



Efficacy of Plant Defence Activators for Disease Reduction and Growth Promotion in Bell Pepper (*Capsicum annuum* L.) in Sub-Temperate, Semi-Humid Climate Conditions

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Abstract: Bell pepper production is often constrained by diseases such as Cercospora leaf spot, anthracnose, bacterial spot, Phytophthora rot, and viral infections. This study evaluates the efficacy of plant defence activators, including salicylic acid (SA), jasmonic acid (JA), β -aminobutyric acid (BABA), and potassium nitrate (KNO_3), as eco-friendly strategies for disease management. For this, bell pepper seeds were subjected to seed priming with these activators at various concentrations for 4-10 h before sowing. The effects of these treatments on seed quality and mycoflora incidence were assessed to optimize priming protocols for enhanced plant resistance. Seed priming with 75 ppm SA for 8 h increased germination up to 85%, boosted seed vigor index-length (SVI-I) from 856.88 to 1,078.44, and seed vigor index-mass (SVI-II) from 161.25 to 234.39. KNO_3 priming at 1.5% for 10 h enhanced germination up to 87%, SVI-I from 856.88 to 1,108.38, and SVI-II from 161.25 to 229.03, while reducing seed-borne fungal incidence from over 22% in untreated seeds to as low as 2-3%. BABA showed an optimal effect at moderate concentrations, while higher MeJA doses had inhibitory impacts on early seedling growth. These results demonstrate that seed priming treatments can significantly enhance seed quality, vigor, and disease resistance in bell pepper, offering a sustainable and effective alternative to chemical methods.

Keywords: Seed priming, Seed quality, Seed-borne diseases, Sustainable agriculture, Plant defence activators

Bell pepper (*Capsicum annuum* L.) is a globally cultivated solanaceous vegetable known for its rich nutritional value, particularly high in vitamins A and C and antioxidants, moderate in protein, fiber, carbohydrates, fat, and minerals, boosting immunity and heart health (Sanatombi 2023). In India, bell pepper is grown mainly in Himachal Pradesh, Andhra Pradesh, Uttarakhand, and Darjeeling district of West Bengal as a summer crop and in the states of Maharashtra, Karnataka, Uttar Pradesh, and Tamil Nadu as an autumn crop (Sreedhara et al., 2013). However, its cultivation faces significant challenges due to susceptibility to several biotic and abiotic stresses, especially during humid seasons. To tackle these issues sustainably, plant defence elicitors like salicylic acid, jasmonic acid, butyric acid, and potassium nitrate are being used to enhance the plant's innate immunity without harming the environment (Bektas and Eulgem 2015). Among these, salicylic acid, a phytohormone, is a simple phenolic compound that is actively involved in the regulation of diverse metabolism in plants influencing its growth and development involving seed germination, photosynthesis, stomatal regulation, flowering, senescence, yield and defence mechanism against biotic and abiotic stresses (Mishra et al., 2024). It facilitates internal defence signaling and plays a critical role in triggering systemic resistance

throughout the plant (AL-surhane 2022). Seed priming with salicylic acid enhance plant tolerance to biotic stresses by induction of hypersensitive response (HR) via regulation of antioxidant enzymes and to abiotic stresses by activating defence-related genes and transporters, regulating ion balance and boosting stress resilience (Khan et al., 2022). Likewise, jasmonates (jasmonic acid and its derivatives like methyl jasmonate) are plant hormones having major function in regulation of growth and development of plant from germination of seed to maturation and ageing of the plant. Jasmonic acid (JA) is synthesized by the action of several enzymes which get augmented in response to stress and regulate stress tolerance in plants (Mulaudzi et al., 2023). It plays a crucial role in plant defence against necrotrophic pathogens and insect herbivores by activating the COI1-JAZ signaling pathway, which leads to the release of transcription factors that trigger JA-responsive gene expression (Koo et al., 2020). Besides, β -amino butyric acid (BABA) is a naturally occurring plant metabolite which effectively imparts broad spectrum defence in plants. It activates the regulation of oxidative stress through increased antioxidant activity, protects cell membrane against osmotic stress and promotes plant growth (Bhutta et al., 2023), modulates expression of defence genes, and alters several metabolic pathways

bolstering the immunity of plants and enhancing their resistance against biotic and abiotic stresses (Catoni et al., 2022). Moreover, potassium nitrate (KNO_3) acts both as a nitrogen source as well as a signaling molecule which helps in enhancing seed germination and plant growth by regulating hormonal balance, specifically gibberellic acid and abscisic acid, activation of aquaporins, enhancing amylase activity and nitric oxide production which helps break dormancy through interactions with phytochrome signaling, ethylene biosynthesis, and reactive oxygen species (Nyandwi et al., 2024). These elicitors are usually applied through seed priming, a pre-sowing treatment involving controlled hydration (without allowing germination) of seeds that activate the metabolic processes to enhance germination, utilizing stored nutrients, increasing enzyme activity and responding more effectively to environmental stress resulting in quicker and more uniform germination (Özkurt and Bektaş 2022). Therefore, in this context, this research aimed to explore eco-friendly disease management strategies for bell pepper using plant defence activators (SA, JA, BABA, KNO_3) and standardize their doses under laboratory conditions.

MATERIAL AND METHODS

Location and experimental details: The present investigation was carried out during 2019-20 at Dr Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan (30.51°N, 77.09°E, Elevation: 1183m) located in the mid-hill zone of Himachal Pradesh features sub-temperate, semi-humid climate conditions with cold winters and hot summers., December and January are the coldest while, May and June are the hottest months (Fig. 1). The study was conducted on bell pepper, cultivar Solan Bharpur. Seeds

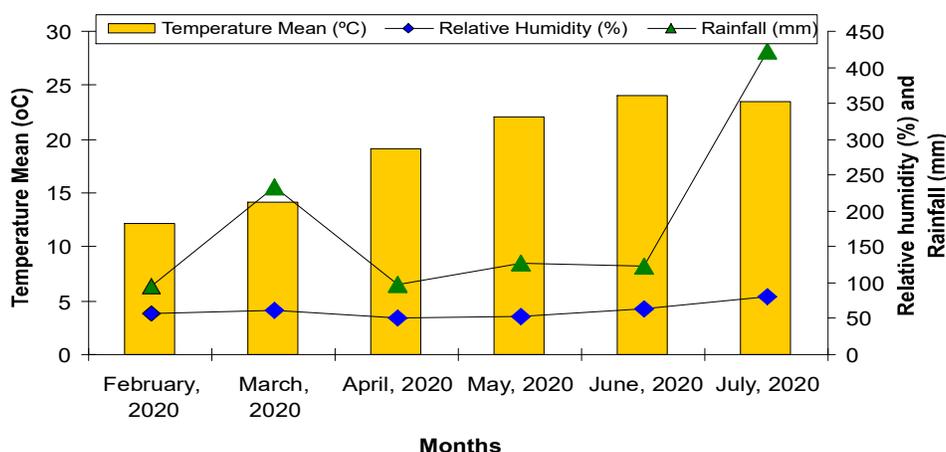
were surface sterilized with 1% solution of sodium hypochlorite (NaOCl , Central Drug House PVT. Ltd) two minutes, followed by three washings with distilled water to remove the traces of NaOCl . The experiment involved seed priming with four plant defence activators at varying concentrations, each concentration for the durations of for 4, 6, 8, and 10 h: salicylic acid (SA, $\text{C}_6\text{H}_4(\text{OH})\text{COOH}$, Central Drug House Pvt. Ltd.), (25, 50, 75, 100 ppm); methyl jasmonate (MeJA, $\text{C}_{13}\text{H}_{20}\text{O}_3$, Sigma Aldrich), (25, 50, 75, 100 ppm); potassium nitrate (KNO_3 , Life Sciences Pvt. Ltd.), (0.5, 1.0, 1.5, 2.0%); and β -Aminobutyric Acid (BABA, $\text{C}_4\text{H}_9\text{NO}_2$, SigmaAldrich), (25, 50, 75, 100 ppm).

Priming solutions were prepared by measuring required amounts of SA (25, 50, 75, and 100 mg) and mixed with ethanol, subsequently adding drop-wise to distilled water (ethanol/water: 1/1000, v/v) as described by Khandaker et al., (2011). The required amounts of MeJA (25, 50, 75 and 100 μl), BABA (25, 50, 75 and 100 mg) and KNO_3 (0.5, 1, 1.5 and 2 g) were initially dissolved in a small amount of distilled water and were diluted to required final volume with additional distilled water (Kazemi, 2014; Kim et al., 2013; Nego et al., 2015).

The prepared solutions were used for seed priming. Seeds were soaked in the solutions at a volume five times that of the seeds and maintained at room temperature (25°C) for the required duration. After priming, the seeds were rinsed with distilled water and dried in the shade for 24 h before further use (Shatpathy et al., 2018).

In vitro trials

Rolled paper towel method: The germination and vigor tests were performed using paper towel method as per the ISTA rules in which, over a wax paper, a moist germination



Source: Meteorological Observatory, Department of Environmental Science, Dr YS Parmar University of Horticulture and Forestry, Nauni, Solan (HP) 173 230

Fig. 1. Mean monthly meteorological data of Dr YS Parmar University of Horticulture and Forestry, Nauni, Solan (HP) for the year 2020 (w.e.f. February 2020 to June 2020)

paper was placed and 100 treated seeds were orderly laid on it. Seeds were covered with another moist germination paper and rolled carefully to avoid pressure on the seeds. These rolled towels were kept for incubation in seed germinator for 14 days at 25°C (Anonymous 1996).

Blotter paper test: The procedure for the standard blotter paper test was followed (ISTA, 2005). One or more layers of blotter paper were placed in the Petri plates after soaking in sterilized water. In aseptic conditions, 50 seeds of bell pepper were placed in the Petri plate equidistantly and kept for incubation for 7 days at 20±2°C in an incubation room under near UV light/fluorescent light having alternate cycles of 12 hrs light and darkness. Examination of seeds was done on the 7th day of germination for incidence of pathogens. Identification of pathogens was done under the microscope on the basis of the symptoms produced on the germinated seedlings and their incidence were also recorded.

Based on these tests, the observations including germination (%); speed of germination; seedling length (cm); seedling dry weight (mg); seed vigor index-length (SVI-I); seed vigor index-mass (SVI-II) and seed mycoflora (%) were recorded under *in vitro* conditions.

The standard germination procedure of ISTA was followed for testing the germination. The first and final counts were taken on the 7th and 14th day, respectively. Germination was calculated on the basis of number of normal seedlings germinated out of the total seeds used. The number of seedlings that emerged from 1st day to the 14th day were counted, and the speed of germination was calculated.

Speed of germination = $n_1/d_1 + n_2/d_2 + n_3/d_3 + \dots + n_{14}/d_{14}$

(where, n = number of germinated seeds, d = number of days)

For seedling length and dry weight, ten seedlings were randomly selected and their length was measured from the tip of the root to the tip of the shoot with a scale, and mean values were expressed in centimeters. Seedlings were dried in the oven at 60°C for 48 h, were weighed and the mean values were expressed in milligrams. The SVI -I & II were calculated (Abdul-Baki and Anderson 1973).

SVI-I = Germination (%) x Seedling length (cm)

SVI-II = Germination (%) x Seedling dry weight (mg)

The standard Petri plate method as per ISTA was followed for observing the seed mycoflora. The numbers of infected seeds were recorded daily. The number of infected seeds was observed, and their per cent incidence was calculated.

Statistical analysis: The statistical analysis was performed using R software (version 4.2.1) according to standard procedures for analyzing variance and treatment effects.

RESULTS AND DISCUSSION

In vitro effect of seed priming in bell pepper on seed quality parameters

Effect of SA: The seed priming with SA at different concentrations significantly influenced the seed quality parameters (Table 1). The germination ranged from 85.00% in seeds primed with 75 ppm SA for 8 h, followed by 100 ppm SA for 4 h and 25 ppm SA for 8 h, to 75.00% in unprimed seeds. The seeds primed with 75 ppm SA for 8 h exhibited the highest speed of germination (28.47), followed by 100 ppm SA for 4 h and SA at 75 ppm for 10 h, while the seeds primed with SA at 50 ppm for 8 h had the lowest speed of germination. The maximum seedling length (12.69 cm) and seedling dry weight (2.76 mg) were observed in seeds primed with 75 ppm SA for 8 h, followed closely by SA at 25 ppm for 8 h and 100 ppm for 4 h. The shortest seedlings (11.52 cm) and lowest seedling dry weight (2.24 mg) were recorded in unprimed seeds. Consequently, the seeds primed with 75 ppm SA for 8 h had the highest SVI-I (1,078.44) and SVI-II (234.39), again closely followed by seeds primed with 100 ppm for 4 h and SA at 25 ppm for 10 h. The lowest SVI-II was recorded in unprimed seeds.

Effect of MeJA: Seed priming with MeJA at different concentrations had significant effect on the seed quality parameters. Seed germination was highest (82.50%) in seeds primed with 100 ppm MeJA for 4 h, followed by the seeds primed with 75 ppm for 10 h and 100 ppm for 6 h, while the seeds primed with 50 ppm MeJA for 6 h showed the least germination (70.00%) (Table 2). The speed of germination showed the same trend being maximum (25.27%) in seeds primed with 100 ppm MeJA for 4 h. The unprimed seeds were the slowest to germinate (19.69%). The average seedling length, seedling dry weight, SVI-I and SVI-II were highest in the seeds primed with 100 ppm MeJA for 4 h. (11.93 cm, 2.52 mg, 983.81 and 207.69, respectively). MeJA at 75 ppm for 10 h and 100 ppm for 6 h, closely followed maximum seedling dry weight and SVI-II, while the treatments MeJA at 100 ppm for 6 h and 75 ppm for 10 h were also at par with the highest SVI-I. The minimum average seedling length (11.09 cm), seedling dry weight (2.08 mg), SVI-I (793.45) and SVI-II (150.16) were recorded in the seeds primed with MeJA at 75 ppm for 4 h, 50 ppm for 8 h, 50 ppm for 6 h and unprimed seeds, respectively.

Effect of BABA: Priming the bell pepper seeds with 100 ppm BABA for 4 h significantly enhanced seed quality parameters (Table 3) including germination (84.75%), speed of germination (27.98), average seedling length (12.62 cm), average seedling dry weight (2.66 mg), SVI-I (1,069.55) and SVI-II (225.01). Seeds primed with 75 ppm BABA for 8h and 6h were at par with the highest germination, while the lowest

Table 1. Effect of seed priming with SA on seed quality parameters in bell pepper

Treatments (SA conc./ duration)	Seed quality parameters					
	Germination (%)	Speed of germination	Seedling length (cm)	Seedling dry wt. (mg)	SVI – I (Length)	SVI – II (Mass)
T1(25 ppm/4hrs)	76.25 (8.79)	24.56	12.35	2.51	941.50	191.01
T2 (25 ppm/6hrs)	77.75 (8.87)	24.93	12.34	2.67	959.05	207.59
T3 (25 ppm/8hrs)	82.50 (9.14)	26.17	12.66	2.72	1044.66	214.91
T4 (25 ppm/10hrs)	79.25 (8.96)	20.87	11.70	2.61	927.42	215.56
T5 (50 ppm/4hrs)	78.50 (8.92)	20.97	11.86	2.30	931.01	192.72
T6 (50 ppm/6hrs)	77.25 (8.85)	23.86	12.13	2.43	937.24	191.00
T7 (50 ppm/8hrs)	76.00 (8.78)	19.85	12.08	2.30	917.70	174.80
T8 (50 ppm/10hrs)	77.50 (8.86)	25.75	12.03	2.46	932.52	175.15
T9 (75 ppm/4hrs)	76.00 (8.78)	22.89	12.34	2.55	938.03	193.42
T10 (75 ppm/6hrs)	75.50 (8.75)	25.05	12.39	2.55	935.26	192.53
T11 (75 ppm/8hrs)	85.00 (9.27)	28.47	12.69	2.76	1078.44	234.39
T12 (75 ppm/10hrs)	78.50 (8.92)	26.76	12.65	2.61	993.22	204.49
T13 (100 ppm/4hrs)	83.75 (9.21)	27.91	12.61	2.67	1056.30	221.94
T14 (100 ppm/6hrs)	77.50 (8.86)	25.78	12.30	2.29	953.44	177.67
T15 (100 ppm/8hrs)	78.75 (8.93)	22.19	11.91	2.26	938.11	181.13
T16 (100 ppm/10hrs)	76.75 (8.82)	23.22	12.23	2.47	938.84	186.31
T17 (Control)	75.00 (8.72)	20.80	11.56	2.24	866.81	167.81
CD (p=0.05)	(0.19)	2.71	0.08	0.09	58.26	23.76

Parentheses are square root transformed values

Table 2. Effect of seed priming with MeJA on seed quality parameters in bell pepper

Treatments (MeJA)	Seed quality parameters					
	Germination (%)	Speed of germination	Seedling length (cm)	Seedling dry wt. (mg)	SVI – I (Length)	SVI – II (Mass)
T1	72.75 (58.52)	21.00	11.28	2.16	820.26	156.96
T2	75.25 (60.16)	22.14	11.24	2.22	846.00	166.87
T3	77.50 (61.70)	23.54	11.80	2.18	914.11	169.14
T4	76.75 (61.23)	24.82	11.28	2.32	865.93	178.25
T5	72.00 (58.04)	22.47	11.60	2.29	835.20	164.88
T6	70.00 (56.80)	19.95	11.34	2.08	793.45	145.60
T7	75.25 (60.20)	23.21	11.24	2.19	845.62	164.42
T8	71.75 (57.96)	21.18	11.67	2.25	837.32	161.26
T9	74.25 (59.52)	20.50	11.09	2.11	823.62	156.85
T10	73.75 (59.20)	19.69	11.52	2.18	849.42	160.59
T11	78.50 (62.42)	22.57	11.45	2.21	898.83	173.29
T12	80.50 (63.84)	24.01	11.49	2.45	925.15	196.82
T13	82.50 (65.31)	25.27	11.93	2.52	983.81	207.69
T14	79.00 (62.74)	24.58	11.90	2.36	939.71	186.44
T15	74.00 (59.36)	19.85	11.36	2.15	840.64	159.29
T16	76.75 (61.19)	22.07	11.43	2.19	877.06	168.27
T17	74.25 (59.50)	19.69	11.13	2.11	826.03	156.48
CD (p=0.05)	(3.37)	0.38	0.08	0.07	78.64	21.06

Parentheses are angular transformed values
See Table 1 for treatment details

germination (70.50%) was observed in the seeds primed with 25 ppm BABA for 10 h. The unprimed seeds exhibited the slowest germination (19.94). Similarly, the seeds primed with BABA at 75 ppm for 8h and 6h followed the highest seedling length and unprimed seeds showed the minimum average seedling length (11.68 cm). The maximum seedling dry weight was in BABA at 75 ppm for 4 h and 8 h, while the seeds primed with BABA at 25 ppm for 10 h had the minimum seedling dry weight (2.00 mg). The seeds primed with 75 ppm BABA for 8 h and 6 h were significantly close to the maximum SVI-I and SVI-II. The minimum SVI-I (832.96) and SVI-II (140.82) were recorded in the seeds primed with BABA at 100 ppm for 8 h and 25 ppm for 10h.

Effect of KNO₃: The significantly highest germination (87.00%) was recorded in seeds primed with KNO₃ at 1.5% for 10 h, closely followed by the seeds primed with KNO₃ at 2.0% for 10 h and 4 h, while the lowest germination (75.00%) was observed in the unprimed seeds. The seeds primed with KNO₃ at 1.5% for 10 h were the fastest (27.53) to germinate, followed by KNO₃ at 1.5% and 2.0% each for 4 h, whereas the unprimed seeds were the slowest (19.41) to germinate. The maximum average seedling length (12.74 cm) and consequently SVI-I (1,108.38) were also exhibited by the

seeds primed with KNO₃ at 1.5% for 10 h followed by the seeds primed with KNO₃ at 2.0% for 10 h and 4 h, while the unprimed seedlings had the lowest length (11.43 cm) and SVI-II (856.88). Seeds primed with KNO₃ at 1.5% for 10 h recorded the maximum seedling dry weight (2.63 mg) and SVI-II (229.03), followed by the treatments KNO₃ at 2.0% for 10 h and 1.0% for 8 h, while the unprimed seedlings had the minimum dry weight (2.15 mg) and SVI-II (161.25) (Table 4).

In vitro effect of seed priming in bell pepper on seed mycoflora

Effect of SA: The association of seed mycoflora, including *Alternaria* spp., *Penicillium* spp., *Fusarium* spp., *Colletotrichum* spp., and *Curvularia* spp., with bell pepper cv. Solan Bharpur was observed (Table 5). The highest incidence of all fungal species and total mycoflora (22.50%) was observed in the control. The lowest mycoflora incidence (2.25%) was in the seeds treated with 75 ppm SA for 8 h, followed by priming with SA at 100 ppm for 6 h and 4 h, and 25 ppm for 8 h, recording a total mycoflora incidence of 5.25% ($p \leq 0.05$).

Effect of MeJA: *Alternaria* spp., *Penicillium* spp., *Fusarium* spp., *Colletotrichum* spp., and *Curvularia* spp. associated with bell pepper seeds exhibited the highest total incidence

Table 3. Effect of seed priming with BABA on seed quality parameters in bell pepper

Treatments (BABA)	Seed quality parameters					
	Germination (%)	Speed of germination	Seedling length (cm)	Seedling dry wt. (mg)	SVI – I (Length)	SVI – II (Mass)
T1	72.75 (58.54)	20.55	12.43	2.46	904.46	179.15
T2	72.25 (58.26)	23.60	12.08	2.30	872.78	165.99
T3	73.00 (58.75)	22.90	12.33	2.12	900.09	154.94
T4	70.50 (57.14)	22.52	12.18	2.00	858.51	140.82
T5	76.25 (60.82)	20.85	11.77	2.19	897.08	166.80
T6	73.25 (58.84)	24.62	12.19	2.28	892.92	167.19
T7	72.25 (58.26)	21.91	11.71	2.45	846.23	176.83
T8	75.50 (60.33)	22.87	12.39	2.53	935.63	190.83
T9	77.25 (61.56)	23.93	12.49	2.62	965.43	202.59
T10	80.75 (63.99)	25.67	12.53	2.39	1011.39	193.19
T11	81.50 (64.53)	25.79	12.58	2.56	1025.07	208.64
T12	75.75 (60.52)	24.27	12.46	2.28	943.47	172.52
T13	84.75 (67.00)	27.98	12.62	2.66	1069.55	225.01
T14	73.50 (59.02)	24.41	12.38	2.42	910.11	178.05
T15	70.50 (57.10)	20.74	11.82	2.37	832.96	166.73
T16	75.00 (59.99)	26.13	12.36	2.41	927.00	180.94
T17	73.00 (58.71)	19.94	11.68	2.20	852.46	160.78
CD (p=0.05)	(3.25)	2.63	0.08	0.09	69.92	27.36

Parentheses are angular transformed values
See Table 1 for treatment details

Table 4. Effect of seed priming with KNO₃ on seed quality parameters in bell pepper

Treatments (KNO ₃ conc./ duration)	Seed quality parameters					
	Germination (%)	Speed of germination	Seedling length (cm)	Seedling dry wt. (mg)	SVI – I (Length)	SVI – II (Mass)
T1 (0.5%/4hrs)	75.75 (8.76)	21.32	12.06	2.21	913.55	167.029
T2 (0.5%/6hrs)	76.75 (8.82)	20.95	12.42	2.45	953.43	188.23
T3 (0.5%/8hrs)	76.50 (8.80)	21.63	11.74	2.16	897.73	165.81
T4 (0.5%/10hrs)	80.50 (9.03)	23.53	12.40	2.55	998.20	205.28
T5 (1.0%/4hrs)	80.75 (9.04)	22.70	11.82	2.45	954.06	197.43
T6 (1.0%/6hrs)	79.50 (8.97)	24.06	12.73	2.37	1012.23	188.22
T7 (1.0%/8hrs)	78.25 (8.90)	20.95	12.21	2.61	955.43	204.23
T8 (1.0%/10hrs)	81.50 (9.08)	23.73	12.52	2.18	1020.18	177.47
T9 (1.5%/4hrs)	80.75 (9.04)	26.55	11.94	2.26	963.75	182.29
T10 (1.5%/6hrs)	77.50 (8.86)	22.77	12.26	2.33	949.96	180.38
T11 (1.5%/8hrs)	79.00 (8.94)	22.98	12.58	2.51	993.23	198.09
T12 (1.5%/10hrs)	87.00 (9.38)	27.53	12.74	2.63	1108.38	229.03
T13 (2.0%/4hrs)	83.50 (9.19)	25.35	12.68	2.48	1058.99	206.87
T14 (2.0%/6hrs)	78.50 (8.92)	21.57	12.45	2.21	976.93	173.29
T15 (2.0%/8hrs)	76.00 (8.77)	23.63	12.32	2.31	935.94	175.75
T16 (2.0%/10hrs)	83.50 (9.19)	25.19	12.72	2.62	1061.70	218.98
T17 (Control)	75.00 (8.72)	19.41	11.43	2.15	856.88	161.25
CD (p=0.05)	(0.23)	2.53	0.10	0.09	82.15	29.00

Parentheses are square root transformed values

Table 5. Effect of seed priming with SA on seed mycoflora in bell pepper

Treatments (SA)	Seed mycoflora (%)					
	<i>Alternaria</i> spp.	<i>Penicillium</i> spp.	<i>Fusarium</i> spp.	<i>Colletotricum</i> spp.	<i>Curvularia</i> spp.	Seed mycoflora (Total)
T1	3.50 (2.10)	1.25 (1.49)	1.50 (1.57)	1.75 (1.64)	0.00	8.00 (2.56)
T2	4.00 (2.24)	1.50 (1.57)	1.75 (1.64)	2.75 (1.87)	0.00	10.00 (3.01)
T3	0.25 (1.10)	2.25 (1.79)	0.75 (1.29)	2.00 (1.73)	0.00	5.25 (2.12)
T4	2.00 (1.68)	2.00 (1.72)	2.50 (1.85)	1.50 (1.57)	0.00	8.00 (2.59)
T5	2.25 (1.74)	1.50 (1.57)	1.50(1.57)	3.00 (1.99)	0.00	8.25 (2.61)
T6	1.00 (1.39)	1.75 (1.64)	3.00 (1.98)	2.25 (1.80)	0.00	8.00 (2.57)
T7	1.75 (1.62)	2.25 (1.79)	2.00 (1.70)	2.00 (1.71)	0.00	8.00 (2.60)
T8	2.50 (1.85)	2.00 (1.71)	2.75 (1.93)	1.75 (1.65)	0.00	9.00 (2.72)
T9	2.00 (1.70)	1.75 (1.64)	2.00 (1.72)	1.50 (1.57)	0.00	7.25 (2.50)
T10	1.00 (1.39)	1.50 (1.57)	1.75 (1.64)	2.25 (1.79)	0.00	6.50 (2.38)
T11	0.00 (1.00)	1.00 (1.39)	0.50 (1.18)	0.75 (1.29)	0.00	2.25 (1.60)
T12	0.75 (1.29)	1.25 (1.47)	1.50 (1.56)	2.50 (1.87)	0.00	6.00 (2.28)
T13	1.25 (1.47)	2.00 (1.72)	1.00 (1.39)	1.00 (1.39)	0.00	5.25 (2.18)
T14	0.50 (1.21)	1.50 (1.57)	0.75 (1.29)	1.50 (1.57)	0.00	4.25 (2.00)
T15	2.50 (1.87)	1.75 (1.64)	2.00 (1.72)	1.75 (1.64)	0.00	8.00 (2.60)
T16	1.00 (1.39)	2.25 (1.79)	1.50 (1.57)	2.00 (1.72)	0.00	6.75 (2.41)
T17	4.75 (2.40)	4.50 (2.33)	4.25 (2.29)	5.00 (2.45)	4.00	22.50 (4.36)
CD (p=0.05)	0.45	0.37	0.41	0.38	NS	1.08

Parentheses are square root transformed values
See table 1 for treatment details

(21.25%) in the untreated control (Table 6). The lowest mycoflora incidence (3.25%) was in seeds primed with 100 ppm MeJA for 4 h, followed by MeJA at 100 and 50 ppm for 8 h.

Effect of BABA: The association of *Alternaria* spp., *Penicillium* spp., *Fusarium* spp., *Colletotrichum* spp., and *Curvularia* spp. in bell pepper seeds was observed (Table 7). The control exhibited the highest mycoflora incidence (23.00%), while the lowest total mycoflora incidence (1.00%) was in seeds treated with 100 ppm BABA for 4 h, followed by priming with 75 ppm for 4 h and 8 h.

Effect of KNO₃: The association of *Alternaria* spp., *Penicillium* spp., *Fusarium* spp., *Colletotrichum* spp., and *Curvularia* spp. in bell pepper seeds is given in Table 8. The highest total mycoflora incidence (22.25%) was observed in the control and the lowest incidence (3.25%) was in seeds treated with KNO₃ at 1.5% for 10 h, closely followed by KNO₃ at 2.0% and 1.5% for 4 h.

This study provides the first comprehensive evaluation of seed priming across various concentrations of SA, MeJA, BABA and KNO₃ to enhance seed quality parameters in bell pepper. The findings align with prior research on other crops, highlighting the role of different priming agents in improving germination, seedling growth, and vigor. Among the

treatments, SA priming at 75 ppm for 8 h significantly enhanced germination percentage, seedling dry weight, and vigor indices. Similar effects were observed in Arabidopsis, where SA concentrations above 50 ppm improved germination (Rajjou et al., 2006), and in rice, where SA priming in the 75-100 ppm range reduced germination time and enhanced seedling dry weight (Shatpathy et al., 2018), in Indian mustard (*Brassica juncea*), where SA priming improved germination, SVI-I and II, and early seedling establishment (Dan 2014). The observed enhancement in seed vigour can be attributed to the SA-induced activation of metabolic pathways, including the glyoxylate cycle, pentose phosphate pathway, glycolysis, and gluconeogenesis. These pathways play a crucial role in transitioning seeds from quiescence to active seedling growth by promoting enzyme activation and energy mobilization (Rajjou et al., 2006). However, seed priming with MeJA negatively affected germination, seedling growth, and vigor indices. This aligns with previous studies demonstrating that MeJA inhibits seed germination in various angiosperms (Norastehnia et al., 2007). The reduction in seedling performance may be linked to MeJA's role in activating defence mechanisms at the cost of growth-related processes, leading to energy trade-offs that negatively impact early seedling establishment (Li et al.,

Table 6. Effect of seed priming with MeJA on seed mycoflora in bell pepper

Treatments (MeJA)	Seed mycoflora (%)					
	<i>Alternaria</i> spp.	<i>Penicillium</i> spp.	<i>Fusarium</i> spp.	<i>Colletotrichum</i> spp.	<i>Curvularia</i> spp.	Seed mycoflora (Total)
T1	1.50 (1.54)	2.75 (1.91)	0.75 (1.28)	1.75 (1.64)	0.00	6.75 (2.39)
T2	1.00 (1.39)	3.25 (2.05)	1.00 (1.39)	3.25 (2.05)	0.00	8.50 (2.59)
T3	1.25 (1.47)	3.00 (1.99)	1.50 (1.54)	2.50 (1.85)	0.00	8.25 (2.60)
T4	1.75 (1.60)	2.50 (1.86)	1.75 (1.72)	3.00 (1.99)	0.00	9.00 (2.72)
T5	2.25 (1.79)	2.00 (1.72)	1.50 (1.55)	3.25 (2.05)	0.00	9.50 (2.71)
T6	1.00 (1.39)	3.50 (2.12)	2.00 (1.72)	2.50 (1.85)	0.00	9.00 (2.69)
T7	1.75 (1.64)	1.75 (1.64)	1.25 (1.43)	2.00 (1.68)	0.00	6.75 (2.42)
T8	1.5 (1.57)	2.25 (1.79)	0.50 (1.18)	3.75 (2.17)	0.00	8.00 (2.51)
T9	2.25 (1.77)	3.75 (2.16)	1.50 (1.57)	2.50 (1.85)	0.00	10.00 (2.83)
T10	2.00 (1.72)	1.75 (1.65)	2.75 (1.93)	3.00 (1.98)	0.00	9.50 (2.78)
T11	1.25 (1.43)	2.25 (1.79)	1.00 (1.35)	2.75 (1.90)	0.00	7.25 (2.46)
T12	1.50 (1.56)	1.50 (1.57)	1.25 (1.46)	2.25 (1.80)	0.00	6.50 (2.38)
T13	0.75 (1.31)	1.25 (1.46)	0.25 (1.10)	1.00 (1.39)	0.00	3.25 (1.82)
T14	1.75 (1.62)	1.75 (1.65)	2.00 (1.72)	1.75 (1.64)	0.00	7.25 (2.50)
T15	1.50 (1.57)	1.50 (1.57)	1.75 (1.64)	1.25 (1.49)	0.00	6.00 (2.31)
T16	1.00 (1.39)	2.50 (1.87)	1.25 (1.47)	2.00 (1.72)	0.00	6.25 (2.40)
T17	4.50 (2.34)	4.75 (2.40)	4.00 (2.23)	5.00 (2.45)	3.00	21.25 (2.34)
CD (p=0.05)	(0.47)	(0.36)	(0.49)	(0.42)	NS	(0.47)

Parentheses are square root transformed values
See table 1 for treatment details

2022). The effect of BABA on seed quality parameters revealed a concentration-dependent trend. At lower concentrations, BABA enhanced seed vigour parameters; however, beyond 100 ppm, a decline in seed vigour indices was observed. This phenomenon is consistent with previous reports suggesting that the direct toxic effects of BABA or the energetic costs of induced resistance can negatively impact plant growth (Silue et al., 2002). The optimal seed vigor recorded at moderate BABA concentrations suggests that BABA-induced resistance mechanisms may contribute to improved seed performance, but excessive concentrations may impose physiological stress, leading to reduced germination and seedling vigor (Cohen et al., 2016). KNO₃ priming at 1.5% for 10 h significantly improved seed germination, seedling vigor, seedling length, and seedling dry weight. Similar enhancements in seed and seedling vigor indices, and germination were reported in hot pepper (Amjad et al., 2007), tomato (Behera 2016), soybean (Ahmadvand et al., 2012) and cotton (Cokkizgin and Bolek 2015) on priming their seeds with KNO₃. Several findings in other crops support our results in which SA application significantly reduced occurrence of *Fusarium* spp. and *Cercospora* spp. in soybean (Kuchlan et al., 2017), *Alternaria alternata* incidence in pear fruits (Tian et al., 2006). Seed priming with

SA has also been shown to lower Ascomycota fungi, including *Verticillium* spp. and *Fusarium* spp. (Mustafa et al., 2019). This is due to the reason that salicylic acid activates plant resistance pathway by affecting the enzymes and genes involved in ROS scavenging, prompting pathogenesis related genes (Mishra et al., 2024) and activating the defense genes like chitinase, -1,3-glucanase, peroxidase, and phenylalanine ammonia-lyase providing resistance against both necrotrophic and biotrophic pathogens (Glazebrook 2005). Seed priming with methyl jasmonate can enhance resistance to both abiotic and biotic stresses by modulating antioxidant activity and secondary metabolite production. However, its effectiveness is reduced under *in vitro* conditions due to possible phytotoxicity at higher concentrations and longer durations, and differences in uptake and signaling compared to natural growing conditions. BABA-induced resistance (BABA-IR) operates via an ABA-dependent pathway, independent of SA, JA, or ethylene (Ton & Mauch-Mani 2004). The activation of reactive oxygen species (ROS) and glycolate oxidase (GO) contributes to its antifungal effects, supporting the observed lowest mycoflora incidence in BABA-treated seeds. Likewise, potassium application in cotton reduced *Fusarium* wilt (Prabhu et al., 2007), and higher potassium levels

Table 7. Effect of seed priming with BABA on seed mycoflora in bell pepper

Treatments (BABA)	Seed mycoflora (%)					Seed mycoflora (Total)
	<i>Alternaria</i> spp.	<i>Penicillium</i> spp.	<i>Fusarium</i> spp.	<i>Colletotricum</i> spp.	<i>Curvularia</i> spp.	
T1	2.50 (1.84)	2.00 (1.68)	1.50 (1.57)	1.75 (1.64)	0.00	7.75 (2.56)
T2	2.25 (1.74)	1.25 (1.49)	0.75 (1.29)	2.25 (1.74)	0.00	6.50 (2.36)
T3	1.75 (1.65)	2.25 (1.72)	1.75 (1.64)	3.00 (1.99)	0.00	8.75 (2.69)
T4	1.75 (1.65)	1.50 (1.54)	1.00 (1.39)	2.50 (1.47)	0.00	6.75 (2.41)
T5	2.50 (1.85)	2.50 (1.85)	2.00 (1.70)	1.25 (1.29)	0.00	8.25 (2.65)
T6	2.50 (1.85)	2.00 (1.68)	2.00 (1.70)	2.50 (1.85)	0.00	9.00 (2.73)
T7	1.50 (1.54)	2.50 (1.85)	2.25 (1.79)	1.75 (1.64)	0.00	8.00 (2.59)
T8	2.00 (1.72)	1.50 (1.57)	0.75 (1.29)	2.25 (1.80)	0.00	6.50 (2.36)
T9	0.50 (1.21)	1.00 (1.39)	0.50 (1.21)	0.50 (1.21)	0.00	2.50 (1.69)
T10	1.00 (1.39)	1.50 (1.54)	1.75 (1.65)	2.00 (1.49)	0.00	6.25 (2.34)
T11	0.75 (1.29)	1.25 (1.49)	1.00 (1.39)	0.75 (1.29)	0.00	3.75 (1.94)
T12	2.00 (1.68)	1.75 (1.65)	1.50 (1.54)	1.25 (1.49)	0.00	6.50 (2.39)
T13	0.00 (1.00)	0.75 (1.29)	0.00 (1.00)	0.25 (1.10)	0.00	1.00 (1.28)
T14	1.00 (1.39)	1.50 (1.56)	1.00 (1.39)	1.25 (1.49)	0.00	4.75 (2.16)
T15	1.50 (1.54)	2.00 (1.70)	0.75 (1.29)	1.50 (1.54)	0.00	5.75 (2.26)
T16	1.00 (1.39)	2.50 (1.85)	2.75 (1.90)	2.50 (1.84)	0.00	8.75 (2.67)
T17	5.00 (2.46)	5.50 (2.55)	4.25 (2.28)	4.75 (2.40)	3.50	23.00 (4.39)
CD (p=0.05)	(0.48)	(0.45)	(0.45)	(0.45)	NS	(1.03)

Parentheses are square root transformed values
See table 1 for treatment details

Table 8. Effect of seed priming with KNO₃ on mycoflora in bell pepper

Treatments (KNO ₃)	Seed mycoflora (%)					Seed mycoflora (Total)
	<i>Alternaria</i> spp.	<i>Penicillium</i> spp.	<i>Fusarium</i> spp.	<i>Colletotricum</i> spp.	<i>Curvularia</i> spp.	
T1	1.75 (1.64)	1.75 (1.64)	2.75 (1.93)	2.25 (1.80)	0.00	8.50 (2.66)
T2	1.50 (1.57)	2.25 (1.80)	2.00 (1.72)	1.25 (1.49)	0.00	7.00 (2.45)
T3	1.50 (1.57)	2.00 (1.72)	1.75 (1.64)	1.75 (1.64)	0.00	7.00 (2.46)
T4	2.00 (1.73)	2.25 (1.79)	3.00 (1.99)	2.00 (1.72)	0.00	9.25 (2.75)
T5	1.75 (1.64)	2.75 (1.93)	2.75 (1.93)	1.50 (1.54)	0.00	8.75 (2.68)
T6	2.25 (1.79)	1.50 (1.57)	2.00 (1.72)	2.50 (1.85)	0.00	8.25 (2.63)
T7	2.50 (1.85)	2.25 (1.80)	2.25 (1.79)	2.25 (1.80)	0.00	9.25 (2.76)
T8	2.25 (1.79)	1.25 (1.47)	2.50 (1.83)	2.00 (1.72)	0.00	8.00 (2.59)
T9	1.75 (1.64)	2.00 (1.71)	1.75 (1.64)	1.25 (1.47)	0.00	6.75 (2.42)
T10	2.00 (1.72)	1.50 (1.57)	3.75 (2.15)	2.75 (1.90)	0.00	10.00 (2.82)
T11	1.50 (1.57)	1.75 (1.65)	2.25 (1.78)	1.75 (1.65)	0.00	7.25 (2.49)
T12	1.00 (1.41)	1.00 (1.39)	0.50 (1.21)	0.75 (1.31)	0.00	3.25 (1.84)
T13	1.25 (1.49)	1.25 (1.49)	0.75 (1.31)	1.00 (1.39)	0.00	4.25 (2.03)
T14	1.75 (1.65)	1.50 (1.55)	2.50 (1.85)	2.00 (1.72)	0.00	7.75 (2.56)
T15	2.00 (1.72)	2.25 (1.78)	2.25 (1.80)	1.50 (1.57)	0.00	9.00 (2.59)
T16	1.50 (1.57)	2.00 (1.72)	1.75 (1.64)	1.50 (1.57)	0.00	6.75 (2.42)
T17	4.50 (2.34)	5.00 (2.45)	4.00 (2.23)	5.25 (2.50)	3.50	22.25 (4.33)
CD (p=0.05)	(0.31)	(0.36)	(0.33)	(0.37)	NS	(1.04)

Parentheses are square root transformed values
See Table 4 for treatment details

enhanced resistance in several crops including rice, wheat, tomato, and soybean (Sweeney et al., 2000). This mechanism likely involves reduced pathogen competition for nutrients and enhanced cell wall strengthening, contributing to lower mycoflora incidence (Holzmueller et al., 2007; Mengel 2001).

CONCLUSION

This study demonstrates that seed priming with plant defence activators like SA, MeJA, BABA, and KNO₃, can significantly improve seed quality and reduce seed-borne fungal incidence in bell pepper. Among the treatments, priming with 75 ppm SA for 8 h and 1.5% KNO₃ for 10 h resulted in the highest germination rates, seedling vigor, and the lowest seed mycoflora incidence. BABA exhibited a concentration-dependent effect, enhancing seed vigor at moderate levels, while MeJA, although beneficial under certain conditions, showed a slight inhibitory effect on early seedling growth when used in higher doses and longer durations. The findings support the use of seed priming with selected defence activators as an eco-friendly alternative to chemical seed treatments, thereby promoting sustainable agriculture and healthier crop establishment. Further research is encouraged to optimize protocols and

understand the mechanisms underlying these benefits.

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