seeds primed with urea @ 2%	83.53 B	175.42 B	292.36 B	41.51 B
P_5=Seed primed with KNO_3 @ 1%	83.16 C	174.64 C	291.06 B	41.00 C
P_6=Seeds primed with KNO_3 @ 2%	85.40 A	179.34 A	298.89 A	42.52 A
S.E.	0.0245	0.1589	2.8175	0.0099
LSD 0.05	0.0509	0.3295	5.8431	0.0206
P-Value	0.0000^{**}	0.0000^{**}	0.0000^{**}	0.0000^{**}
VARIETIES (V)				
V_1=Fighter	79.03 B	165.19 B	276.02 B	48.98 A
V_2 =Palee	84.56 A	177.58 A	295.97 A	40.90 B
S.E.	0.0142	0.0917	1.6267	0.0073
LSD 0.05	0.0294	0.1902	3.3735	0.0119
P-Value	0.0000^{**}	0.0000^{**}	0.0000^{**}	0.0000^{**}
TREATMENTS INTERACTION (SEED PRIMING × VARIETIES)				
T_1=Seed priming control × Fighter	73.88 K	150.50 K	255.11	37.89 L
T_2=Seed priming Control × Palee	79.05 I	166.02 I	276.70	38.77 J
T_3=Seed priming with tap water × Fighter	77.10 J	161.92 J	269.87	38.37 K
T_4=Seed priming with tap water × Palee	82.50 E	173.26 E	288.76	39.25 I
T_5=Seed priming with Urea 1% × Fighter	79.62 H	167.21 F	278.68	40.04 H
T_6=Seed priming with Urea 1% × Palee	85.19 D	178.92 D	298.19	40.96 F
T_7=Seed priming with Urea 2% × Fighter	80.70 F	169.48 F	282.47	41.04 E
T_8=Seed priming with Urea 2% × Palee	86.35 B	181.35 B	302.24	41.98 C
T_9=Seed priming with KNO_3 1% × Fighter	80.35 G	168.83 G	281.22	40.54 G
T_{10}=Seed priming with KNO_3 1% × Palee	85.97 C	180.54 C	300.91	41.47 D
T_{11}=Seed priming with KNO_3 2% × Fighter	82.51 E	173.27 E	288.79	42.04 B
T_{12}=Seed priming with KNO_3 2% × Palee	88.28 A	185.40 A	309.00	43.01 A
S.E.	0.0347	0.2247	3.9845	0.0141
LSD 0.05	0.0719	0.4659	8.2634	0.0291
P-Value	0.0000^{**}	0.0000^{**}	0.7926^{NS}	0.0004^{**}

DAYS TO FRUITING

In bitter gourd, the amount of time it took to reach fruiting was greatly influenced by the seed priming agents and concentrations. Priming with KNO_3 at 2% (P6) led to the most delayed fruiting, requiring 59.53 days, compared to unprimed seeds (P1), which exhibited the earliest fruiting at 53.66 days on average (table 2). In comparison to the control, the application of fresh tap water (P2), 1% urea (P3), 2% urea (P4), and 1% KNO_3 (P5) gradually delayed fruiting, with the biggest delay occurring at P6. Results from the statistical analysis showed that there were significant differences between the treatments (P-value = 0.0000), suggesting that priming agents based on nutrients, especially KNO_3, at greater concentrations slowed the blossoming period. Palee (V2) typically needs more days to fruit than Fighter (V1), and these results were further reinforced by the interaction between seed priming and variety (P × V). When planted as Palee (T12), seeds primed with 2% KNO_3 had the longest fruiting period (60.21 days). Palee (V2) had a far longer

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fruiting time than Fighter (V1), at 57.27 days on average, demonstrating the importance of variety. Palee typically took longer than Fighter across all treatments, but both kinds suffered delayed fruiting with seed priming. This was shown by the extremely significant statistical interaction between priming and variety (P × V; P-value = 0.0009). In terms of timing, the unprimed Fighter seeds (T1) had the earliest fruiting at 53.05 days, while the Palee seeds primed with KNO_3 at 2% (T12) had the longest delay at 60.21 days.

Fruit Length

Table 2. indicates that the length of bitter gourd fruits was significantly affected by seed priming treatments. Fruits averaged 20.00 cm in length when grown from unprimed seeds (P1), but reached a maximum of 22.80 cm when grown from seeds primed with 2% KNO_3 (P6). Treatments with fresh tap water (P2), 1% urea (P3), 2% urea (P4), and 1% KNO_3 (P5) resulted in intermediate fruit lengths, gradually increasing as the priming agent concentrations rose. With a p-value of 0.0000, the LSD test verified that there were substantial treatment-specific changes. Palee (V2) yields much longer fruits (22.61 cm) than Fighter (20.55 cm), suggesting that Palee reaps more advantages from seed priming when it comes to fruit length, another important factor. The results showed that Palee seeds primed with KNO_3 at 2% (T12) produced the longest fruits (24.08 cm), but unprimed Fighter seeds (T1) produced the smallest fruits (19.49 cm). This was due to the interaction between priming and variety (P × V). Varieties and seed priming worked together to produce fruit length variations that were statistically significant. Palee showed a more noticeable increase in fruit length, especially when stimulated with greater doses of KNO_3, compared to Fighter, which consistently produced shorter fruits across all treatments. The tallest fruit, measuring 24.08 cm, was produced by Palee seeds that were primed with KNO_3 at a 2% concentration (T12), while the smallest fruit, measuring 19.49 cm, was produced by unprimed Fighter seeds (T1). This indicates that priming is beneficial for both types, although Palee responds more strongly in terms of fruit length.

Single Fruit weight (g)

Priming the seeds has a substantial impact on the bitter gourd fruit weight per fruit. The seeds that were not primed (P1) produced the lightest fruits (93.15 g) whereas the seeds that were primed with 2% KNO_3 (P6) yielded the heaviest fruits (104.87 g). A favorable link was seen between the concentration of the priming agent and fruit weight, as other treatments, such as fresh tap water (P2), urea at 1% (P3), urea at 2% (P4), and KNO_3 at 1% (P5), all led to increasingly heavier fruits. The statistical study validated the noteworthy variations across treatments (P-value = 0.0000). Palee (V2) produced much heavier fruits (107.29 g) than Fighter (93.29 g), demonstrating that variety also had a large impact on fruit weight. Palee seeds primed with KNO_3 at 2% (T12) had the maximum fruit weight (112.19 g), while unprimed Fighter seeds (T1) had the lowest weight (86.65 g), as shown by the interaction between priming and variety (P × V). Priming treatments had a greater impact on Palee, resulting in much heavier fruits compared to Fighter, as seen by the relationship between seed priming and variety. Unprimed Fighter seeds (T1) produced the lightest fruit (86.65 g), while Palee seeds primed with KNO_3 at 2% (T12) produced the heaviest fruit (112.19 g). The findings indicate that priming seeds, especially with greater concentrations of KNO_3, increases fruit weight, notably in the Palee variety.

Number of fruits vine^{-1}

There was a substantial effect of seed priming treatments on fruit yield vine-1 as well (table 2). Priming with 2% KNO_3 (P6) yielded the maximum fruit number (16.98 fruits vine^{-1}), in contrast to the control (P1), which produced the fewest fruits (14.28 fruits vine-1). From P2, which was fresh tap water, to P3, which was urea at 1%, to P4, which was urea at 2%, and P5, which was KNO_3 at 1%, the quantity of fruits vine-1 grew gradually as the priming agent concentration increased. Treatment differences were verified by the LSD test (P-value = 0.0000). Another important factor was variety; for example, compared to Fighter, Palee (V2) produced 17.80 fruits vine-1, whereas Fighter only managed 13.59. The results showed that Palee seeds primed with KNO_3 at 2% (T12) produced the most fruits (19.26), but unprimed Fighter seeds (T1) produced the fewest fruits (12.37), as a result of the interaction between priming and variety (P × V).

Across all trials, Palee consistently produced more fruits vine-1 than Fighter, as shown by the interaction between seed priming and variety (P × V). Palee seeds primed with 2% KNO_3 (T12) produced the most fruits (19.26), but unprimed Fighter seeds (T1) produced the fewest (12.37). Palee had a larger reaction than Fighter, suggesting that seed priming, especially with KNO_3 at higher doses, considerably increases the amount of fruits vine-1.

TABLE 2 DAYS TO FRUITING, FRUIT LENGTH, SINGLE FRUIT WEIGHT AND NUMBER OF FRUITS VINE^{-1} OF BITTER GOURD VARIETIES UNDER THE INFLUENCE OF VARIOUS SEED PRIMING TECHNIQUES

TREATMENTS	NO. OF DAYS TO FRUITING	FRUIT LENGTH (CM)	SINGLE FRUIT WEIGHT (G)	NO. OF FRUITS VINE^{-1}

[Citation: Anwar, M., Wahocho, N.A., Memon, N.U.N., Kandhro, M.N., Abbas, T., Talpur, K.H., Jamali, M.F., Kakar, K. (2024). Nitrogen priming sources affect the seed germination, growth and fruit attributes of bitter gourd. *Biol. Clin. Sci. Res. J.*, **2024***: 1443*. doi: https://doi.org/10.54112/bcsrj.v2024i1.1443]

SEED PRIMING (P)				
P_1=Un-primed seeds (Control)	53.66 F	20.00 F	93.15 F	14.28 F
P_2 =Seed primed with fresh tap water	54.33 E	20.62 E	97.82 E	14.67 E
P_3=Seeds primed with urea @ 1%	56.70 D	21.68 D	100.50 D	15.83 D
P_4=Seeds primed with urea @ 2%	58.11 B	22.33 B	103.85 B	16.34 B
P_5=Seed primed with KNO_3 @ 1%	57.40 C	22.07 C	101.56 C	16.08 C
P_6=Seeds primed with KNO_3 @ 2%	59.53 A	22.80 A	104.87 A	16.98 A
S.E.	0.0142	0.0233	0.0948	0.0488
LSD 0.05	0.0294	0.0482	0.1966	0.1011
P-Value	0.0000**	0.0000**	0.0000**	0.0000**
VARIETIES (V)				
V_1=Fighter	55.98 B	20.55 B	93.29 B	13.59 B
V_2 =Palee	57.27 A	22.61 A	107.29 A	17.80 A
S.E.	0.0081	0.0134	0.0547	0.0282
LSD 0.05	0.0170	0.0278	0.1135	0.0584
P-Value	0.0000**	0.0000**	0.0000**	0.0000**
TREATMENTS INTERACTION (SEED PRIMING × VARIETIES)				
T_1=Seed priming control × Fighter	53.05 L	19.49 K	86.65 L	12.37 L
T_2=Seed priming Control × Palee	54.27 J	20.50 I	99.64 F	16.20 F
T_3=Seed priming with tap water × Fighter	53.71 K	19.83 J	90.99 K	12.70 K
T_4=Seed priming with tap water × Palee	54.95 I	21.41 F	104.64 E	16.64 E
T_5=Seed priming with Urea 1% × Fighter	56.05 H	20.50 I	93.49 J	13.70 J
T_6=Seed priming with Urea 1% × Palee	57.34 F	22.85 D	107.51 D	17.95 D
T_7=Seed priming with Urea 2% × Fighter	57.45 E	21.13 G	96.60 H	14.14 H
T_8=Seed priming with Urea 2% × Palee	58.77 C	23.53 B	111.09 B	18.53 B
T_9=Seed priming with KNO_3 1% × Fighter	56.75 G	20.84 H	94.47 I	13.92 I
T_{10}=Seed priming with KNO_3 1% × Palee	58.06 D	23.30 C	108.65 C	18.24 C
T_{11}=Seed priming with KNO_3 2% × Fighter	58.86 B	21.51 E	97.56 G	14.70 G
T_{12}=Seed priming with KNO_3 2% × Palee	60.21 A	24.08 A	112.19 A	19.26 A
S.E.	0.0200	0.0329	0.1340	0.0690
LSD 0.05	0.0415	0.0682	0.2780	0.1430
P-Value	0.0009**	0.0000**	0.0000**	0.0000**

Weight of fruit vine^{-1} (g)

Seed priming had a statistically significant influence on fruit weight vine^{-1}, with treatments using KNO_3 priming producing the highest results (table 3). Priming seeds with 2% KNO_3 (P6) at 1.79 g resulted in the maximum fruit weight vine-1, followed by urea at 2% (P4) at 1.71 g and KNO_3 at 1% (P5) at 1.64 g. The unprimed control treatment (P1), on the other hand, had the lowest fruit weight vine-1, averaging 1.34 g. Using urea and fresh tap water also led to notable gains compared to the control, however the impact was much more noticeable with KNO_3. When comparing the two varieties, Palee (V2) produced much more fruit vine-1 (1.91 g) than Fighter (V1) (1.27 g). The patterns were further reinforced by the interaction between priming treatments and types. The combination of Palee primed with KNO_3 at 2% (T12) produced the maximum fruit weight vine-1, measuring 2.16 g. On the other hand, with a fruit weight vine-1 of just 1.07 g, Fighter had the lowest yield in the control treatment (T1). Evidence like this suggests that priming seeds, especially with KNO_3, may increase fruit weight, and the Palee variety is no exception.

Fruit diameter (cm)

Seed priming treatments and varieties both had a substantial impact on fruit diameter. The biggest fruit diameter, an average of 5.52 cm, was generated by seeds primed with KNO_3 at a concentration of 2% (P6). Fruit diameters of 5.41 cm and 5.39 cm, respectively (table 3), were produced after priming with 1% KNO_3 (P5) and 2% urea (P4). With a diameter of only 5.09 cm, the unprimed control treatment (P1) produced the tiniest fruit. The results that were obtained were intermediate when using fresh tap water (P2) and 1% urea (P3). The average fruit diameter for Palee (V2) was 5.78 cm, making it the largest variety, while Fighter (V1) had a lesser fruit diameter of 4.90 cm, making it the smallest. Based on the results of the interaction between priming treatments and varieties, the variety Palee primed with 2% KNO_3 (T12) had the biggest fruit diameter at 5.98 cm, while the variety Fighter under the control treatment (T1) had the shortest diameter at 4.67 cm. The significance of KNO_3 priming in increasing fruit size, especially in the Palee variety, is shown by these data.

4.1.11 Number of seeds fruit^{-1}

Priming the seeds, variety, and the interplay between the two had a significant impact on the number of seeds per fruit ($P<0.05$). Priming seeds with KNO_3 at 2% (P6) resulted in the maximum number of seeds per fruit, with an average of 35.60 seeds per fruit. Next came urea at 2% (P4) and KNO_3 at 1% (P5), resulting in 35.10 and 35.17 seeds per fruit, respectively (table 3). The control treatment (P1) had the lowest number of seeds, with 32.77 seeds per fruit on average. The seed per fruit were much higher in Palee (V2) at 37.04 seeds per fruit compared to Fighter (V1) at 31.94 seeds per fruit. There was a significant interaction between seed priming and variety, with the maximum number of seeds per fruit (38.26) generated by combining Palee with KNO_3 at a 2% concentration (T12), and the lowest number of seeds per fruit (30.27) by Fighter in the control treatment (T1). Priming, particularly with KNO_3, has a good effect on seed growth; specifically, the Palee variety responds the most.

Table 3 Fruit weight vine^{-1}, fruit diameter, seeds fruit^{-1} and fruit yield plot^{-1} of bitter gourd varieties under the influence of various seed priming techniques

Treatments	Fruit weight (g) vine^{-1}	Fruit diameter (cm)	No. of seeds fruit
P_1=Un-primed seeds (Control)	1.34 f	5.09 f	32.77 e
P_2 =Seed primed with fresh tap water	1.44 e	5.20 e	33.60 d
P_3=Seeds primed with urea @ 1%	1.60 d	5.38 d	34.77 c
P_4=Seeds primed with urea @ 2%	1.71 c	5.39 c	35.10 b
P_5=Seed primed with KNO_3 @ 1%	1.64 b	5.41 b	35.17 b
P_6=Seeds primed with KNO_3 @ 2%	1.79 a	5.52 a	35.60 a
S.E.	0.0118	0.0073	0.0286
LSD 0.05	0.0244	0.0152	0.0593
P-Value	0.0000**	0.0000**	0.0000**
Varieties (V)			
V_1=Fighter	1.27 b	4.90 b	31.94 b
V_2 =Palee	1.91 a	5.78 a	37.04 a
S.E.	0.0068	0.0042	0.0165
LSD 0.05	0.0141	0.0087	0.0342
P-Value	0.0000**	0.0000**	0.0000**
Treatments interaction (Seed priming × Varieties)			
T_1=Seed priming control × Fighter	1.07 l	4.67 l	30.27 j
T_2=Seed priming Control × Palee	1.61 f	5.51 f	35.27 e
T_3=Seed priming with tap water × Fighter	1.15 k	4.77 k	30.95 i
T_4=Seed priming with tap water × Palee	1.74 e	5.63 e	36.26 d
T_5=Seed priming with Urea 1% × Fighter	1.28 j	4.93 j	32.27 h
T_6=Seed priming with Urea 1% × Palee	1.93 d	5.82 d	37.26 c
T_7=Seed priming with Urea 2% × Fighter	1.36 h	4.99 h	32.60 g
T_8=Seed priming with Urea 2% × Palee	2.05 b	5.89 b	37.59 b
T_9=Seed priming with KNO_3 1% × Fighter	1.31 i	4.96 i	32.61 g
T_{10}=Seed priming with KNO_3 1% × Palee	1.98 c	5.86 c	37.60 b
T_{11}=Seed priming with KNO_3 2% × Fighter	1.43 g	5.06 g	32.94 f
T_{12}=Seed priming with KNO_3 2% × Palee	2.16 a	5.98 a	38.26 a
S.E.	0.0167	0.0104	0.0405
LSD 0.05	0.0346	0.0215	0.0839
P-Value	0.0000**	0.0006**	0.0000**

Shelf life (days)

Priming the seeds also affected the shelf life; increasing the KNO_3 concentration to 2% (P6) increased the shelf life to 6.07 days, a considerable improvement over the control (P1), which had a shelf life of 5.24 days (table 4). Priming seeds with urea or potassium nitrate increased their shelf life more than unprimed seeds or tape water. With a shelf life of 6.07 days, Palee (V2) outlasted Fighter (V1), which had a shelf life of 5.43 days. The results showed that Palee primed with 2% KNO_3 (T12) had the highest shelf life at 6.37 days; whereas Fighter under control (T1) had the lowest at 4.71 days, as a result of the interaction between seed priming and variety. Priming seeds, in particular with KNO_3, significantly increased their shelf life. Priming methods have been shown to delay fruit degradation, however, this treatment proved to be the most

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successful in extending fruit post-harvest life. A longer shelf life was seen in the Palee type compared to Fighter, which might be due to genetic considerations as well. Priming and variety selection work together to preserve fruit quality, and the longest shelf life was seen when KNO_3 priming was used in conjunction with the Palee variety. The extended storage life was greatly enhanced by the seed priming methods and cultivars, as seen by the statistically significant P-values and LSD values. The results show that some priming treatments, such KNO_3 for Palee, can improve post-harvest storage.

4.1.15 Weight Loss (%)

The results (table 4) showed that 2% KNO_3 priming (P6) resulted in the least amount of weight loss (4.61%), while the control treatment (P1) had the greatest loss (9.72%) during storage. In terms of reducing weight loss, KNO_3 priming outperformed urea and tap water, according to the rating. The weight loss rate for Palee (V2) was 7.29%, which is lower than Fighter (8.24%) rate. Based on the results of the interaction between seed priming and variety, the variety Palee primed with 2% KNO_3 (T12) lost the least amount of weight (4.11%), while the variety Fighter under control circumstances (T1) lost the most weight (10.08%). Priming the seeds greatly decreased weight loss throughout storage, with KNO_3 showing the most promise for reducing weight loss after harvest. For fruit to retain its quality throughout transportation and storage, weight loss must be minimized. More evidence that variety matters for post-harvest stability came from the superior resistance of variety Palee to weight loss compared to Fighter. Evidence suggests that priming Palee with KNO_3 has the greatest results in terms of both minimizing weight loss and preserving fruit quality. Weight loss was significantly different among treatments and cultivars (P=0.0000), suggesting that priming had a considerable impact on lowering post-harvest weight loss. In terms of reducing weight loss during storage, the LSD data confirm that KNO_3 is beneficial.

Chlorophyll content in leaves (mg g^{-1})

There was a notable difference in total chlorophyll content according to seed priming techniques. Seeds treated with urea at 2% (P4) had the maximum chlorophyll content in leaves at 327.52 mg g^{-1}, whereas seeds treated with KNO_3 at 2% (P6) had 306.86 mg g^{-1}. With 233.73 mg g^{-1}, the control (P1) had the lowest chlorophyll content (Table 4)s. Comparing the varieties, Palee (V2) had 304.18 mg g^{-1} of chlorophyll, whereas Fighter (V1) had 260.25 mg g^{-1}. According to the results of the treatment interaction, the total chlorophyll content was 356.20 mg g^{-1} in the unprimed Fighter seeds (T1) and 212.54 mg g^{-1} in the combination of Palee and urea at 2% (T8). Different priming treatments and types were shown to cause significant changes in total chlorophyll concentration, according to the statistical analysis (P<0.0001). The chlorophyll concentration was greatest in the leaves of plants that were primed with 2% urea (P4) and lowest in the control group (P1). Palee (V2) had a higher total chlorophyll content than Fighter (V1) among the varieties. Palee primed with 2% urea (T8) had the maximum chlorophyll content, and this was only one of several statistically significant interactions between priming treatments and varieties. The results showed that priming seeds with urea greatly increases the chlorophyll content, with better outcomes seen at greater doses.

Table 4 Fruit yield ha^{-1}, shelf life, weight loss^{-1} and leaf area of bitter gourd varieties under the influence of various seed priming techniques

Treatments	Shelf life (days)	Weight loss (%)	Total chlorophyll content
P_1=Un-primed seeds (Control)	5.24 E	9.72 A	233.73 F
P_2=Seed primed with fresh tap water	5.64 D	9.50 B	246.74 E
P_3=Seeds primed with urea @ 1%	5.77 C	8.74 C	291.88 C
P_4=Seeds primed with urea @ 2%	5.92 B	8.55 D	327.52 A
P_5=Seed primed with KNO_3 @ 1%	5.86 B	5.48 E	286.58 D
P_6=Seeds primed with KNO_3 @ 2%	6.07 A	4.61 F	306.86 B
S.E.	0.439	0.0188	0.3234
LSD 0.05	0.0911	0.0390	0.6708
P-Value	0.0000**	0.0000**	0.0000**
Varieties (V)			
V_1=Fighter	5.43 B	8.24 A	260.25 B
V_2 =Palee	6.07 A	7.29 B	304.18 A
S.E.	0.0254	0.0109	0.1867
LSD 0.05	0.0526	0.0225	0.6708
P-Value	0.0000**	0.0000**	0.0000**
Treatments interaction (Seed priming × Varieties)			
T_1=Seed priming control × Fighter	4.71 G	10.08 A	212.54 L

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T_2=Seed priming Control × Palee	5.77 D	9.36 C	254.91 J
T_3=Seed priming with tap water × Fighter	5.39 F	9.92 B	233.89 K
T_4=Seed priming with tap water × Palee	5.90 D	9.09 D	259.59 I
T_5=Seed priming with Urea 1% × Fighter	5.49 EF	9.19 E	266.92 G
T_6=Seed priming with Urea 1% × Palee	6.05 C	8.30 F	316.84 C
T_7=Seed priming with Urea 2% × Fighter	5.62 E	9.08 E	298.85 E
T_8=Seed priming with Urea 2% × Palee	6.22 B	8.02 G	356.20 A
T_9=Seed priming with KNO_3 1% × Fighter	5.58 E	6.11 H	261.59 H
T_{10}=Seed priming with KNO_3 1% × Palee	6.14 BC	4.86 J	311.56 D
T_{11}=Seed priming with KNO_3 2% × Fighter	5.78 D	5.10 I	287.73 F
T_{12}=Seed priming with KNO_3 2% × Palee	6.37 A	4.11K	325.98 B
S.E.	0.0622	0.0266	0.4574
LSD 0.05	0.1289	0.0552	0.9486
P-Value	0.0006**	0.0000**	0.0000**

Discussion

The present study appraised the effect of six priming treatments on germination, vegetative development, fruit yield and shelf life of two bitter gourd varieties (Fighter and Palee). The study showed that seed priming had a significant effect on seed germination, seedling vigor, fruit yield and shelf life. Seed priming with KNO_3 at 2% concentration emerged as the superior treatment across multiple growth parameters, yielding the highest germination rate, longest vine length, and most abundant leaf count vine^{-1}. This priming also led to a significant reduction in days to flowering and enhanced the fruiting phase, resulting in earlier fruit development, increased fruit length, and the highest single fruit weight. The findings of Adhikari et al. (2021) and Chandrasekaran et al., (2018) also advocated the outcomes of our study and reported that priming had a profound effect on seed germination, stand establishment, quality, and overall productivity of bitter gourd. Similarly, Baig et al. (2020) reported that bitter gourd seeds primed with phosphorous sources (DAP and SSP solution) effectively enhanced emergence, seedling vigor, survival percentage (%), fruit characteristics and eventually the crop productivity. These results are in line with those of Nascimento et al. (2004) who reported that seed priming with potassium nitrate has a significant and positive impact on seed germination and seedling vigor. Rehman et al. (2011) reported that seed priming with urea solution had a positive impact *($p<0.05$)* on seed germination and seedling vigor in rice. The treated vines produced more foliage as compared to the control vines. Kamithi et al. (2016), Tavili et al. (2011), Khan et al. (2019), and Farooq et al. (2019) studied the effect of various seed priming agents and reported markedly significant *($p<0.05$)* effect on the seed germination, growth traits as well as yield attributes.

The KNO_3 showed more promising results than urea priming in various growth and productivity metrics, with a 2% concentration of KNO_3 identified as the optimal dosage. KNO_3 priming is effective due to its dual role as a source of potassium and nitrate, which enhances early germination and improves root and shoot development. Potassium plays a crucial role in regulating water control and facilitating nutrient transfer, resulting in vigorous vine growth and a profusion of leaves. Consequently, plants can increase their photosynthetic surface area, directly influencing productivity. Furthermore, KNO_3 priming facilitates earlier fruiting and blooming stages. The presence of nitrate enhances flowering in plants by activating enzymes responsible for nitrogen uptake. Urea serves as a significant nitrogen source; however, it lacks potassium, which is essential for balanced nutrient availability. Additionally, its absorption during seed priming may be prolonged due to necessary conversion processes.

The study further showed that KNO_3 at higher concentration maximized fruit yield, with an improved shelf life and minimal weight loss. Between the two varieties, 'Palee' consistently outperformed 'Fighter,' showcasing superior growth, higher fruit weight vine^{-1} , and greater yield. The findings highlight the significant of KNO_3 at 2% as a promising priming treatment to optimize bitter gourd production, particularly when applied to 'Palee.' It was noted that seeds primed with urea at 2% concentration (P4) and KNO_3 at 2% concentration (P6) outperformed other treatments. Similar results have also been reported by many past researchers. Ghassemi-Golezani et al. (2012) reported that varietal response to seed priming agents varied significantly *($p<0.05$)*; while Soleimanzadeh (2013) has reported significant improvement in seed germination *($p<0.05$)* in crop sown with soaked seeds with potassium nitrate as compared to control or other seed soaking agents. Aghbolaghi & Sedghi (2014), Elouaer, & Hannachi (2013), Rafi et al. (2015), Hussain et al. (2016), Ehsanfar et al. (2020), Bailly et al. (2019), Finkelstein et al. (2021) and Bewley et al. (2020) conducted studies on similar aspects in different parts of the world and unanimously agreed that seed priming affected the seed germination positively *($p<0.05$)* and seedlings

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from primed seeds were healthier as compared to those of control or soaked by tap water. Ibrahim et al. (2020) reported that seed priming with potassium nitrate was more effective than any other technique in improving seed germination and other physiological attributes of bitter gourd. The studies carried out by Kaya et al. (2019), Selvarani et al. (2017), Ribeiro et al. (2014), Wang et al. (2017) and Hameed et al. (2014) performed studies on the effect of seed priming techniques on the germination and subsequent impact on crop productivity in different crop species. According to their findings, there were significant impacts of priming treatments on germination, crop vigor as well as productivity. However, potassium nitrate-based solution was more effective in improving germination and increasing seedling vigor as well as CGR and NAR as compared to the rest of the seed priming techniques applied.

KNO_3 priming appears to enhance several fruit indicators, including fruit size, weight, and storage life. A potential explanation for these enhancements is that the potassium in KNO_3 facilitates the transport of carbohydrates to developing fruits, a critical process in carbohydrate metabolism. This nutrition delivery not only reduces post-harvest weight loss and extends the shelf life of the fruit but also enhances the structure and toughness of the cell walls. Urea contributes nitrogen and enhances specific growth rates; however, it does not provide the balanced nutrients necessary to fully sustain these qualitative attributes. KNO_3 and urea both possess advantageous nutritional and biochemical properties; however, KNO_3 demonstrated greater efficacy in enhancing overall growth and yield. The balanced nutrient profiles of KNO_3, resulting from its dual supply of potassium and nitrate, support fruit length, weight, and total yield. The maintenance of these qualities occurs without compromising quality or growth metrics. KNO_3 seed priming at a concentration of 2% is the most effective method for enhancing productivity and marketable traits in bitter gourd, as it optimizes yield, early growth, and fruit quality. This suggests that although urea and KNO_3 possess certain benefits, KNO_3 priming provides a more comprehensive approach to optimizing the growth, yield, and shelf life of bitter gourd.

Conclusion and Recommendations

The findings of the current investigation underscored the favorable effect of seed priming on germination, growth and development of bitter gourd. The seed priming techniques showed that seed soaked with KNO_3 at a concentration of 2% proved to be the most effective treatment, significantly improving germination rates, vine development, and yield characteristics in bitter gourd. Moreover, the application of KNO_3 at a concentration of 2% during seed priming significantly decreased the duration needed for flowering and fruit initiation, thereby facilitating earlier harvests. The application of KNO_3 demonstrated an enhancement in shelf life and a reduction in weight loss in fruits, suggesting an improvement in post-harvest quality. It is recommended that bitter gourd seeds be primed with 2% KNO_3 for better seed germination, seedling development, production, and extending fruit shelf life without compromising weight loss. However other nutrient sources may be used for consistent germination and optimum growth and development of crop plants.

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Declaration

Acknowledgement
Not applicable

Ethics Approval and Consent to Participate
Not applicable.

Consent for Publication
The study was approved by authors.

Funding Statement
Not applicable

Authors' Contribution
All authors contributed equally.

Conflict of interest
There is no conflict of interest among the authors of the manuscript.

[Citation: Anwar, M., Wahocho, N.A., Memon, N.U.N., Kandhro, M.N., Abbas, T., Talpur, K.H., Jamali, M.F., Kakar, K. (2024). Nitrogen priming sources affect the seed germination, growth and fruit attributes of bitter gourd. *Biol. Clin. Sci. Res. J.*, **2024***: 1443*. doi: https://doi.org/10.54112/bcsrj.v2024i1.1443]