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Optimization of gibberellic acid dose for mungbean (*Vigna radiata*) under hot arid climate

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ABSTRACT

The present study was carried out during rainy (*kharif*) seasons of 2018, 2019 and 2020 at the Agricultural Research Station, Mandor, Agriculture University, Jodhpur, Rajasthan to optimize the application rate of gibberellic acid during critical growth stages to enhance mungbean [*Vigna radiata* (L.) R. Wilczek] yield and economic returns. The experiment was conducted in a randomized block design (RBD) comprised of 8 treatments, viz. T_1, Absolute control; T_2, Water spray at flowering and pod initiation; T_3, GA_3 at 30 ppm spray at flowering initiation; T_4, GA_3 at 30 ppm spray at pod initiation; T_5, GA_3 at 45 ppm spray at flowering initiation; T_6, GA_3 at 45 ppm spray at pod initiation; T_7, GA_3 at 30 ppm spray at both flowering and pod initiation; and T_8, GA_3 at 45 ppm spray at both flowering and pod initiation, replicated thrice. Results indicated that the foliar application of GA_3 at 45 ppm during flowering and pod initiation (T_8) led to a significant increase of 36.26% in the number of pods/plant compared to the control. Additionally, both the T_8 treatment and T_7 showed statistically comparable effects on plant height, seeds/pod, root nodules/plant and biological yield. The seed yield increased significantly by 36% with the foliar application of GA_3 at 45 ppm during flowering and pod initiation compared to the control. Moreover, the sustainability yield index (SYI) and production efficiency (PE) were notably higher with the application of GA_3 at 45 ppm during flowering and pod initiation (T_8), demonstrating a 1.4-fold increase in each parameter relative to the control. This treatment also yielded higher net returns of ₹63,853/ha and a benefit-cost ratio (B:C) ratio of 3.9, surpassing the other treatments. These findings emphasize the critical role of GA_3 in promoting sustainable agricultural practices, highlighting its potential to enhance crop productivity and economic viability in the challenging agricultural environment of arid regions.

Keywords: Gibberellic acid, Mungbean, Production efficiency, Sustainability yield index

Mungbean [*Vigna radiata* (L.) R. Wilczek] is a highly valued crop in the human diet, renowned for its nutritional content and protein richness compared to cereals. It possesses the remarkable ability to fix atmospheric nitrogen through root nodules, and enhances soil quality and fertility (Sengupta and Tamang 2015). It's well-suited for cultivation in areas with limited water resources, as it is a drought resistant crop that thrives under conditions of soil moisture stress (Yadav *et al.* 2017). Mungbean is grown across almost all states of India, making the country the largest global producer of this pulse. In the *kharif* season of 2022–23, India produced 17.5 lakh tonnes of mungbeans, covering an area of 33.37 lakh ha, with a productivity of 524 kg/ha (source: agricoop.nic). Over the past two decades, In Rajasthan, a significant growth has been seen in mungbean cultivation, where it is now cultivated on approximately 21.66 lakh hectares and production of 13.22 lakh tonnes, with a productivity of 610 kg/ha (source: tourism.rajasthan.gov.in).

Moisture stress has a significant impact on plant physiological and biochemical processes ultimately leading to hampered plant growth and reduced crop yields. These challenges are crucial for achieving sustainable crop production in the face of changing agricultural needs and environmental conditions. The ability of crops to withstand such moisture stress is of paramount economic importance (Amarapalli 2022). Gibberellic Acid (GA_3) is a prominent plant growth regulator known for its versatile role in enhancing various physiological processes in plants. It is widely utilized for its ability to break seed dormancy, thereby promoting germination. By stimulating internodal elongation, GA_3 effectively increases plant height, which is particularly beneficial in crops where vertical growth is advantageous. Additionally, GA_3 fosters cell division in the cambial zone, contributing to the thickening of stems and the overall robustness of the plant structure. This growth regulator is instrumental in modulating several developmental processes, making it a valuable tool in both agricultural and horticultural practices (Yamaguchi 2008,

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Yang *et al.* 2010, Ansari *et al.* 2013, Shariatmadari *et al.* 2017, Du *et al.* 2022).

The literature reveals a scarcity of research on the application of GA_3 in mungbean under such conditions. Based on the attributes of GA_3, we hypothesized that the judicious application of GA_3 could enhance mungbean productivity and economic viability. Therefore, a study was planned to identify the optimal dosage of gibberellic acid (GA_3) to enhance mungbean growth, yield and economic viability under the hot arid climatic conditions of western Rajasthan.

MATERIALS AND METHODS

Locality and soil description: The experiment was conducted during rainy (*kharif*) seasons of 2018, 2019 and 2020 at the Agricultural Research Station, Mandor, Agriculture University, Jodhpur (26° 15' N to 26° 45' N and 73° 00' E to 73° 29' E), Rajasthan. This experimental site falls within the agro-climatic zone Ia (Arid Western Plains Zone) of Rajasthan. The average annual rainfall in the area is approximately 367 mm, with about 85–90% of this rainfall occurring from June–September, primarily attributed to the south-west monsoon (Fig. 1 and 2). The soil used in the experiment was loamy sand, characterized by low nitrogen levels (184 kg/ha), medium levels of phosphorus (24 kg/ha), and high levels of potassium (325 kg/ha). The soil was found to be saline, with a *p*H of around 8.1 and an electrical conductivity (EC) of 0.632 dS/m.

Experimental details: The experiment was conducted in a randomized block design (RBD) comprised of 8 treatments, viz. T_1, Absolute control; T_2, Water spray at flowering and pod initiation; T_3, GA_3 at 30 ppm spray at flowering initiation; T_4, GA_3 at 30 ppm spray at pod initiation; T_5, GA_3 at 45 ppm spray at flowering initiation; T_6, GA_3 at 45 ppm spray at pod initiation; T_7, GA_3 at 30 ppm spray at both flowering and pod initiation; and T_8, GA_3 at 45 ppm spray at both flowering and pod initiation, replicated thrice. Each individual plot measured 3.0 m × 4.0 m (12.0 m²). Land preparation involved mechanical methods, including ploughing and harrowing, to create a smooth soil surface that enhances seed germination and fertilizer management throughout all growing seasons. Mungbean variety GM 4 was sown with a spacing of 30 cm × 10 cm. The recommended fertilizer doses (RDF) for mungbean were 10:40:00 kg/ha of N: P_2O_5. Nitrogen and phosphorus fertilizers were uniformly applied at the time of sowing across all plots. The crop was sown on June 28, July 23, and July 7, and harvested on September

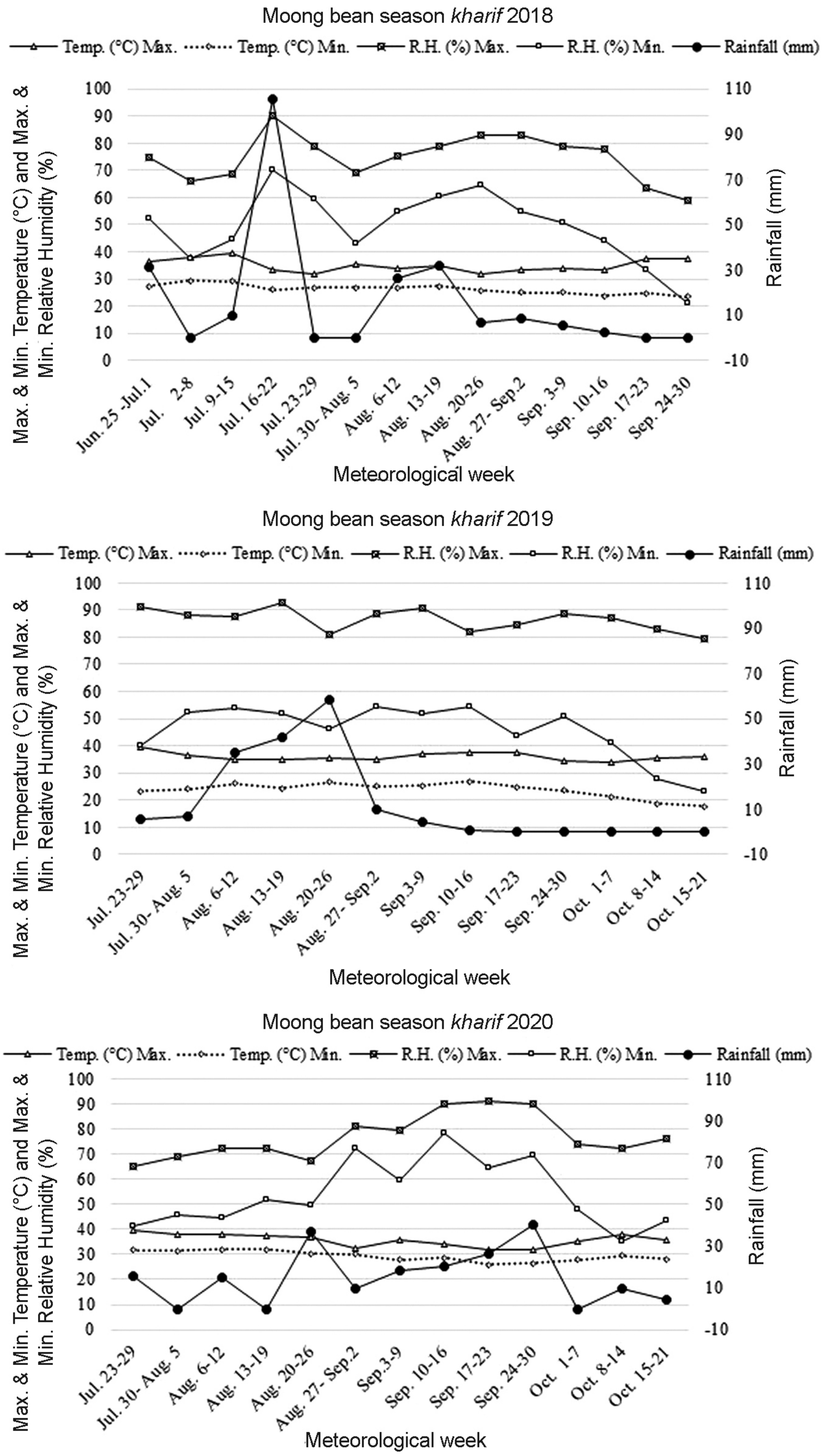

Fig. 1 Meteorological data of *kharif* season 2018, 2019 and 2020.

25, October 19, and September 25 during the *kharif* 2018, 2019, and 2020, respectively. The total crop growth period (CGP), defined as the duration from sowing to physiological maturity, varied among the seasons, with durations of 89, 88, and 80 days (mean of 86 days, CV of 4.70%) for the mungbean crop.

Biometric observations: Growth and yield parameters, including the number of branches/plant, pods/plant, seeds/pod, and root nodules/plant, were recorded from five randomly selected plants within the net plot. Additionally, seed yield and total biomass were measured from the net plot, and the net plot yield was then converted to a hectare basis.

Sustainability and efficiency indices: The Sustainability Yield Index (SYI), represented by the symbol 'η,' was used to assess the minimum guaranteed yield compared to the maximum yield observed for mung beans over several years. This index, introduced by Vittal *et al.* (2003), serves as a tool for evaluating sustainable agricultural practices in mungbean cultivation. It offers important insights into how well mungbean yields can be maintained over a specified period.

The Sustainability yield index (SYI) was calculated as:

$$\eta_t = (Y_t - \sigma)/Y_{max}$$

where, Y_t, Estimated mean yield for year t; σ is the estimated standard deviation; and $Y_{max,}$ Observed maximum yield. An SYI value close to 1.0 indicates an ideal scenario where maximum crop yields can be sustained over multiple years, while a deviation from 1.0 signifies losses in sustainability.

Production efficiency (PE) was calculated by dividing the total crop production by the total number of days the crop was grown during the season.

Monetary efficiency: The economic analysis of mungbean cultivation was determined by recording the prevailing market prices for various inputs and outputs. The gross returns (₹/ha) were calculated based on the seed and stover yields for each treatment. Using the itemized prices for the corresponding years, the cost of cultivation for each treatment was determined. The net returns (₹/ha) for each treatment were obtained by subtracting the total cost of cultivation from the gross returns of the respective treatment. The benefit-cost ratio (B: C) for each treatment was calculated as:

$$\text{Benefit cost ratio} = \frac{\text{Net realization (₹/ha)}}{\text{Total cost of cultivation (₹/ha)}}$$

Statistical analysis: Results are presented as the mean values of the replications. Analysis of variance (ANOVA) was carried out using OPSTAT software. Mean comparisons were conducted using the critical difference (CD) method at a significance level of $P \leq 0.05$. Homogeneity of variance for all traits was verified using Bartlett's test. A pooled analysis for the three years was performed following the methodology described by Panse and Sukhatme (1985).

RESULTS AND DISCUSSION

Effect of growth regulator on growth and yield attributes: In order to quantify the consequences perceived due to growth regulators, the plant growth and yield attributes were assessed. In the present study, growth and yield parameters, viz. branches/plant, root nodules/plant, seeds/pod, pods/plant and test weight of mungbean were significantly increased with application of different dose of growth regulator at different growth stages (Table 1). Application of GA_3 @30 ppm at flowering and pod initiation (T_7) significantly enhanced the branches/plant and showed non-significant response to GA_3 @45 ppm spray at flowering and pod initiation (T_8) and GA_3 @45 ppm spray at flowering initiation (T_5). Foliar spray of GA_3 @45 ppm at flowering and pod initiation (T_8) gave significantly highest pods/plant (37.2) but in case of seeds/pod and root nodules/plant, GA_3 @45 ppm at flowering and pod initiation (T_8) and GA_3 @30 ppm at flowering and pod initiation (T_7) applied plants had an additive effect and recorded increased seeds/pod (15% and 11%), root nodules/plant (28% and 19%) as compared to absolute control which produced least numbers with values of 10.7 and 20.1, respectively. Test weight of grains was significantly enhanced due to application of GA_3 as compared to absolute control and sole water spray and recorded in the range of 45.9–46.8 g.

The findings of the present study confirm the alteration in growth and yield attributes in response to foliar application of GA_3. The probable reason behind that gibberellins (GA_3) promote the elongation of stems and roots, expansion of leaves, flowering, fruit senescence, and seed germination/dormancy. They trigger the transcription of genes assembled with cell

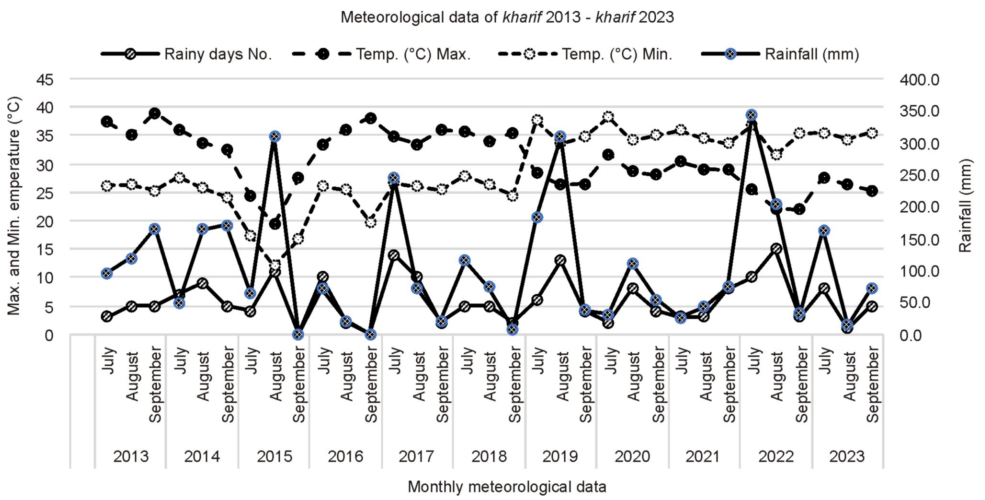

Fig. 2 Average meteorological data from *kharif* 2013–2023.

Table 1 Effect of growth regulator on growth, yield attributes and yield of mungbean (Pooled data of three years)

Treatment	Branches/ plant	Root nodules/ plant	Pods/ plant	Seeds/ pod	Test weight (g)	Seed yield (t/ha)	Biological yield (t/ha)	Harvest index (%)
T_1	5.4	20.13	27.3	10.7	44.9	0.89	2.11	42.3
T_2	5.5	22.49	28.6	10.9	45.3	0.94	2.21	42.9
T_3	6.1	21.63	35.7	11.4	45.9	1.17	2.63	44.6
T_4	6.1	23.22	32.7	11.1	45.9	1.07	2.46	43.2
T_5	6.2	20.88	34.9	11.6	46.1	1.16	2.65	44.1
T_6	6.0	24.00	33.7	11.3	46.1	1.10	2.54	43.0
T_7	6.5	23.11	35.2	11.9	46.5	1.20	2.74	43.6
T_8	6.4	25.69	37.2	12.3	46.8	1.22	2.81	43.3
SEm±	0.1	0.68	0.6	0.2	0.3	0.02	0.04	0.83
CD (P=0.05)	0.3	1.98	1.7	0.5	1.0	0.06	0.12	NS
CV (%)	4.8	7.40	5.4	4.5	2.3	5.87	5.0	5.7

Treatment details are given under Materials and Methods.

division and elongation during growth and enhance the expression of hydrolytic enzymes that convert starch into sugar (Manjari *et al.* 2018). Likewise, increased growth and yield parameter were recorded under crop plants sprayed with GA_3 @100 ppm (Prakash *et al.* 2019, Haritha *et al.* 2020). Similar findings were reported by Dawar (2019) and Panchal and Prajapat (2019) in different varieties of mungbean. This might be due to that gibberellins have role in cell multiplication, elongation, and metabolic pathways of protein synthesis and also improves nutrient uptake from the soil (Rahman *et al.* 2018). In the present study, a notable upward trend in the number of nodules was observed. This increase in root nodules can be attributed to the significant improvements achieved through foliar GA_3 application (Navya *et al.* 2021). Furthermore, prior studies have shown that plant growth regulators (PGRs), such as GA_3, play a crucial role in influencing the source and sink dynamics of field crops. They contribute to the improved distribution and transportation of accumulated nutrients (Mustafa *et al.* 2016).

Effect of growth regulator on yield: The most promising results were obtained due to application of GA_3 @45 ppm spray at flowering and pod initiation during crop season 2018, 2019 and 2020 as well as in pooled results (Table 1 and Fig. 3). Seed yield was significantly enhanced as 36, 34, 31 and 30% under treatment T_8, T_7, T_3 and T_5 which behaved statistically alike to each other's over control. Further, it was also noted that application of GA_3 @30 ppm spray at flowering and pod initiation (T_7) produced 1.64% lesser yield than treatment T_8 (GA_3 @45 ppm spray at flowering and pod initiation). The least increase (5%) in seed yield was recorded with the application of sole water (T_2) over control. Furthermore, 10% and 5% yield reduction was noted under single application (T_6 and T_5) as compared to two application of GA_3@45 ppm (T_8). With respect to total biomass, application of GA_3 @45 ppm spray at flowering and pod initiation (T_8) enhanced a significant yield over other treatments except GA_3 @30 ppm at flowering and pod initiation (T_7) and both the treatments gave the maximum increase in biological yield i.e. 33 and 30%, compared to absolute control. A significant variation was not found in harvest index due to different treatments of GA_3. GA_3 exerted a positive improvement on seed and biological yield (Rai *et al.* 2019). The results of present study were accordance with reported by Haritha *et al.* (2020) and Rafique *et al.* (2021). The increasing trends of seed yield and biological yields of greengram and blackgram were noted and also found that foliar spray of

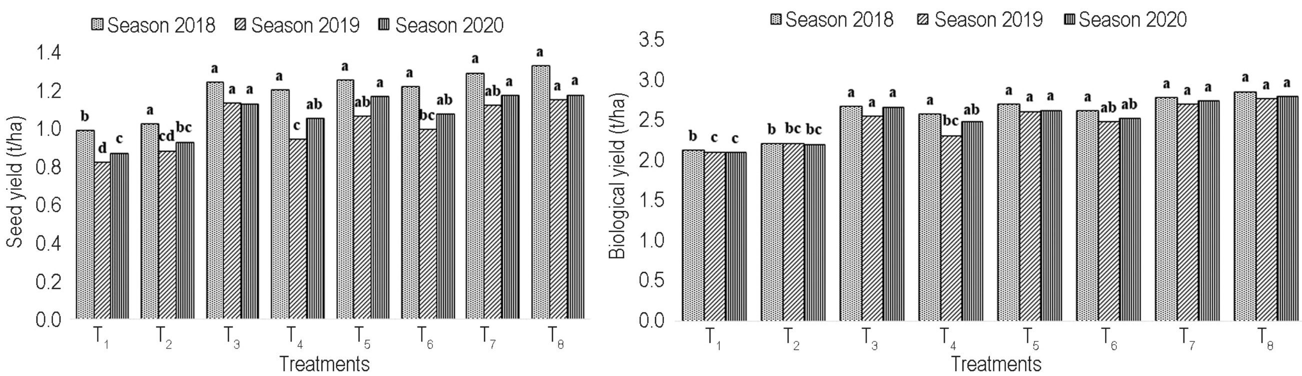

Fig. 3 Effect of growth regulator on seed and biological yields of mungbean during *kharif* 2018, 2019 and 2020.

Table 2 Effect of growth regulator on crop efficiency and economics of mungbean (Pooled data of three years)

Treatment	SYI*	PE (kg/ ha/day)	Gross returns (₹/ha)	Net returns (₹/ha)	B:C ratio
T_1	0.56	10.45	63247	42893	3.1
T_2	0.59	11.04	66751	45197	3.1
T_3	0.76	13.65	82613	61389	3.9
T_4	0.63	12.47	75425	54201	3.6
T_5	0.73	13.60	82187	60828	3.8
T_6	0.68	12.82	77549	56191	3.6
T_7	0.77	13.97	84499	62405	3.8
T_8	0.78	14.25	86216	63853	3.9
SEm±	0.03	0.25	-	-	-
CD (P=0.05)	0.09	0.71	-	-	-
CV (%)	7.4	6.0	-	-	-

Treatment details are given under Materials and Methods. SYI, Sustainability yield index.

GA 120 and 150 ppm performed better (Iqbal *et al.* 2023 and Aninth and Singh 2024). The increased yield observed due to additive effect of enhancement in growth and yield attributing characters, improved by foliar application of GA_3 could potentially be attributed to amplified photosynthetic efficiency and boost up the capacity of the reproductive sinks to utilize the incoming assimilates (Range and Giri 2020). Average productivity of greengram of Jodhpur (Rajasthan) from *kharif* 2013–2023 suggested that maximum yield was recorded in 2014 (~900 kg/ha) followed by 2020 (~700 kg/ha). Average productivity was gradually increased from 2018–2020 (Supplementary Fig. 1).

Sustainability and efficiency indices: Irrespective of different doses of GA_3 at various stage, improvement in SYI with foliar spray of GA_3 was noticed in comparison to the control (Table 2). The SYI for mungbean was calculated over the three years (pooled) varied from 0.59 (T_2) to 0.78 (T_4) compared to 0.56 under absolute control (T_1). The SYI was higher in treatment comprising with GA_3 @45 ppm spray at flowering and pod initiation (T_8) i.e. 1.4 fold over absolute control (T_1) and remained significantly differed from application of GA_3 @30 ppm spray at flowering initiation (T_4) and water spray at flowering and pod initiation (T_2) rather than other treatments. The PE i.e. per day production of the mungbean, mirrored the yield responses to different treatments of GA_3 (Table 2). The mean PE of the crop, calculated over the three seasons varied from 10.45 kg/ha/day (T_1) to 14.25 kg/ha/day (T_8). Application of GA_3 @ 45 ppm spray at flowering and pod initiation (T_8) registered maximum PE and remained at par with treatments T_7, T_3 and T_5. Whereas, least values of PE was calculated with absolute control. The declining trend of SYI and PE was observed with other treatments of GA_3 might be due to inadequacy or sprayed at improper growth stages.

Effect on monetary efficiency: The economic analysis demonstrated that the application of varying doses of growth regulators at different growth stages resulted in favourable returns, offsetting the additional costs incurred. Specifically, the application of GA_3 at 45 ppm during flowering and pod initiation yielded the highest net returns (₹63,853/ha) and B:C ratio of 3.9, followed closely by the treatment involving GA_3 at 30 ppm during the same stages (T_8), which achieved net returns of ₹62,405/ha and a B:C ratio of 3.8. These results align with findings by Navya *et al.* (2021), who also reported increased monetary returns with the application of GA_3. Not using any growth regulator proved to be less cost-effective, resulting in lower returns and a lower B: C ratio compared to treatments involving the proper application of GA_3 at key plant growth stages (Table 2).

The mungbean is one of the most widely accepted crop for arid and semi-arid conditions. It is most responsive crop to exogenously applied growth regulators. The effect is varied with the concentration of GA_3 and as well as according to their growth stages with reference to growth and yield characters of mungbean. In present study application of $GA_3$was evaluated for optimizing dose and stage of foliar spray. From the three-year experimentation it can be concluded that mungbean crop sprayed with GA_3 @45 ppm at flowering and pod initiation enhanced growth, yield and economics of mungbean under moisture stress conditions. For producing maximum SYI and PE mungbean can also be sprayed with GA_3 @45 ppm at flowering and pod initiation.

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