

New approach to increasing rice (*Oryza sativa* L.) lodging resistance and biomass yield through the use of growth retardants

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Abstract

Yield reduction in paddy crop is quite high due to post heading lodging. Lodging is due to the interaction between susceptibility to the lodging of the plant and external force. Tall phenotypic feature of the plant is one of the major factors for crop lodging. In rice, the application of growth retardant can lessen crop height by reduction of internodes elongation. The present work evaluates the use of two plant growth regulators as mepiquat chloride and paclobutrazol, which are synthetic crop growth regulators that showed reliable stem shortening to combat abiotic stress. Experiment was carried out at Bidhan Chandra Krishi Viswavidyalaya during *Kharif* season of 2017 to 2019 in randomized block design with four replications comprised of ten treatments, which include five levels of mepiquat chloride (37.5, 50, 62.5, 75 and 100 g a.i. ha⁻¹), four levels of paclobutrazol (25, 50, 75 and 100 g a.i. ha⁻¹) and untreated control (water only). Application of plant growth retardants reduced internode and culm length and enhance culm diameter. Significantly more grain yield was observed with the mepiquat chloride @ 50 g a.i. ha⁻¹ (47.34 q ha⁻¹) and was at par with the paclobutrazol @ 25 g a.i. ha⁻¹ (44.09 q ha⁻¹) and paclobutrazol @ 50 g a.i. ha⁻¹ (45.94 q ha⁻¹). The result indicated that mepiquat chloride decreases plant height and the occurrence of lodging and likewise enhanced yield more than the control by 27 q ha⁻¹. The highest straw yield was obtained either at paclobutrazol @ 50 g a.i. ha⁻¹ and was at par only with the paclobutrazol @ 25 g a.i. ha⁻¹ and significantly superior to other treatments. More net return [(Rs. 35,421 ha⁻¹ and B:C (1.87)] observed with the mepiquat chloride @ 50 g a.i. ha⁻¹ and was closely followed by paclobutrazol @ 25 g a.i. ha⁻¹ and paclobutrazol @ 50 g a.i. ha⁻¹.

Keywords: Abiotic stress, growth retardant, internode, lodging, yield.

1. Introduction

Rice (*Oryza sativa* L.) is the most significant staple food in South East Asia, with an average of 32% of total energy intake (Mukherjee, 2015). This is an important staple crop feeding more than 65 percent of the inhabitants in India. Rice is grown on nearly 42.93 mha in India under different cropping sequence, with a production of 103.55 m ton and productivity of 2393 kg ha⁻¹ (Kaur *et al.*, 2019). Various abiotic stresses such as high salinity, crop lodging, low water availability, and nutrient deficiency are presently accountable for noteworthy losses in per unit productivity and decrease in the quality of world

wide rice production. These constraints can be overcome by the farming community by adopting zone specific suitable crop cultivars along with proper crop husbandry practices (Okuno *et al.*, 2014). Crop lodging is one of the most vital abiotic problems during the later phase of the crop life cycle in the north-eastern plain zone of India. Wind speed and torrential rain are mainly responsible for such incidence (Singh *et al.*, 2011; Zandalinas *et al.*, 2017). West Bengal, Assam and Bihar farmers are keen to grow Basmati varieties due to high demand for its excellent cooking quality, aroma and good return. Most of the

basmati/scented rice is tall and prone to lodging due to wind and rain in the later phases of crop life cycle (Singh *et al.*, 2011; Mukherjee 2017). Under the present scenario of crop diversification and decreasing underground water level in the state, cultivation of scented rice could be of great worth as it needs less irrigation over non scented rice, thus saving a lot of water. However, lodging becomes an imperative problem in West Bengal due to recurrent cyclone, heavy rain, thunder storm etc. Breaking/ bending of crop stem is one of the most concerning trouble faced by the farming community at global levels (Tams *et al.*, 2004; Dahiya *et al.*, 2018). Lodging severely affects rice grain production and quality. This will ultimately affect the global rice productivity (Saha *et al.*, 2019). Different growth regulators play vital roles in crop behavioural process, and reduced crop lodging problem to some extent (Rajendra and Jones 2009; Anjum *et al.*, 2011). The use of various growth stimulators such as paclobutrazol, mepiquat chloride or their compound, are fetching importance for good crop harvest.

Notable actions of plant growth regulators on crop physiology system had been well known in recent past (Pan *et al.*, 2013; Mukherjee 2019). This can modify growth of plant under different environment and showed a remarkable effect on reducing crop lodging. Paclobutrazol [(2RS, 3RS)-1-(4-chlorophenyl)-4-(4-dimethyl-2(1,2,4-triazol-1-yl)-pentan-3-yl)] is a member of the triazole plant-growth inhibitor group. This helps to improve resistance against various abiotic and biotic stresses, mainly fungal or bacterial infection, high and low temperature stress, drought etc. by sinking oxidative damage via increase of antioxidants or reduce the action of oxidative enzymes (Dong *et al.*, 2012). Paclobutrazol hinders IAA and GA₃, whilst enhances ethylene, cytokinin and abscisic acid assimilation in the crop physiological system (Fletcher *et al.*, 2000; Gu *et al.*, 2010). Commonly, paclobutrazol regulates crop morphological and physiological function mainly on reduction in shoot growth, root growth stimulation, improvement of chlorophyll content, net photosynthetic rate, and decrease of free-radical induced losses (Reddy *et al.*, 1996). Mepiquat chloride (N,N-dimethyl piperidinium chloride) is used as the active ingredient for reducing extreme vegetative expansion on lakh of acres of potatoes, sweet potatoes, cotton, grapes, wheat, tomatoes, onions and citrus (<https://patents.google.com/patent/US5705648A/en>). Rice

quality and yield are the result of the interface between a genotype latent expression and the surroundings, which is customized by crop husbandry practices in order to meet the goal of the farming community. Thus, improving rice yield by new agronomic methods and exogenous crop stimulator to reduce crop lodging will be need of the hour for maximizing rice yield under the new alluvial region. Foliar applied paclobutrazol and mepiquat chloride induce growth regulations have been reported in the past (Fletcher *et al.*, 2000). Moreover scanty information is known about the effect of this growth retardant under Indian context. Therefore, the present work was designed to investigate the effects of two different growth regulators on rice yield.

2. Materials and methods

The present study was conducted under the umbrella of Bidhan Chandra Krishi Viswavidyalaya during kharif seasons of 2017, 2018 and 2019 in lowland situations. The soil of the experimental plot was loamy in texture and with pH 7.1, organic carbon 0.69%, available nitrogen 288.9 kg, available phosphorus 20.8 and available potassium 254.3 kg ha⁻¹. The experiment was conducted in a randomized block design with ten treatments replicated four times. Treatments comprise of five levels of mepiquat chloride (37.5, 50, 62.5, 75 and 100 g a.i ha⁻¹), four levels of paclobutrazol (25, 50, 75 and 100 g a.i. ha⁻¹) and untreated control (water only). Rice variety 'Pusa Basmati 1121' was used at the rate of 30 kg ha⁻¹. Twenty-five days old seedlings were transplanted on 20th July during 2017, 22nd July during 2018 and 2019. Twenty-five days old seedlings were manually transplanted in line (2-3 seedlings hill⁻¹) with a spacing of 20 cm × 15 cm. Plant growth regulators were sprayed with knapsack sprayer fitted with hollow cone nozzle (500 l ha⁻¹) as per different treatments at 60 DAT (days after transplanting). The fertilizer dose was 80:40:40:25 kg ha⁻¹ of N:P₂O₅:K₂O:Zn in kharif season, respectively. Well rotten FYM @ 10 tonnes ha⁻¹ was applied at the time of the last ploughing. A full dose of P₂O₅, K₂O and half of the amount of nitrogen was applied through single super phosphate, muriate of potash and urea respectively as basal application. The remaining half amount of nitrogen was top-dressed in two equal splits at tillering and before the panicle initiation stage. Weeds were managed by use of butachlor @ 1.5 kg a.i. ha⁻¹ as pre-emergence three days after transplanting followed by two hand weedings at 30 and 50 DAT. The water level of 5 ± 2 cm was maintained all through the crop development

phase. All agronomic practices were performed uniformly for all the treatments. Plant height along with other growth parameters was measured in the field at 60 and 90 DAT. Lodging score was measured as per Islam *et al.* (2007). Internodal elongation, culm diameter and length were measured at the time of harvest. Length and diameters were measured based on Yoshida (1981). Harvesting was done from 05 to 15th December, depending upon the maturity of the plant in the respective year. At the time of harvesting, the grains were subjected to hard enough, having less than 16 percent moisture in the grains. The plant samples collected at harvest were dried at 70°C, powdered in Willey mill and digested to analyze the various nutrient compositions. The nitrogen, phosphorus and potassium content in plant parts were estimated by Nessler's reagent method (Nicholas and Nason, 1957), $\text{HNO}_3:\text{HClO}_4$ (9:4) digestion, colour development by Vanadomolybdate solution followed by spectrophotometer determination (Jackson, 1973) and flame photometric determination after digestion in $\text{HNO}_3:\text{HClO}_4$ (9:4) (Jackson, 1973), respectively. The nutrient uptake was estimated by multiplying the nutrient concentration with the grain and straw yield. Analysis of variance (ANOVA) for the randomized block design of three years was pooled by using the CoStat Software (Gomez and Gomez, 1984).

3. Results and discussion

3.1 Growth parameters

The application of different plant growth regulators as foliar spray significantly influenced crop growth as compared with untreated plants (Table 1). Use of mepiquat chloride @ 37.5 g a.i. ha⁻¹ resulted into taller plants and showed parity with control. Least plant height was found with the mepiquat chloride @ 100 g a.i. ha⁻¹ and was at par with the paclobutrazol @ 100 g a.i. ha⁻¹, and all other levels of mepiquat chloride application except mepiquat chloride @ 37.5 g a.i. ha⁻¹. However, at 90 DAT, the least plant height was observed with the paclobutrazol @ 100 g a.i. ha⁻¹ and showed parity with the paclobutrazol @ 75 g a.i. ha⁻¹, mepiquat chloride @ 75 g a.i. ha⁻¹ and mepiquat chloride @ 100 g a.i. ha⁻¹ and notably better to all other treatments regarding reducing plant height. Mepiquat chloride, being an anti-gibberellin usually cause a decrease in cell elongation. Similar findings of reduction in growth parameters due to mepiquat chloride were also reported earlier (Muthukumar *et al.*, 2005). The number of leaves

per hill did not show any statistical difference at 60 DAT, however, at 90 DAT, more number of leaves per hill were observed with the control and was at par with the paclobutrazol @ 50 g a.i. ha⁻¹ and mepiquat chloride @ 50 g a.i. ha⁻¹. The number of tillers per hill was significantly more with the mepiquat chloride @ 62.5 g a.i. ha⁻¹ and was better to other treatments, however at 90 DAT more tillers were observed with the mepiquat chloride @ 50 g a.i. ha⁻¹ and was at par only with the paclobutrazol @ 50 g a.i. ha⁻¹. At 60 DAT, shoot dry matter was more with the mepiquat chloride @ 37.5 g a.i. ha⁻¹ and showed parity only with untreated ones. However, at 90 DAT, more dry matter observed with the paclobutrazol @ 25 g a.i. ha⁻¹, was at par mepiquat chloride @ 50 g a.i. ha⁻¹ and statistically better to other treatments. Leaf area index, significantly influenced by various growth regulators only at 60 DAT of data recording. Notably, more LAI seen with the paclobutrazol @ 75 g a.i. ha⁻¹ and showed parity with mepiquat chloride @ 50 g a.i. ha⁻¹ and paclobutrazol @ 50 g a.i. ha⁻¹. LAI failed to produce any statistical difference at 90 DAT. This may be owing to the fact that the use of crop growth regulator at the panicle initiation stage, where the process and formation of leaf area and their attributes is decreasing and resulted in no noteworthy effect at later phase of the crop life cycle. Chlorophyll is a significant factor of the primary photosynthetic response that has a dual function in photosynthesis. It captures light, and also serves as a medium for the light-driven charge separation and transport of electrons (Syahputra *et al.*, 2013). The biosynthesis of chlorophyll was significantly affected by paclobutrazol as indicated in Table 1. Chlorophyll content of plant varies considerably with the various treatments, at 60 DAT significantly more observed only with the paclobutrazol @ 50 g a.i. ha⁻¹, however at 90 DAT maximum observed with the mepiquat chloride @ 50 g a.i. ha⁻¹ and showed parity only with the paclobutrazol @ 75 g a.i. ha⁻¹. More chlorophyll content treated with paclobutrazol may be from minimal harm caused by reactive oxygen and change in the level of carotenoids, ascorbate and the ascorbate peroxidase (Syahputra *et al.*, 2016).

Reduced internode elongation is directly related to plant height. Various treatment revealed that, significantly low internode length observed with the treated plants as against untreated ones (Table 1). Internodal distance significantly influenced by various growth parameters,

Table 1. Effect of treatments on various growth parameters of rice plant (pooled data of three years)

Treatments	Plant height (cm)		No. of leaves (hill ⁻¹)		No. of tillers (hill ⁻¹)		Shoot dry matter (g hill ⁻¹)		Leaf area index (LAI)		Chlorophyll content (SPAD unit)		Internodal distance (cm)		Percent lodging	
	60 DAT	90 DAT	60 DAT	90 DAT	60 DAT	90 DAT	60 DAT	90 DAT	60 DAT	90 DAT	60 DAT	90 DAT	60 DAT	90 DAT	At head initiation	At harvest
Mepiquat chloride @ 37.5 g a.i. ha ⁻¹	85.23	105.24	32.21	34.62	9.81	12.64	24.07	39.11	5.61	4.32	33.21	27.31	9.12	32.38	7.35	11.09
Mepiquat chloride @ 50 g a.i. ha ⁻¹	80.54	99.07	36.85	41.07	13.14	15.61	21.29	41.65	7.35	4.71	40.24	36.04	8.65	27.74	4.98	9.38
Mepiquat chloride @ 62.5 g a.i. ha ⁻¹	79.65	98.28	36.34	30.14	14.15	12.77	18.14	35.34	6.92	4.44	37.98	33.75	8.04	26.22	4.04	5.67
Mepiquat chloride @ 75 g a.i. ha ⁻¹	76.92	93.99	38.77	33.64	12.15	10.46	14.11	32.17	6.11	4.28	34.14	22.31	7.93	25.31	0.00	3.59
Mepiquat chloride @ 100 g a.i. ha ⁻¹	76.04	95.07	35.67	25.26	10.37	12.06	16.34	23.45	5.88	4.15	32.07	26.04	7.87	23.11	0.00	3.05
Paclobutrazol @ 25 g a.i. ha ⁻¹	87.15	100.34	40.09	29.61	10.37	14.88	18.44	44.42	6.28	4.95	38.62	30.29	8.92	29.35	5.66	10.64
Paclobutrazol @ 50 g a.i. ha ⁻¹	85.30	98.18	37.85	40.24	12.33	15.15	20.32	38.71	7.11	5.34	44.31	31.36	8.83	28.75	4.14	8.34
Paclobutrazol @ 75 g a.i. ha ⁻¹	81.75	94.49	34.25	23.07	11.65	12.25	17.20	33.56	7.77	4.91	38.65	34.62	8.34	27.97	3.39	7.00
Paclobutrazol @ 100 g a.i. ha ⁻¹	78.03	92.34	36.32	17.33	10.21	8.53	18.53	29.84	6.37	4.81	23.43	29.40	7.95	27.34	0.00	6.07
Untreated control (water only)	85.59	109.31	34.74	42.34	12.35	14.31	23.39	34.45	7.04	5.09	40.19	32.71	9.57	33.13	10.35	25.56
S.Em ±	1.44	2.01	3.55	2.04	0.16	0.19	0.59	1.27	0.22	0.55	0.59	0.71	0.33	0.71	0.75	0.88
LSD (P=0.05)	4.14	5.61	NS	5.31	0.47	0.57	1.59	3.77	0.61	NS	1.80	2.15	0.97	2.33	2.01	2.55

NS = Non significant

and relatively less internodal distance at 60 DAT observed with the mepiquat chloride @ 75 g a.i. ha⁻¹ and was at par with all the treatments except paclobutrazol @ 25 g a.i. ha⁻¹, mepiquat chloride @37.5 g a.i. ha⁻¹ and control. Moreover, at 90 DAT internodal elongation was significantly lowest observed with the mepiquat chloride @ 100 g a.i. ha⁻¹ and was at par paclobutrazol @ 100 g a.i. ha⁻¹ and mepiquat chloride @ 75 g a.i. ha⁻¹. Paclobutrazol and mepiquat chloride hinder gibberellin biosynthesis by blocking ent-kaurene synthesis in the metabolic pathway of gibberellin production, which produced low amount of active gibberellins resulting decrease in intermodal length (Tesfahun, 2018). Observation from Setter *et al.* (1997) revealed that, inhibition of gibberellin synthesis does not reduce cell division, but the new cells do not lengthen. Therefore, the number of leaves or spikelets are not affected, but the internodes are compressed into a shorter length.

Lodging score at ear head initiation revealed that, control plot had more lodging compared to all the treated ones. No lodging found at ear head initiation with paclobutrazol @ 100 g a.i. ha⁻¹, mepiquat chloride @ 100 g a.i. ha⁻¹ and mepiquat chloride @ 75 g a.i. ha⁻¹. At harvest considerably less lodging score observed with the mepiquat chloride @ 100 g a.i. ha⁻¹ and was at par mepiquat chloride @ 50 g a.i. ha⁻¹ and mepiquat chloride @ 75 g a.i. ha⁻¹. The physical strength of culms is very important for lodging resistance of the crop against various stress situation (Ookawa and Ishihara, 1993). Culm diameter significantly influenced by various treatments under transplanted condition. However, it failed to produce any statistical difference at 4th and 5th internode stage of data recording. It is interesting to note that the reduced internode length in treated plants was compensated by the increase in culm diameter at all internodes (Table 2) as compared with the untreated controls. This corroborates with the earlier findings of Reddy *et al.* (1996).

Table 2. Effect of growth retardants on diameter of rice culm (pooled data of three years)

Treatments	Culm diameter at different internode (mm)				
	1st	2nd	3rd	4th	5th
Mepiquat chloride @37.5 g a.i. ha ⁻¹	1.96	3.09	3.38	3.62	3.88
Mepiquat chloride @ 50 g a.i. ha ⁻¹	2.23	3.32	3.59	3.81	4.21
Mepiquat chloride @ 62.5 g a.i. ha ⁻¹	1.83	3.22	3.48	3.73	3.93
Mepiquat chloride @ 75 g a.i. ha ⁻¹	1.89	3.07	3.27	4.02	4.11
Mepiquat chloride @ 100 g a.i. ha ⁻¹	1.91	3.00	3.07	3.94	4.05
Paclobutrazol @ 25 g a.i. ha ⁻¹	2.11	3.13	3.22	3.63	4.08
Paclobutrazol @ 50 g a.i. ha ⁻¹	2.25	3.19	3.24	3.93	4.12
Paclobutrazol @ 75 g a.i. ha ⁻¹	1.76	3.15	3.27	3.61	4.05
Paclobutrazol @ 100 g a.i. ha ⁻¹	2.01	3.38	3.45	3.70	3.97
Untreated control (water only)	1.83	3.06	3.11	3.59	3.84
S.Em ±	0.05	0.11	0.09	0.16	0.14
LSD (P =0.05)	0.14	0.31	0.26	NS	NS

NS = Non significant

Effective tiller was more observed with the mepiquat chloride @ 50 g a.i. ha⁻¹ and was at par with the mepiquat chloride @ 62.5 g a.i. ha⁻¹, paclobutrazol @ 25 g a.i. ha⁻¹ and paclobutrazol @ 50 g a.i. ha⁻¹. Ineffective tillers was significantly lower observed with the paclobutrazol @ 25 g a.i. ha⁻¹ and was followed by mepiquat chloride @ 50 g a.i. ha⁻¹. Panicle length and filled grains per panicle more recorded with the mepiquat chloride @ 62.5 g a.i.

ha⁻¹ and was at par with mepiquat chloride @ 50 g a.i. ha⁻¹. Further table 3 revealed that, highest panicle weight with the paclobutrazol @ 25 g a.i. ha⁻¹ and showed parity only with paclobutrazol @ 50 g a.i. ha⁻¹. Test weight failed to produce any statistical difference, however the highest thousand grain weight was observed with the mepiquat chloride @ 50 g a.i. ha⁻¹. An enhance in yield parameter due to mepiquat chloride spray may be due to efficient

Table 3. Effect of treatments on yield attributes, yield and economics of rice plant (pooled data of three years)

Treatments	Effective tillers (No. m ⁻²)	Ineffective tillers (No. m ⁻²)	Panicle length (cm)	Panicle weight (g)	Filled grains panicle ⁻¹ (No.)	Unfilled grains panicle ⁻¹ (No.)	1000 grains weight (g)	Straw yield (q ha ⁻¹)	Harvest index (%)	Cost of production (Rs ha ⁻¹)	Gross return (Rs ha ⁻¹)	Net return (Rs ha ⁻¹)	B: C ratio (Rs rupee ⁻¹)
Mepiquat chloride @ 37.5 g a.i. ha ⁻¹	252.19	27.27	25.17	3.11	66.39	15.61	27.3	54.95	41.52	39,533	69,547	30,014	1.76
Mepiquat chloride @ 50 g a.i. ha ⁻¹	361.24	26.16	27.78	4.11	80.54	8.79	28.1	69.84	40.91	40,658	76,079	35,421	1.87
Mepiquat chloride @ 62.5 g a.i. ha ⁻¹	348.62	51.78	28.24	3.64	83.95	6.35	26.3	56.31	40.42	41,413	60,438	19,025	1.46
Mepiquat chloride @ 75 g a.i. ha ⁻¹	261.42	59.88	26.83	3.25	67.17	13.11	25.1	50.22	39.14	42,914	67,140	24,226	1.56
Mepiquat chloride @ 100 g a.i. ha ⁻¹	179.92	93.18	25.16	2.42	55.13	21.34	22.3	28.13	38.42	44,804	50,335	5,531	1.12
Paclobutrazol @ 25 g a.i. ha ⁻¹	341.32	22.92	27.15	4.65	76.25	14.25	26.3	74.31	38.43	38,564	71,087	32,523	1.84
Paclobutrazol @ 50 g a.i. ha ⁻¹	355.37	29.67	27.04	4.44	72.11	11.45	26.7	77.37	37.91	39,863	72,897	33,034	1.83
Paclobutrazol @ 75 g a.i. ha ⁻¹	302.69	42.37	26.07	3.61	74.15	10.50	26.1	70.78	32.95	40,798	66,602	25,804	1.63
Paclobutrazol @ 100 g a.i. ha ⁻¹	241.19	51.28	24.85	3.19	71.84	16.71	26.0	46.69	38.45	42,544	57,523	14,979	1.35
Untreated control (water only)	333.87	75.35	27.93	3.54	77.35	10.84	27.3	56.35	35.13	38,488	60,043	21,555	1.56
S.Em ±	6.99	4.19	0.27	0.09	2.41	0.48	2.06	2.12	0.41				
LSD (P = 0.05)	20.24	3.02	0.73	0.26	6.68	1.29	NS	6.22	1.23				

NS = Non significant

Table 4. Effect of treatments on nutrient uptake pattern of rice crop (pooled data of three years)

Treatments	Nitrogen						Phosphorus						Potassium					
	Contents (%)			Uptake (q ha ⁻¹)			Contents (%)			Uptake (q ha ⁻¹)			Contents (%)			Uptake (q ha ⁻¹)		
	Grain	Straw	Total	Grain	Straw	Total	Grain	Straw	Total	Grain	Straw	Total	Grain	Straw	Total	Grain	Straw	Total
Mepiquat chloride @37.5 g a.i. ha ⁻¹	0.86	0.49	60.41	33.48	26.93	60.41	0.19	0.14	7.40	7.69	15.09	0.23	1.51	8.95	83.05	92.00		
Mepiquat chloride @ 50 g a.i. ha ⁻¹	0.99	0.61	90.46	47.86	42.60	90.46	0.21	0.18	10.21	12.60	22.81	0.26	1.59	12.6	111.02	123.62		
Mepiquat chloride @ 62.5 g a.i. ha ⁻¹	0.79	0.55	61.11	30.14	30.97	61.11	0.15	0.15	5.72	8.45	14.17	0.21	1.36	8.01	76.60	84.61		
Mepiquat chloride @ 75 g a.i. ha ⁻¹	0.82	0.48	50.52	26.41	24.11	50.52	0.22	0.13	7.09	6.53	13.62	0.24	1.72	7.73	86.40	94.13		
Mepiquat chloride @ 100 g a.i. ha ⁻¹	0.76	0.42	25.15	13.34	11.81	25.15	0.15	0.14	2.63	3.94	6.57	0.19	1.39	3.33	39.11	42.44		
Paclobutrazol @ 25 g a.i. ha ⁻¹	0.93	0.52	81.78	43.14	38.64	81.78	0.19	0.11	8.81	8.17	16.98	0.24	1.44	11.10	107.00	118.1		
Paclobutrazol @ 50 g a.i. ha ⁻¹	0.89	0.56	85.37	42.04	43.33	85.37	0.18	0.15	8.50	11.61	20.11	0.23	1.35	10.90	104.00	115.3		
Paclobutrazol @ 75 g a.i. ha ⁻¹	0.97	0.47	66.84	33.57	33.27	66.84	0.15	0.15	5.19	10.60	15.79	0.25	1.56	8.65	110.01	119.1		
Paclobutrazol @ 100 g a.i. ha ⁻¹	0.84	0.41	43.50	24.46	19.14	43.50	0.15	0.13	4.37	6.07	10.44	0.19	1.59	5.53	74.20	79.77		
Untreated control (water only)	0.85	0.50	54.15	25.97	28.18	54.15	0.18	0.15	5.51	8.45	13.96	0.23	1.55	7.03	87.30	94.33		
S.Em ±	0.02	0.9	3.83	1.89	3.69	3.83	0.03	0.03	0.89	0.94	1.71	0.04	0.14	1.19	4.59	4.68		
LSD (P =0.05)	0.05	NS	10.52	5.14	9.11	10.52	NS	0.08	2.22	2.62	4.42	NS	NS	3.15	13.81	14.61		

NS = Non significant

translocation of photosynthates from source to sink which is resulted from decrease of the length amid sink and source. Further, excessive growth of plant was restricted due to application of mepiquat chloride, which help to reduce transpiration losses of plant and enhance the chlorophyll content and more supply of photosynthates for its larger sink and thereby improved the yield attribute of the treated plants.

3.3 Yield

Growth regulators spray had an encouraging result on yield and significantly influenced by various treatments. Significantly more grain yield was observed with the mepiquat chloride @ 50 g a.i. ha⁻¹ (47.34 q ha⁻¹) and was at par with the paclobutrazol @ 25 g a.i. ha⁻¹ (44.09 q ha⁻¹) and paclobutrazol @ 50 g a.i. ha⁻¹ (45.94 q ha⁻¹). The use of mepiquat chloride reduces plant height, alters plant morphology and can alter assimilate partitioning in favour of grain growth by increasing radiation utilization efficiency (Reddy *et al.*, 1996). Further, paclobutrazol application increased chlorophyll content which led to greater rate in photosynthesis and higher yield (Dewi *et al.*, 2016). These treatments recorded 54.95, 40.32 and 50.37% more grain yield over the untreated ones. The increase in yield due to mepiquat chloride spray might be due to more yield attributes which in turn resulted from effective translocation of photosynthates from source to sink due to the restriction of length between source and sink (Muthukumar *et al.*, 2005). Application of paclobutrazol @ 100 g a.i. ha⁻¹ and mepiquat chloride @ 100 g a.i. ha⁻¹ reduced yield to 29.12 and 17.55 below control treatment. Further, plants treated with growth retardant had a greater number of filled grain per panicle and 1000 filled grain weight compared with the controls (Table 3). More straw

production was found with paclobutrazol @ 50 g a.i. ha⁻¹ and was at par only with the paclobutrazol @ 25 g a.i. ha⁻¹ and statistically better to erstwhile options. Highest, harvesting index observed with the mepiquat chloride @ 37.5 g a.i. ha⁻¹ and showed parity with the mepiquat chloride @ 62.5 g a.i. ha⁻¹ and mepiquat chloride @ 50 g a.i. ha⁻¹.

3.4. Nutrient uptake

Nutrient uptake pattern varies significantly with various treatments and was more observed with the mepiquat chloride @ 50 g a.i. ha⁻¹. This treatment showed parity with paclobutrazol @ 25 g a.i. ha⁻¹ and paclobutrazol @ 50 g a.i. ha⁻¹ for nitrogen and potassium uptake and only with paclobutrazol @ 50 g a.i. ha⁻¹ for phosphorus uptake pattern of crop (Table 4).

3.5 Economics

Economics revealed that, more net return (Rs. 35,421 ha⁻¹) and B:C (1.87) observed with the mepiquat chloride @ 50 g a.i. ha⁻¹ and was closely followed by paclobutrazol @ 25 g a.i. ha⁻¹ and paclobutrazol @ 50 g a.i. ha⁻¹ (Table 3). In this study, an additional cost of growth regulator per hectare was incurred with the application of mepiquat chloride and paclobutrazol. However, this added cost is likely to be easily recovered by a direct increase of about 38-54 % in economic output, but, more significantly, the indirect increase in harvestable yields through decreases in losses of up to 23 to 40 % are due to lodging.

The results of the present studies recommend that in order to obtain optimum rice yield in lodging prone area, application of plant growth regulators of mepiquat chloride @ 50 g a.i. ha⁻¹ was found to better to fetch more return per rupee investment along with less crop damage.

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