



RESEARCH ARTICLE

Impact of seed priming treatments and paclobutrazol applications on growth, flowering and seed yield in *Salvia splendens* Sellow ex. Schult.

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Abstract

An investigation was carried out to assess the effect of seed priming treatments and foliar application of paclobutrazol, on growth, flowering and seed yield attributes in "*Salvia splendens*". The study was structured using a randomized complete block design (RCBD) with sixteen treatment combinations replicated thrice with plot size of 1.0 × 1.0 m and followed spacing as 30 × 30 cm. Among the seed priming treatments, priming of seed in cow dung slurry for 24 hr significantly improved all the growth, flowering and yield parameters under study. Whereas, among different doses of paclobutrazol, spraying of plants with 10.0 ppm paclobutrazol resulted in the highest values for plant spread (39.04 cm), number of branches per plant (10.78), number of spikes per plant (15.42), number of florets per spike (50.31), number of pods per plant (460.80), seed yield per plant (6.48 g), per plot (58.27 g) except plant height (42.42 cm) and spike length (12.81 cm) which were highest in control. The treatment combination, SPT₂ × PD₃ i.e. seed priming with cow dung slurry for 24 hr and foliar application of paclobutrazol at 10 ppm, exhibited highest values for plant spread (42.34 cm), number of branches per plant (12.03), number of spikes per plant (16.83), number of florets per spike (60.67), number of pods per plant (546.03), seed yield per plant (7.36 g), per plot (16.83 g). However, the control lot (SPT₂ × PD₁) revealed maximum values for plant height and spike length as well. Accordingly, it may be inferred from the outcomes of the investigation that seed priming with cow dung slurry for 24 hr along with the foliar application of paclobutrazol at 10.0 ppm is an appropriate treatment combination for promoting the growth, flowering and seed production in salvia.

Keywords: cow dung slurry; cow urine; GA₃; Paclobutrazol; growth retardants; seed priming; Salvia; seed yield; seed production.

Introduction

Salvia splendens Sellow ex Schult, a member of the Lamiaceae family, is a popular winter season annual flower. It is commonly called as scarlet sage or tropical sage and is native to Brazil. The genus *Salvia* contains over 900 species worldwide (1). *Salvia* is often referred to as 'red sum' or 'fire flower' due to its striking, vibrant red colour. It grows up to a height of 90 cm depending upon species/genotype, climate and growing environment (2). It is regarded as an attractive or valuable bedding or potted plant, mostly because of its decorative qualities and prolonged ornamentation of flowering. It is also an excellent flowering plant for rock gardens as well as border areas. It produces a perfect bell-shaped flower with two-lips in top of the inflorescences, which emerge through the bracts and start blooming at the beginning of summer and continue till autumn (3). *Salvia splendens* can contribute to creating biodiversity hotspots by attracting a wide range of pollinators, including bees, butterflies and hummingbirds, which in turn helps in supporting other plant species and wildlife. Hence, this plant holds a valuable place in enhancing the aesthetic value of landscapes and the natural world, too. Therefore, salvia is

an important herbaceous plant for its aesthetic appeal, ecological contributions and ease of cultivation, including its potential roles in education, research and cultural significance as well.

Seasonal flowers are much in demand all over the world for enhancing the beauty of our landscape gardening (4). They serve as an essential component in both indoor and outdoor gardening. *Salvia* is utilised more frequently in landscaping to alter the colour scheme of the gardens in accordance with the season and necessity because of its short duration and colourful blooms. Most annual flowers are propagated through seeds. The seed market for flowering annuals has also grown to be an important industry due to their huge demand in global floricultural trade. There are various factors that have developed the potential of commercial floriculture, which include an increase in population and the aesthetic taste of the people. As a result, the demand for annual flower seeds for house landscaping, educational institutes, farm complexes, roadways and industrial units has expanded potentially worldwide.

The need for upgrading seed quality is primarily warranted for addressing the necessary demand for high standards of seeds in

the global floriculture trade. It is widely acknowledged that the best crop performance can only be achieved with high-quality seed, prompt and uniform seedling emergence, which ultimately results in a healthy crop stand. Seed priming is a method of improving seed performance by any post-harvest or physico-chemical treatment or organic priming, resulting in better storability, improved germination and field performance over a wide range of climatic conditions. Improved seed priming techniques are used to reduce emergence time, accomplish uniform emergence, better allometric (changes in growth of plant parts over time) attributes and requisite stand in many horticultural and field crops (5). Organic priming agents such as cow dung slurry and cow urine are rich in readily available macro and micronutrients, beneficial microorganisms (including plant growth-promoting rhizobacteria) and biologically active metabolites that stimulate early metabolic repair processes during imbibition. These inputs have been shown to enhance enzymatic activation, nutrient uptake efficiency and early vegetative growth in various crops. Despite their increasing use in sustainable agriculture, the role of organic priming agents in ornamental seed crops, particularly for seed yield enhancement in *Salvia splendens*, remains poorly explored.

A priming tool can be successfully used in salvia seeds to alleviate the problems of poor and slow seed germination, which in turn will ensure larger benefits to the commercial growers as there will be no crop failure due to poor germination and consequently quality of plant growth, vigour and flowering will be better (6–8). Further growth retardants have been proven to be of immense importance in controlling plant height. Most of the available retardants, including paclobutrazol, are primarily used to retard the plant height, besides improving other quality attributes. Paclobutrazol aims to reduce the length of the internodes and to reduce the size of plants for efficient utilisation of the area and increasing the marketing value of vegetative and flowering groups, in addition to the stem strength and hardness, along with condensed growth (9).

Although paclobutrazol is traditionally used as a growth retardant, several studies indicate that it also alters source-sink relationships by suppressing excessive vegetative growth and enhancing assimilate allocation toward reproductive organs,

thereby improving reproductive efficiency and seed yield (10, 11). While paclobutrazol is extensively used to control plant height and improve ornamental quality in salvia and other bedding plants, its potential role in improving reproductive efficiency and seed yield through altered source-sink relationships has received limited attention.

Thus, practising seed priming will be very economical for the seed companies in terms of high returns from export of primed seeds as well as for the growers, as higher seed cost will be compensated by the improved germination values, production of stocky seedlings, as well as better growth and flowering attributes. So much so, the application of different growth retardants had also been utilised in various flower crops, including salvia, to improve plant growth, flowering and seed production as well. Considering the aforementioned information, the investigation was conducted to examine the effects of seed priming for enhancing early vigour and reproductive potential, while an optimum dose of paclobutrazol could redirect vegetative growth toward reproductive output, ultimately improving seed yield in *Salvia splendens*.

Materials and Methods

The field experiment was carried out at the Experimental Farm of the Department of Seed Science and Technology, Dr YS Parmar UHF Nauni, Solan (HP), to evaluate the effect of seed priming treatments and foliar application of paclobutrazol, on growth, flowering and seed yield attributes in salvia. An overview of the field trial is shown in Fig. 1. The experimental farm is located at an altitude of 1060 m above mean sea level having latitude of 30.51° N and a longitude of 77.10° E. The experimental area falls under the mid-hill zone of Himachal Pradesh. The climate, in general, is sub-temperate and sub-humid, mostly characterised by mild summers and cool winters. Generally, May and June are the hottest months, while January and February are the coldest. Seeds of *Salvia splendens* cv. Flamex-2000 were obtained from the Department of Seed Science and Technology, Dr YS Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh, India. The seeds were primed with cow dung slurry for 24 hr, cow urine at 10 % for 12 hr and GA₃ seed priming at 150 ppm for 12 hr. The slurry



Fig. 1. Field view of *Salvia splendens* plots at peak flowering under different treatment combinations.

was prepared by combining fresh cow dung and water in equal proportions (1:1). The nursery was raised using primed seeds along with a control seed lot under polyhouse conditions in the month of October and was transplanted after 4 weeks. There were total 16 treatment combinations comprising of three seed priming treatments viz., SPT₂ (cow dung slurry for 24 hr), SPT₃ (cow urine at 10 % for 12 hr) and SPT₄ (GA₃ at 150 ppm for 12 hr) along with control SPT₁ (no priming) and three doses of foliar application of paclobutrazol viz., PD₁ (5 ppm), PD₂ (10 ppm) and PD₃ (20 ppm) along with control PD₀ (0 ppm) applied once at 40 days after transplanting. Paclobutrazol (25% ai) solutions were prepared by dissolving 0.02, 0.04 and 0.08 mL of the commercial formulation in 1 L of water to obtain 5, 10 and 20 ppm concentrations, respectively. The paclobutrazol solution was applied as a foliar spray using a hand sprayer at a spray volume of 200 mL solution per plot. The experiment was laid out in a randomised complete block design (factorial) at a spacing of 30 × 30 cm in the plot size of 1.0 × 1.0 m replicated thrice. Observations on various parameters, viz., plant height (cm), plant spread (cm), number of branches per plant, number of flower spikes per plant, number of pods per plant and seed yield (g/plant and kg/h) were recorded as per the standard procedures. The number of pods per plant was determined by counting all pods present in each plant per experimental plot. Seeds were harvested in the month of April. For estimation of seed yield per plant, plants were harvested individually at maturity, seeds were separated by hand threshing and the final seed weight was recorded on an individual plant basis. The data were statistically analysed through a randomised complete block design (factorial) and the significance of the data was calculated with two-way ANOVA using windows-based computer application OPSTAT (12, 13). Treatment means were compared using the critical difference (CD) test at 5 % level of significance ($\alpha=0.05$) following analysis of variance.

Results and Discussion

Plant height (cm)

The data presented in Table 1 indicate significant variation in plant height due to different levels of seed priming and paclobutrazol doses. Among seed priming treatments, maximum plant height (37.01) was observed in SPT₂, i.e. seed priming with cow dung slurry for 24 hr whereas minimum plant height (29.97) was reported in SPT₁, i.e. control. The data in Table 2 represent the doses of paclobutrazol. The maximum plant height (42.42) was observed in

PD₁, i.e. 0 ppm paclobutrazol, whereas the minimum plant height (28.11) was observed in PD₄, i.e. plants sprayed with 20 ppm paclobutrazol. The data in Table 3 showed that the interaction effect of priming treatments along with the doses of paclobutrazol have significant effect on plant height. The maximum plant height (46.51) was observed in SPT₂ PD₁ (i.e., seed priming with cow dung slurry for 24 hr + 0 ppm paclobutrazol), whereas the minimum (23.40) plant height was revealed in SPT₁ PD₄ (i.e., no seed priming + 20 ppm paclobutrazol). Seed priming with cow dung slurry for 24 hr consistently produced taller plants compared to the control, indicating enhanced seed vigour and early seedling establishment. This can be explained through their contrasting physiological roles in early seed metabolism and subsequent hormonal regulation. Cow dung slurry is rich in beneficial microflora, including plant growth-promoting rhizobacteria (PGPR), which enhances enzymatic activity during germination. Increased activity of hydrolytic enzymes such as α -amylase facilitates rapid starch breakdown in the endosperm, supplying readily available sugars that support early seedling growth and subsequent vegetative development. In addition, cow dung slurry provides readily available macro and micronutrients along with biologically active compounds that may stimulate endogenous synthesis of growth-promoting hormones such as auxins and gibberellins, ultimately resulting in enhanced cell elongation and increased plant height. The results agree with the findings in maize fodder and carrot respectively (14, 15).

On the other hand, with an increase in the dose of paclobutrazol, plant height reduces because the isoprenoid pathway is altered, which prevents the synthesis of GA₃, lowers the production of ethylene and eventually increases the amount of cytokinins and abscisic acid. They are used to controllably reduce plant height without causing phytotoxicity to plants or altering their developmental patterns. The primary effect of paclobutrazol in plants is the inhibition of gibberellin biosynthesis, resulting in reduced plant height and altered source-sink relationships through the redistribution of carbohydrates from the shoot apex to other plant organs. The significant variation in plant height observed under different seed priming treatments and paclobutrazol doses can be explained through their contrasting physiological roles in early seed metabolism and subsequent hormonal regulation. Similar physiological responses associated with paclobutrazol-induced gibberellin inhibition and growth modulation have been documented in Ker- Gawn cultivar of *Salvia splendens*, black iris, Salvador red, Vista red cultivars of *Salvia splendens* and *Pelargonium zonal* (16-19).

Table 1. Effect of different seed priming treatments on growth and flowering of salvia (Pooled data of 2 years)

Treatment details	Plant height (cm)	Plant spread (cm)	Number of branches per plant	Days to first flowering	Number of spikes per plant
Seed Priming treatments					
Control (No Priming)	29.97	29.52	8.03	55.92	11.51
Cow Dung Slurry (24 hr)	37.01	39.90	10.53	53.83	14.84
Cow Urine at 10 % (12 hr)	34.86	35.60	9.06	54.83	13.79
GA ₃ at 150 ppm (12 hr)	36.40	39.01	9.61	53.38	14.49
CD _{0.05}	0.45	0.41	0.21	0.36	0.24
SE(m)	0.16	0.15	0.06	0.13	0.08

Table 2. Effect of foliar application of paclobutrazol on growth and flowering of salvia (Pooled data of 2 years).

Paclobutrazol doses	Plant height (cm)	Plant spread (cm)	Number of branches per plant	Days to first flowering	Number of spikes per plant
Control (0 ppm)	42.42	32.78	8.07	50.38	11.81
Paclobutrazol (5 ppm)	35.82	36.92	9.65	53.92	13.97
Paclobutrazol (10 ppm)	31.89	39.04	10.78	55.33	15.42
Paclobutrazol (20 ppm)	28.11	35.29	8.72	58.33	13.43
CD _{0.05}	0.45	0.41	0.21	0.36	0.24
SE(m)	0.16	0.15	0.08	0.13	0.08

Table 3. Interaction effect of different seed priming treatments and foliar application of paclobutrazol on growth and flowering in salvia (Pooled data of 2 years)

Treatment details	Plant height (cm)	Plant spread (cm)	Number of branches per plant	Days to first flowering	Number of spikes per plant
Seed priming treatments × paclobutrazol doses					
SPT ₁ × PD ₁	38.93	25.67	7.20	53.00	10.33
SPT ₁ × PD ₂	31.85	31.08	8.23	54.67	11.50
SPT ₁ × PD ₃	25.71	32.83	9.17	56.00	13.13
SPT ₁ × PD ₄	23.40	28.49	7.50	60.00	11.07
SPT ₂ × PD ₁	46.51	38.80	8.63	49.00	12.53
SPT ₂ × PD ₂	37.44	40.95	11.03	53.67	15.37
SPT ₂ × PD ₃	34.07	42.34	12.03	55.17	16.83
SPT ₂ × PD ₄	30.01	37.50	10.43	57.50	14.62
SPT ₃ × PD ₁	40.63	35.33	8.17	50.83	12.00
SPT ₃ × PD ₂	36.70	35.93	9.15	54.17	14.07
SPT ₃ × PD ₃	33.47	39.82	10.53	55.67	15.30
SPT ₃ × PD ₄	28.65	31.33	8.40	58.67	13.78
SPT ₄ × PD ₁	43.63	38.53	8.29	48.67	12.37
SPT ₄ × PD ₂	37.28	39.73	10.20	53.17	14.95
SPT ₄ × PD ₃	34.30	41.16	11.40	54.50	16.40
SPT ₄ × PD ₄	30.40	36.60	8.53	57.17	14.23
CD _{0.05}	0.90	0.82	0.42	0.72	0.48
SE(m)	0.32	0.30	0.15	0.25	0.17

SPT₁: Control (No priming), SPT₂: Cow dung slurry (24 hr), SPT₃: Cow urine at 10 % concentration (12 hr), SPT₄: GA₃ at 150 ppm (12 hr), PD₁: Control (0 ppm), PD₂: Paclobutrazol at 5 ppm, PD₃: Paclobutrazol at 10 ppm, PD₄: Paclobutrazol at 20 ppm

Plant spread

An examination of the data in Table 1 revealed that different treatments and their combinations led to a significant difference in plant spread. As regards the data of seed priming treatments, maximum plant spread (39.90) was observed in SPT₂, i.e. seed priming with cow dung slurry for 24 hr, whereas minimum plant spread (29.52) was reported in SPT₁, i.e., control. Among the foliar applications of paclobutrazol, maximum plant spread (39.04) was observed in PD₂, i.e. 10 ppm paclobutrazol, whereas minimum plant spread (32.78) was observed in PD₁, i.e. plants sprayed with 0 ppm paclobutrazol. An appraisal of data disclosed in Table 3 revealed that the interaction effect of seed priming treatments along with the doses of paclobutrazol have significant effect on plant spread. The maximum plant spread (42.34) was observed in SPT₂PD₃ (i.e. seed priming with cow dung slurry for 24 hr + 10 ppm paclobutrazol), whereas the minimum (25.67) plant spread was observed in SPT₁PD₁ (i.e. control). The enhanced lateral growth under cow dung slurry priming may be attributed to improved nutrient availability and microbial-mediated synthesis of phytohormones. The increased number of lateral shoots with cow dung slurry is also resulting from the synthesis of auxins and cytokinins, which promote enough cell division and faster cell elongation. Similar findings were observed in okra (20). In general, an increase in plant spread with the application of 10 ppm paclobutrazol reflects a shift from vertical to lateral growth, likely due to altered hormonal balance and weakened apical dominance under inhibited gibberellin biosynthesis, which promotes axillary bud initiation and canopy expansion. This architectural modification can enhance light interception and photosynthetic capacity despite compact stature. Earlier studies in China aster have demonstrated that paclobutrazol modifies plant architecture by restricting vertical growth while encouraging lateral expansion, thereby increasing plant spread (21). Similar responses involving enhanced branching and broader canopy development have been reported in *Callistemon citrinus*, potted chinchinchee and chrysanthemum (22-24).

Days taken to first flowering

Data pertaining to days to first flowering has been recorded and accordingly presented in Table 1. Among the seed priming treatments, minimum days to first flowering (53.38) was recorded in SPT₄ i.e., priming using GA₃ at 150 ppm for 12 hr whereas maximum time taken to first flowering (55.92) was observed in control (SPT₁). Further look in data (Table 2) also revealed that among the foliar application of paclobutrazol, earliest flowering (50.38) was observed in PD₁ i.e., control. Delayed flowering (58.33) was observed in PD₄ i.e., 20 ppm paclobutrazol. Further data in Table 3 also revealed that the interaction effect of seed priming treatments along with the doses of paclobutrazol have significant impact on days to first flowering. The minimum days to first flowering (48.67) was observed in SPT₄ PD₀ (seed priming with GA₃ at 150 ppm for 12 hr + 0 ppm paclobutrazol), whereas the maximum days to first flowering (60.00) was observed in SPT₁PD₄ (i.e., no seed priming + 20 ppm paclobutrazol). The earliest flowering was observed in the salvia plants grown from seeds primed in a 150 ppm GA₃ solution, which could be due to an increase in the endogenous level of gibberellins in plant tissues. Gibberellins are responsible for controlling the activity of the subapical meristem and, ultimately transformation of vegetative buds into floral buds, which blossom and cause early flowering. The findings are consistent with the results obtained by previous authors in tuberose, tulips and china aster (25, 26, 27).

In general, there was an increase in time for first flowering with the increasing concentrations of paclobutrazol. The significant delay in flowering of salvia plants sprayed with paclobutrazol in comparison to the control might be associated with the inhibition of gibberellin biosynthesis, along with redirecting the energy and nutrients directly towards the vegetative phase, which leads to the development of a greater number of side shoots. The previous studies also reported delayed flowering with an increase in doses of paclobutrazol in *Salvia splendens* cv. 'Vista Red' and *Salvador Red* (18, 28).

Number of branches per plant

Data (Table 1) revealed that different treatments and their combinations has significant effect on the number of branches per plant. The maximum number of branches per plant (10.53) was observed in SPT₂ i.e., seed priming with cow dung slurry for 24 hr whereas the minimum number of branches per plant (8.03) was observed in SPT₁ i.e., control. Further look in data (Table 2) also showed that among the foliar applications of paclobutrazol, the maximum number of branches per plant (10.78) was revealed in PD₃ i.e., 10 ppm paclobutrazol, whereas the minimum number of branches per plant (8.07) was observed in PD₁ i.e., plants sprayed with 0 ppm paclobutrazol. The data reflected in Table 3 showed that the interaction effect of seed priming treatments along with the doses of paclobutrazol have significant influence on the number of branches per plant. The maximum number of branches per plant (12.03) was observed in SPT₂ PD₃ (i.e., seed priming with cow dung slurry for 24 hr+ 10 ppm paclobutrazol), whereas the minimum (7.20) number of branches per plant was observed in SPT₁PD₁ (i.e., no seed priming + 0 ppm paclobutrazol).

The greatest number of branches per plant was observed in the plants grown from the seed lot primed with cow dung slurry. This might have happened because there were an optimal supply and synthesis of vitamins, nutrients, plant bioregulators and other organic materials that could aid in encouraging plant growth. In fact, rhizobacteria that promote plant growth are also present in cow dung slurry. These bacteria not only facilitate easy uptake of the nutrients by plants but also aid in their conversion from unavailable to available forms (29). The microbial metabolites. A similar trend in okra has also been obtained (20, 30).

Moreover, paclobutrazol at a specific concentration leads to the production of high levels of cytokinin along with a decrease in the level of IAA and gibberellins, which suppresses the apical dominance of the main stem and ultimately may be responsible for increasing the number of side shoots. Reduced auxin dominance at the apical meristem permits the activation of dormant axillary buds, resulting in increased branch formation (31, 32). Enhanced branching increases the number of potential reproductive sites, thereby strengthening sink capacity and improving yield potential (33). The maximum shoot initiation was observed with application of paclobutrazol at a specific concentration in China aster, *Callistemon citrinus*, potted chinchinchee and chrysanthemum (21–24)

Number of spikes per plant

The results indicated that different treatment combinations have a significant effect on the number of spikes per plant. The increase in the number of spikes per plant (14.84) was observed in SPT₂ i.e., seed priming with cow dung slurry for 24 hr whereas the minimum number of spikes per plant (11.51) was observed in SPT₁ i.e., control (Table 1). Data enumerated in Table 2 reveals the maximum number of spikes per plant (15.42) with foliar application of paclobutrazol, PD₃ i.e., 10 ppm. The minimum number of spikes per plant (11.99) was observed in PD₁ i.e., plants sprayed with 0 ppm paclobutrazol. Further data in Table 3 also revealed that the interaction effect of seed priming treatments along with the doses of paclobutrazol have significant impact on the number of spikes per plant. The maximum number of spikes per plant (16.83) was observed in SPT₂ PD₃ (i.e., seed priming with cow dung slurry for 24 hr+ 10 ppm paclobutrazol), whereas the minimum (10.33) number of spikes per plant was observed in SPT₁PD₁ (i.e., no seed priming + 0 ppm paclobutrazol). The salvia plants grown from the seed lot subjected to priming in cow dung slurry for 24 hr could produce the greatest number of vegetative shoots, which subsequently developed into reproductive shoots. As a result, each plant generated more spikes. The slurry of cow dung contains plant growth-promoting rhizobacteria, which help in converting the nutrients from non-available to available forms, besides ensuring their easy uptake by the plants, there were more inflorescences in salvia plants (29). Also, optimum dosage of paclobutrazol resulted in the highest plant spread, a greater number of branches per plant, hence more spikes were produced per plant. In Antirrhinum, the author also recorded a greater number of spikes per plant with the application of paclobutrazol (35).

Spike length

The data presented in Table 4 reveals a significant effect of different treatment combinations on the length of the spike. The increase in spike length (14.35) was observed in SPT₂ i.e., seed priming with cow dung slurry for 24 hr whereas the minimum spike length (12.73) was observed in SPT₁ i.e., control. Contents of data presented in Table 5 indicated an increase in spike length (16.31) with foliar application of paclobutrazol, PD₃ i.e., 0 ppm, whereas the minimum spike length (11.39) was observed in PD₄ i.e., plants sprayed with 20 ppm paclobutrazol. The data reflected in Table 6 showed that the interaction effect of seed priming treatments along with the doses of paclobutrazol have significant influence on

Table 4. Effect of different seed priming treatments on flowering and yield of salvia (Pooled data of 2 years)

Treatment details	Spike length (cm)	Number of florets per spike	Number of pods per plant	Seed yield per plant (g)	Seed yield per plot (g)
Seed priming treatments					
Control (No Priming)	12.73	48.33	288.46	3.87	34.83
Cow Dung Slurry (24 hr)	14.35	55.10	472.90	6.52	59.03
Cow Urine at 10 % (12 hr)	13.26	51.01	388.28	5.61	50.45
GA ₃ at 150 Ppm (12 hr)	13.67	53.43	451.24	6.24	55.75
CD _{0.05}	0.27	0.61	10.03	0.03	0.26
SE(m)	0.10	0.22	3.55	0.01	0.09

Table 5. Effect of foliar application of paclobutrazol on flowering and yield of salvia (Pooled data of 2 years)

Treatment details	Spike length (cm)	Number of florets per spike	Number of pods per plant	Seed yield per plant (g)	Seed yield per plot (g)
Paclobutrazol doses					
Control (0 ppm)	16.31	58.19	276.72	3.81	34.29
Paclobutrazol (5 ppm)	13.50	53.38	446.07	6.12	54.51
Paclobutrazol (10 ppm)	12.81	50.31	460.80	6.48	58.27
Paclobutrazol (20 ppm)	11.39	45.99	404.09	5.82	53.09
CD _{0.05}	0.27	0.61	10.03	0.03	0.53
SE(m)	0.10	0.22	3.55	0.01	0.09

Table 6. Interaction effect of different seed priming treatments and foliar application of paclobutrazol on flowering and yield in salvia (Pooled data of 2 years)

Treatment details	Spike length (cm)	Number of florets per spike	Number of pods per plant	Seed yield per plant (g)	Seed yield per plot (g)
Seed priming treatments × paclobutrazol doses					
SPT ₁ × PD ₁	14.67	55.28	223.07	3.22	10.33
SPT ₁ × PD ₂	12.85	50.50	316.23	4.10	11.50
SPT ₁ × PD ₃	12.10	44.37	333.67	4.38	13.13
SPT ₁ × PD ₄	11.29	43.17	280.87	3.79	11.07
SPT ₂ × PD ₁	17.31	60.67	337.81	4.59	12.53
SPT ₂ × PD ₂	13.99	55.43	536.00	7.26	15.37
SPT ₂ × PD ₃	13.76	54.33	546.03	7.36	16.83
SPT ₂ × PD ₄	12.35	49.97	471.77	6.84	14.62
SPT ₃ × PD ₁	16.75	56.93	269.93	3.69	12.00
SPT ₃ × PD ₂	13.37	52.77	410.39	6.02	14.07
SPT ₃ × PD ₃	12.54	48.83	477.41	6.91	15.30
SPT ₃ × PD ₄	10.62	45.50	395.40	5.81	13.78
SPT ₄ × PD ₁	16.50	59.87	276.07	3.74	12.37
SPT ₄ × PD ₂	13.78	54.80	521.66	7.10	14.95
SPT ₄ × PD ₃	12.83	53.70	538.90	7.27	16.40
SPT ₄ × PD ₄	11.30	45.33	468.31	6.82	14.23
CD _{0.05}	0.54	1.23	20.07	0.06	0.48
SE(m)	0.19	0.44	7.10	0.02	0.19

SPT₁: Control (No priming), SPT₂: Cow dung slurry (24 hr), SPT₃: Cow urine at 10 % concentration (12 hr), SPT₄: GA₃ at 150 ppm (12 hr), PD₁: Control (0 ppm), PD₂: Paclobutrazol at 5 ppm, PD₃: Paclobutrazol at 10 ppm, PD₄: Paclobutrazol at 20 ppm

spike length. The maximum spike length (17.31) was observed in SPT₂ PD₁ (i.e., seed priming with cow dung slurry for 24 hr + 0 ppm paclobutrazol), the minimum (11.29) spike length was observed in SPT₁PD₄ i.e., No seed priming + 20 ppm paclobutrazol).

Seeds primed with cow dung slurry for 24 hr resulted in producing the tallest plants as well as spikes of longer length. This might be due to the synthesis of auxins and gibberellins at a higher ratio, which could accelerate faster cell division and enlargement of cells, leading to the production of the longest spikes. The results agree with those obtained in fodder maize and carrot (14, 15)

With an increase in the concentration of paclobutrazol, there was a subsequent decrease in the length of spikes, which could be due to an alteration in the isoprenoid pathway, leading to an increase in the endogenous levels of abscisic acid and cytokinins and blockage of GA biosynthesis. Shorter spikes may reduce internal photo competition assimilates and improve resource retention within developing floral organs, thereby supporting effective flower retention and seed development. The reduction in spike length observed under paclobutrazol treatment is consistent with earlier reports in *Salvia splendens* and black iris, where inflorescence elongation was similarly restricted without compromising reproductive performance (16, 17)

Number of florets per spike

A thorough analysis of the data presented in Table 4 indicated that the application of various treatment combinations has statistically significant impacts on the production of the number of florets per spike. Among the seed priming treatments, SPT₂, i.e., seed priming with cow dung slurry for 24 hr produced the maximum (55.10) number of florets per spike, whereas the minimum number of florets per spike (48.33) was observed in SPT₁, i.e., control. Data enumerated in Table 5 reveals the maximum number of florets per spike (58.19) with PD₁, i.e., 0 ppm paclobutrazol. The minimum number of florets per spike (45.99) was observed in PD₄, i.e., plants sprayed with 20 ppm paclobutrazol. Upon examination of the data presented in Table 6, also revealed that the concurrent application of different seed priming and foliar spray treatments of paclobutrazol significantly influenced the number of florets per spike. Notably, SPT₂ PD₁ (i.e., seed priming with cow dung slurry for 24 hr + 0 ppm

paclobutrazol) shows an increase (60.67) in the number of florets per spike and treatment combination and SPT₁PD₄ (i.e., no seed priming + 20 ppm paclobutrazol) shows a decrease (43.17) in the trend of number of florets per spike.

The notable increase in the production of maximum florets in the spikes of salvia plants can be attributed to the fact that using the seeds primed with cow dung slurry for establishing a good crop stand of salvia plants might have resulted in the production of longer spikes, which offered a profuse induction of florets accordingly. Likewise, the increasing doses of paclobutrazol had displayed inverse relations with spike length, maximum spike length and the number of florets produced in each spike. In general, the salvia plants treated with the highest doses of paclobutrazol resulted in the production of the smallest spikes with the induction of a lower count of florets in them in comparison to those salvia plants that did not experience the spray of paclobutrazol. So much so, there was a decreasing trend in the pattern of plant height and spike length including count of florets in every spike with increase in the dosage of paclobutrazol and this may be attributed to the reduction in plant growth by inhibiting the bio synthesis of gibberellin, which leads to decrease in internodal length and expanding the meristematic cells in the internodes hence reduced spike length. Comparable patterns of inflorescence growth regulation under paclobutrazol application have also been reported in China aster (21).

Number of pods per plant

Various seed priming treatments and foliar application of paclobutrazol have exhibited a significant impact on the number of pods per plant. Among the seed priming treatments, SPT₂, i.e., seed priming with cow dung slurry for 24 hr produced the maximum (472.90) number of pods per plant, whereas SPT₁, i.e., no seed priming, produced the lowest (288.46) number of pods per plant. Among the foliar sprays of paclobutrazol, the maximum (460.80) number of pods per plant was observed in PD₃, i.e., foliar application of paclobutrazol at 10 ppm and the minimum (276.72) number of pods per plant was produced in PD₁, i.e., control. The data presented in Table 6 reveals that the interaction effect of seed priming treatments along with the doses of paclobutrazol have significant influence on the number of pods per plant. The maximum number of pods per plant (546.03) was observed

in SPT₂PD₃ (i.e., seed priming with cow dung slurry for 24 hr+ 10 ppm paclobutrazol), whereas the minimum (223.07) number of pods per plant was observed in SPT₁PD₁ (i.e., control).

The highest number of pods per plant in the treatment SPT₂ might be ascribed to the production of a greater number of branches, spikes and induction of maximum florets of better quality. As a result, these florets after pollination could ensure the development of fruits, i.e. pods in adequate quantities. Hence, resulting in a greater number of pods per plant. Paclobutrazol, a growth inhibitor, increases the number of laterals through an array of potential mechanisms, leading to the production of more spikes and flowers over a time and ultimately more pods per plant. It prolonged the onset of the flowering, encouraging additional flower bud formation and subsequently, the pods as well. The life span of the flower is further prolonged by paclobutrazol sprays by delaying leaf senescence and enabling additional time for pollination and pod development. The increase in pod number under paclobutrazol application at 10 ppm is a key indicator of improved reproductive efficiency. Reduced vegetative sink demand, enhances assimilation availability during flowering, improving flower retention and pod set. Increased branching further provides additional sites for pod initiation, collectively strengthening reproductive sink capacity. Studies have demonstrated that PBZ improves pod retention by stabilising carbohydrate supply and reducing flower abscission during critical reproductive phases (10, 36). Optimal paclobutrazol application has been shown to enhance pod number per plant in sesamum and brassica, likely through improved assimilate partitioning toward reproductive sinks (37, 38).

Seed yield

Various seed priming treatments and foliar application of paclobutrazol doses have exhibited a significantly higher seed yield, as evidenced in Table 4. Among the seed priming treatments, the most substantial seed yield (6.52 g per plant and 59.03 g per plot) was achieved with seed priming using cow dung slurry for 24 hr (SPT₂). Conversely, the lowest seed yield (3.87 g per plant and 34.83 g per plot) was observed in the control (SPT₁). Concerning the data on foliar application of paclobutrazol, it was noted that treatment PD₃, i.e. paclobutrazol at 10 ppm, exhibited the highest seed yield (6.48 g per plant and 58.27 g per plot), whereas treatment PD₁ (i.e., control), resulted in the lowest seed yield (3.81 g per plant and 34.29 g per plot). The data presented in Table 6 revealed that the concurrent application of different seed priming treatments and foliar application of paclobutrazol significantly influenced seed yield. Notably, the treatment combination of SPT₂PD₃ resulted in the highest seed yield (7.36 g per plant and 66.20 g per plot). Conversely, the treatment combination SPT₁PD₁ resulted in the lowest seed yield (3.22 g per plant and 28.98 g per plot).

Seed yield improvement under cow dung slurry priming can be attributed to strengthened source establishment during early growth stages, improved nutrient uptake efficiency and enhanced microbial activity leading to better assimilation production and translocation. The combined effects of nutrients, beneficial microorganisms and microbial metabolites result in improved seed filling and final yield. The study is quite matchable with the findings proclaimed in sunflower and china aster by authors who recorded higher seed yield with jeevamrit treatment that might have accelerated plant growth, profuse flowering, increase in number of branches, flower heads and florets per capitulum, which in turn ensured higher seed yield (39, 40). The maximum seed yield with

foliar application of paclobutrazol at 10 ppm may be because of increased level of photosynthesis in the leaves due to high chlorophyll content, which might have led to the accumulation of stem and root dry matter, resulting in a higher quantum of florets and seed yield simultaneously. The enhancement of seed yield under a 10 ppm dose of paclobutrazol, despite reductions in plant height and spike length, clearly demonstrates the role of source-sink reallocation in yield determination. Paclobutrazol reduces investment in non-productive vegetative biomass and redirects assimilates toward developing seeds, thereby increasing harvest index. Additionally, PBZ has been reported to enhance chlorophyll stability and delay senescence, ensuring sustained photosynthate supply during seed filling (10, 11). Research reported that reported yield improvement under paclobutrazol treatment despite reduced vegetative growth in China aster and marigold (21, 41)

Conclusion

Based upon the outcomes of the investigation, it is concluded that seed priming with cow dung slurry for 24 hr in combination with foliar application of paclobutrazol at 10.0 ppm sprayed once at 40 days after transplanting can be recommended as a good production practice for *Salvia splendens* under mid-hill conditions of Himachal Pradesh. This treatment combination consistently improved plant growth, branching, flowering and seed yield, thereby enhancing overall crop performance. The use of cow dung slurry as a low-cost, locally available input, together with an optimum paclobutrazol dose, makes this approach suitable for adoption by commercial growers and seed producers. Further validation under different agro-climatic conditions would help in refining recommendations for wider adoption.

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Authors' contributions

AS participated in analysing the results of experiments carried out in the field experiment and in original draft writing. BSD and PS conceptualised and supervised the research. PK and R help in data analysis. All the authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interest to declare.

Ethical issues: None

References

1. Kandemir N. The morphological, anatomical and karyological properties of endemic *Salvia hypargela* Fich and Mey. (Lamiaceae) in Turkey. Pak J Bot. 2003;35:219–36.
2. Khan A, Rehman NU, Alkharfy KM, Gilani AH. Antidiarrheal and antispasmodic activities of *Salvia splendens* are mediated through activation of K⁺ channels. Bangladesh J Pharmacol. 2011;6(2):111–6 <https://doi.org/10.3329/bjp.v6i2.9156>

3. Hu D, Kawazoe K, Takaishi Y. Diterpenoids from *Salvia splendens*. *Phytochemistry*. 1997;46:781–4 [https://doi.org/10.1016/S0031-9422\(97\)00180-5](https://doi.org/10.1016/S0031-9422(97)00180-5)
4. Ashok AD, Velmurugan S. Review on seed production techniques in flowering ornamentals. *J Pharmacogn Phytochem*. 2020;9(5):190–8.
5. Ashraf M, Foolad MR. Pre-sowing seed treatment: a shotgun approach to improve germination, plant growth and crop yield under saline and non-saline conditions. *Adv Agron*. 2005;88:223–71 [https://doi.org/10.1016/S0065-2113\(05\)88006-X](https://doi.org/10.1016/S0065-2113(05)88006-X)
6. Paparella S, Araújo SS, Rossi G, Wijayasinghe M, Carbonera D, Balestrazzi A. Seed priming: state of the art and new perspectives. *Plant Cell Rep*. 2015;34:1281–93 <https://doi.org/10.1007/s00299-015-1784-y>
7. Chatterjee N, et al. On-farm seed priming interventions in agronomic crops. *Acta Agric Slov*. 2018;111:715–35 <https://doi.org/10.14720/aas.2018.111.3.19>
8. Zulfiqar F. Effect of seed priming on horticultural crops. *Sci Hortic (Amsterdam)*. 2021;286:110197 <https://doi.org/10.1016/j.scienta.2021.110197>
9. Gupta Y, Kaintura P. Response of paclobutrazol as spray and drench on pot-grown fuchsia cv. Pink Galore. *J Plant Sci Res*. 2017;2:13–7.
10. Desta B, Amare G. Paclobutrazol as a plant growth regulator. *Chem Biol Technol Agric*. 2021;8:1–15 <https://doi.org/10.1186/s40538-020-00199-z>
11. Kumar S, et al. Paclobutrazol treatment as a potential strategy for higher seed and oil yield in field-grown *Camelina sativa* L. *BMC Res Notes*. 2012;5:137 <https://doi.org/10.1186/1756-0500-5-137>
12. Panse VG, Sukhatme PV. *Statistical Methods for Agricultural Workers*. New Delhi: Indian Council of Agricultural Research; 2000. p. 157–65.
13. Sheoran OP. OPSTAT: Online statistical analysis tool. Hisar: CCS Haryana Agricultural University; 2006.
14. Rahman SME, Islam MA, Rahman MM, Oh DH. Effect of cattle slurry on growth, biomass yield and chemical composition of maize fodder. *Asian-Australas J Anim Sci*. 2008;21(11):1592–8 <https://doi.org/10.5713/ajas.2008.80190>
15. Jeptoo A, Aguyoh JN, Saidi M. Improving carrot yield and quality through the use of bio-slurry manure. *Sustain Agric Res*. 2013;2(1):164–72 <https://doi.org/10.5539/sar.v2n1p164>
16. Mao L, Gao Y, Yao Y, Qien Y, Tang Y. Dwarfing effects of paclobutrazole, daminozide and chlormequat on potting scarlet sage. *Acta Hortic Sin*. 1991;18(2):177–9.
17. Al-Khassawneh NM, Karam NS, Shibli RA. Growth and flowering of black iris (*Iris nigricans* Dinsm.) following treatment with plant growth regulators. *Sci Hortic (Amsterdam)*. 2006;107(2):187–93 <https://doi.org/10.1016/j.scienta.2005.10.003>
18. Keever GJ, Kessler JR. Paclobutrazol effects on bedding plants during production, shipping and the retail environment when applied in production. *J Environ Hortic*. 2008;26(2):123–7 <https://doi.org/10.24266/0738-2898-26.2.123>
19. El-Aal M, Mohamed Y. Effect of pinching and paclobutrazol on growth, flowering, anatomy and chemical composition of potted geranium (*Pelargonium zonale* L.). *Int J Plant Soil Sci*. 2017;17(6):1–22 <https://doi.org/10.9734/IJPSS/2017/34527>
20. Giradharala RB, Purohit VL. Effect of fresh cow dung slurry soil application on growth and quality parameters of okra (*Abelmoschus esculentus* L. Moench) fruits. *Pharma Innov J*. 2022;11(11):1763–7.
21. Padmini K, Janakiram, Naik LB. Effect of nutrients and growth regulators on seed yield in China aster (*Callistephus chinensis*) cv. Poornima. *Indian J Agric Sci*. 2013;83(3):349–51.
22. Abo-Elhasan JA, Mohamed AT, Darwish MA, Mahgoub MH. Effect of paclobutrazol and growing media on vegetative growth, flowering and total carbohydrates of *Callistemon citrinus*. *Middle East J Agric Res*. 2018;7(3):826–35.
23. Banswal AK, Dilta BS, Sharma BP, Baweja HS, Gupta YC. Effect of bulb sizes, growing substrates and paclobutrazol doses on potted chinchinchee (*Ornithogalum thyrsoides* Jacq.). *Indian J Hortic*. 2015;72(2):257–61 <https://doi.org/10.5958/0974-0112.2015.00048.1>
24. Chauhan V, Bohra M, Tomar R, Dobhal N. Effect of paclobutrazol and daminozide on floral attributes of chrysanthemum (*Dendranthema grandiflora*). *Int J Curr Microbiol Appl Sci*. 2021;10(2):2754–9 <https://doi.org/10.20546/ijcmas.2021.1002.304>
25. Tiwari JK, Singh RP. Effect of pre-planting GA₃ treatment on tuberose. *J Ornamental Hortic*. 2002;5:44–5.
26. Ramzan F, Younis A, Riaz A, Ali S, Siddique MI, Lim KB. Pre-planting exogenous application of gibberellic acid influences sprouting, vegetative growth, flowering and subsequent bulb characteristics of 'Ad-Rem' tulip. *Hortic Environ Biotechnol*. 2015;55:479–88 <https://doi.org/10.1007/s13580-014-0113-7>
27. Pangtu S, Sharma BP, Dilta BS, Chaudhary SVS. Effect of seed priming on growth and flowering of China aster (*Callistephus chinensis* L.) Nees. *Agric Inl*. 2018;5(1):38–42 <https://doi.org/10.5958/2454-8634.2018.00007.4>
28. Magnitskiy SV. *Controlling seedling height by treating seeds with plant growth regulators* [dissertation]. Columbus (OH): The Ohio State University; 2004.
29. Bisht P, et al. Effect of different treatment modules on seed yield and quality in African marigold (*Tagetes erecta* L.). *Int J Plant Soil Sci*. 2023;35(14):42–50 <https://doi.org/10.9734/ijpss/2023/v35i143019>
30. Ibrahim H, Aniyikaye R, Adewoyin DTE, Osunde AO, Bala A. Effect of different combinations of organic and inorganic nitrogen sources on growth and pod yield of okra (*Abelmoschus esculentus* L.). *Colloquia SSSN*. 2020;44:243–8.
31. Cline MG. Apical dominance. *Bot Rev*. 1991;57(4):318–58 <https://doi.org/10.1007/BF02858771>
32. Leyser O. Regulation of shoot branching by auxin. *Trends Plant Sci*. 2003;8(11):541–5 <https://doi.org/10.1016/j.tplants.2003.09.008>
33. Domagalska MA, Leyser O. Signal integration in the control of shoot branching. *Nat Rev Mol Cell Biol*. 2011;12(4):211–21 <https://doi.org/10.1038/nrm3088>
34. Chauhan V, Bohra M, Tomar R, Dobhal N. Effect of paclobutrazol and daminozide on vegetative attributes of China aster (*Callistephus chinensis*) cv. Poornima. *Indian J Agric Sci*. 2020;83(3):349–51.
35. Wainwright H, Irwin HL. The effects of paclobutrazol and pinching on Antirrhinum flowering pot plants. *J Hortic Sci*. 1987;62(3):401–4 <https://doi.org/10.1080/14620316.1987.11515798>
36. Rademacher W. Growth retardants: effects on gibberellin biosynthesis and other metabolic pathways. *Annu Rev Plant Physiol Plant Mol Biol*. 2000;51:501–31 <https://doi.org/10.1146/annurev.arplant.51.1.501>
37. Ahmed S, et al. Shattering and yield expression of sesame (*Sesamum indicum* L.) genotypes influenced by paclobutrazol concentration under rainfed conditions of Pothwar. *Plant Biol (Stuttg)*. 2023;23:1–13 <https://doi.org/10.1186/s12870-023-04145-7>
38. Setia RC, Kaur P, Setia N, Anuradha. Influence of paclobutrazol on growth and development of fruit in *Brassica juncea* (L.) Czern and Coss. *Plant Growth Regul*. 1996;20:307–16 <https://doi.org/10.1007/BF00043323>
39. Manjunatha GS, Upper SN, Pujari BT, Yeledahalli NA, Kuligod VB. Effect of farmyard manure treated with jeevamrutha on yield attributes, yield and economics of sunflower (*Helianthus annuus* L.). *Karnataka J Agric Sci*. 2009;22:198–9.
40. Pathania S, Dilta BS, Kumar A. Response of biostimulants on growth, flowering, seed yield and quality of China aster (*Callistephus chinensis* (L.) Nees). *Int J Bioresour Stress Manag*. 2023;14(8):1108–15 <https://doi.org/10.23910/1.2023.3552>
41. Singh MK, Hemlata P. Effect of foliar application of GA₃ and micro-elements on vigour and flowering behaviour of African marigold (*Tagetes erecta*) cv. Double African Yellow. *J Nat Resour Dev*. 2016;11(2):70–3.

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