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Effect of GA_3 and Other Plant Growth Regulators on Hybrid Rice Seed Production

[1]D.K. Tiwari, [2]P. Pandey, [1]S.P. Giri and [1]J.L. Dwivedi
[1]Department of Genetics and Plant Breeding, Narendra Deva University of Agriculture and Technology, Kumarganj, Faizabad-224229 (U.P), India
[2]Department of Genetics and Plant Breeding, Allahabad Agricultural Institute-Deemed University, Allahabad (U.P)-211007, India

Abstract: The aim of the present investigation is to identify a suitable and cost efficient substitute of Gibberellic acid to enhance hybrid rice seed production. The experimental material comprising both the parental lines of hybrid NDHR2 i.e., IR58025A and NDR3026-3-1R were treated with 34 treatment combination of different growth regulators and one untreated check were grown in randomized block design with three replications. The results indicated that the analysis of variance was significant for all the characters except plant height and effective tillers per plant. The exogenous application of various plant growth hormones significantly increases seed yield with a range of 14.85 g to 23.54 g. Treatment T26 (GA3 45g + C.C.) had highest significant increase in grain yield followed by T2 (GA3 45 g), T1 (GA3 30 g), T5 (NAA 200 g), T3 (NAA 100 g), T27 (Urea 2 g + C.C.) and T24 (GA3 45 g + K2PO4 2 g). The other yield components were also significantly increases with the foliar application of growth regulators. It is concluded that treatment combination T26 (GA3 45 g+ Urea 10g + Boric acid 2 g + ZnSO4 + K2 PO4 2 g) gave best results and could be used to enhance hybrid rice seed production and substitute of GA3 in India as well as other hybrid rice growing countries.

Key words: Plant growth regulators, gibberellic acid, auxins, hybrid rice seed production

INTRODUCTION

Rice is one of the most important crops in the global food system providing energy, protein and vitamins for about half of the world population. At the current growth of population rice requirement increases dramatically and many nations are facing second-generation challenge of producing more rice at less cost in a deteriorating environment; hence, it is challenging task to ensuring food and nutritional security. Thus, improved technologies are required to bridge the gap to feed the increasing population. Therefore, enhancing productivity of rice through novel genetic approaches like hybrid rice was felt necessary. Future global rice production could be increased by efforts to increase rice production area or increase yield or a combination of both. Although future expansion of rice area may require large and costly investments, a substantial yield increase could be obtained with the wide adoption of hybrid rice (Nguyen, 2010).

The presence of sufficient hybrid vigour is an important pre-requisite for successful production of hybrid varieties. In 1976, Chinese scientists had made a crucial breakthrough, successfully commercializing what is known as three line hybrid rice, raising yields to more than 5 t ha^{-1} by 1983. As the technology advanced, nationwide rice yields averaged more than 6 t ha^{-1} by 1995. And by 2004, yields of super hybrid rice cultivated in selected regions had achieved yields of more than 10 t ha^{-1}. Based on these achievements, super hybrid rice breeding program was proposed, in which the yield target is 13.5 t ha^{-1} and can be fulfilled by 2010 (Yuan, 2007, 2010; Li *et al*., 2009). Following the success of China, 18 other countries have intensified their research efforts to exploit the phenomenon of heterosis in rice (Lopez *et al*., 2003). Since rice is a self-pollinated crop, hybrid seed production must be based on male sterility systems. Currently, the most popular male sterility system for commercial exploitation of hybrid rice technology is the CMS, popularly known as the three-line system. Seed production technology is a key to the success of hybrid rice. To enhance the efficiency of hybrid seed production, it is necessary to increase the yield of hybrid seed by improving the out crossing capacity of CMS lines (Shi-Hua *et al*., 2006).

Plant hormones play a vital role in coordination of many growth and behavioral processes in the plant life. They regulate the amount, type and direction of plant growth. Remarkable accomplishments of Plant Growth Regulators (PGR) such as manipulating plant

Corresponding Author: D.K. Tiwari, Department of Genetics and Plant Breeding,
Narendra Deva University of Agriculture and Technology, Kumarganj, Faizabad-224229 (U.P), India

developments, enhancing yield and quality have been actualized in recent years using new emerging and efficient plant growth regulators. It has long been ascertained that plant hormones including auxins, gibberellins, cytokinin and ethylene etc., are involved in controlling developmental events such as cell division, cell elongation and protein synthesis. Plants have the ability to store excessive amounts of exogenously supplied hormones in the form of reversible conjugates which release active hormone when and where plant needs them during the growth period. Auxins (i.e., NAA) and gibberellins (i.e., GA_3) being well known plant growth promoting hormones has shown to be involved in a variety of plant growth and development processes (Frankenberger and Arshad, 1995). Auxins may regulate cell elongation, tissue swelling, cell division, formation of adventitious roots, callus initiation and growth, induction of embryogenesis and promote cell wall loosening at very low concentration (Vanderhoff and Dute, 1981; Azad *et al*., 2004; Woodward and Bartel, 2005; Muthukumar *et al*., 2007; Abel and Theologis, 2010). Similarly, Gibberellins are plant hormones that participate in regulation of many growth and developmental processes in various plants (Hedden and Phillips, 2000; Olszewski *et al*., 2002; Naeem *et al*., 2001; Shah *et al*., 2006; Shibairo *et al*., 2006; Emongor, 2007). And these are especially important in regulating stem elongation (Dunand, 1998; Peng *et al*., 1999; Richards *et al*., 2001; Itoh *et al*., 2001; Spielmeyer *et al*., 2002; Schomburg *et al*., 2003; Sakamoto *et al*., 2004; Sun, 2004). Gibberellic acid is responsible for stimulating the production of mRNA molecules in the cells and mRNA produced in this form, codes for the hydrolytic enzymes, which in turn improves the chances of fast growth (Richards *et al*., 2001; Sun, 2004). Growth regulators are proved to improve effective partitioning and translocation of accumulates from source to sink in the field crops (Solaimalai *et al*., 2001; Senthil *et al*., 2003).

Hybrid rice seed production is quite complex. Many factors affect the yield and quality of hybrid seed. To increase the seed production a series of integrated technologies was also advanced, including the three factors for secure heading and flowering (temperature, sunlight and relative humidity), applying fertilizer and chemicals and spraying a low dosage of Gibberellic acid (GA_3) to improve out-crossing posture. Application of GA_3 is an important component of hybrid rice seed production technology. Its cost is very high in many countries. High seed yields in China have been achieved with a very high dosage of 150-300 g ha^{-1}. Outside China, it is essential to reduce the cost of GA_3, either by reducing the dosage or by producing cheap GA_3 locally (Virmani *et al*., 2007). The advantage of hybrid rice cannot be fully utilized unless a cost effective seed production system successfully developed. Presently, use of a high cost chemical i.e., Gibberellic acid (GA_3) is almost the prerequisite for rice hybrid seed production which increases the cost of hybrid seeds. Hybrid rice seed production is highly dependent on use of gibberellic acid (GA_3). Outside China this is quite expensive (more than US$1.00 per gram), because it is imported. In China it is quite cheap (US$0.30 per gram) because it is produced locally, so it does not cost much to apply a high dosage of this growth regulator (Virmani *et al*., 2007). To overcome this problem, it is necessary to identify cheaper chemicals to substitute GA_3. Keeping in view of these needs the present investigation was undertaken to study the effect of GA_3 and other growth regulators on hybrid seed production.

MATERIALS AND METHODS

The experimental material comprising both the parental lines of hybrid NDHR2 i.e., IR58025A and NDR3026-3-1R were treated with 34 treatment combination of different growth regulators and one untreated check were grown in randomized block design with three replications at Crop Research Station, Narendra Deva University of Agriculture and Technology, Kumarganj, Faizabad during wet season of 2001-02 and 2002-03. The experimental site is located at 26.47°N latitude, 82.12°E longitudes and an altitude of 113 m above mean sea level. This site is in the eastern Gangetic plains of India and has sandy loam soil texture. The detail of treatment combinations is presented in (Table 1). Single row of CMS line (A line) was sown followed by three rows of Restorer line (R line) at three-day interval, CMS line was also sown at seven days interval from last sowing of restorer line. Subsequently, the seedlings were mixed in equal proportion to the three dates of sowing before transplanting. R line was transplanted in paired rows with three seedling per hill keeping 30×15 cm spacing while, A line with single seedling with spacing of 15×15 cm. A line and R line were transplanted in the ratio of 2:6 in a plot of 3×5. GA_3 and other chemical combinations were sprayed in two spraying i.e., at the time of heading and at 50% panicle emergence by Using Ultra-low Volume (ULV) sprayer. One, which remained untreated, was used as the control. The recommended agronomic practices followed to raise good crop stand. The data were recorded on 10 randomly selected plants from each replication for ten quantitative characters. The characters studied were; plant height (cm), effective tillers per plant, panicle length (cm), number of spikelets per panicle,

Table 1: Treatment combinations of various growth regulators

Treatment	Treatment combinations	Treatment	Treatment combinations
T_1	GA_3 (30 g)	T_{18}	GA_3 (45 g)+Urea (2 g)
T_2	GA_3 (45 g)	T_{19}	GA_3 (30 g)+Boric acid (2 g)
T_3	NAA (100 g)	T_{20}	GA_3 (45 g)+Boric acid (2 g)
T_4	NAA (150 g)	T_{21}	GA_3 (30 g)+$ZnSO_4$ (2 g)
T_5	NAA (200 g)	T_{22}	GA_3 (45 g)+$ZnSO_4$ (2 g)
T_6	Urea (20 g)	T_{23}	GA_3 (30 g)+K_2PO_4 (2 g)
T_7	Boric acid (20 g)	T_{24}	GA_3 (45 g)+K_2PO_4 (2 g)
T_8	Chemical composition (C.C.) = (Urea 10 g +Boric acid 2g+$ZnSO_4$ 2g+K_2PO_4 2g)	T_{25}	GA_3 (30 g)+C.C.
T_9	$ZnSO_4$ (20 g)	T_{26}	GA_3 (45 g)+C.C.
T_{10}	K_2PO_4 (20 g)	T_{27}	Urea (2 g)+C.C.
T_{11}	GA_3 (30 g)+NAA (100 g)	T_{28}	Urea (20 g)+C.C.
T_{12}	GA_3 (30 g)+NAA (150 g)	T_{29}	Boric acid (2 g)+K_2PO_4 (20 g)
T_{13}	GA_3 (30 g)+NAA (200 g)	T_{30}	$ZnSO_4$ (20g)+K_2PO_4 (20g)
T_{14}	GA_3 (45 g)+NAA (100 g)	T_{31}	Boric acid (2g)+$ZnSO_4$ (20 g)
T_{15}	GA_3 (45 g)+NAA (150 g)	T_{32}	Boric acid (2 g)+K_2PO_4 (20g)
T_{16}	GA_3 (45 g)+NAA (200 g)	T_{33}	Urea (2g)+$ZnSO_4$ (20 g)
T_{17}	GA_3 (30 g)+Urea (2 g)	T_{34}	Urea (2 g)+K_2PO_4 (20g)
T_{35}	Control		

GA_3: Gibberellic acid, NAA: Naphthalene acid, $ZnSO_4$: Zinc sulphate, K_2PO_4: Potassium sulphate and chemical composition (i.e., C.C.) = (Urea 10 g+ Boric acid 2g+$ZnSO_4$ 2g+K_2PO_4 2g)

number of fertile spikelets, spikelet fertility%, 100 grain weight (g), biological yield (g), grain yield per plant (g) and harvest index (%). The general reference for data collection was standard evaluation system for rice (Anonymous, 2002; Virmani *et al*., 1997). Mean values were subjected to analysis of variance to test the significance for each character as per methodology advocated by Panse and Sukhatme (1967).

RESULTS AND DISCUSSION

The analysis of variance was significant for all the characters except plant height and effective tillers per plant under various treatments of growth regulators (Table 2). The mean performance based on the pooled data of both two years indicated that all the traits were significantly influenced by the application of growth regulators compared to control i.e., untreated check (Table 3). Remarkable increase in growth and yield characteristics with the exogenous application of Gibberellic acid, NAA and other growth hormones were also reported by earlier workers such as Kalavathi *et al*. (2000), Yogesha *et al*. (2000) and Thangaraj *et al*. (2000) in rice, Naeem *et al*. (2001) in tomato, Sarkar *et al*. (2002) in soybean, Muthukumar *et al*. (2007) in baby corn (*Zea mays* L.), Shibairo *et al*. (2006) in potato, Shah *et al*. (2006) in black cumin (*Nigella sativa* L.), Emongor (2007) in cowpea and Mobin *et al*. (2007) in mustard. Better vegetative growth of a crop is largely responsible for higher seed yield because number of photosynthesizing sites i.e., number of vegetative branches is affected by initial growth stages. The significant increase in plant height was observed by all treatment combinations of the exogenous application of various growth regulators.

Table 2: The analysis of variance for different traits under various treatments of growth regulators in rice

Characters	Source of variation: Replications (df = 2)	Treatments (df = 34)	Error (df = 68)
Plant height	0.008	9.675	13.422
Effective tillers/plant	0.003	1.798	1.849
Panicle length	0.001	4.174**	0.813
No. of spikelet/panicle	0.005	11.662**	106.737
No. of fertile spikelet	0.11	20.998**	1.763
Spikelet fertility%	0.045	20.905**	5.707
100 grain weight	0.057	23.0060**	0.067
Grain yield	0.021	16.849**	1.145
Biological yield	0.011	8.772**	3.770
Harvest index	0.108	46.22**	0.68

**1% probability level of significance. The above table obtained by ANOVA and t test

Amongst them treatment T_3 (71.52 cm) had highest estimate followed by T_{26} (71.47 cm), T_6 (70.81 cm), T_{30} (70.12 cm), T_{12} (70.01 cm), T_{28} (69.65 cm) and T_{29} (69.65 cm). The increase in plant height is due to plant hormones promoted vegetative growth by active cell division, cell enlargement and cell elongation and thus helped in improving growth characteristics and also facilitated reproductive growth (Pareek *et al*., 2000). These findings were in closely agreement with the results of Subbaih and Mittra (1997) and Dunand (1998) who also reported significant increase in plant height, stem elongation and yield in response to Gibberellic acid application. Virmani *et al*. (2007) reported that differential application of GA_3 also increases the relative height of the pollen parent over the seed parent.

More effective tillers per plant are believed to be closely associated with high seed yield per plant resulting high productivity. Hybrid rice relies mainly on tillers to

Table 3: Mean performance of various quantitative traits of rice under different levels of treatments with GA_3 and other growth regulators (Pooled data of two years)

Treatments	Treatment combinations	Plant height (cm)	Effective tillers	Panicle length (cm)	No. of spikelets /panicles	No. of fertile spikelets	Spikelet fertility (%)	100 grain weight	Grain yield /plant (g)	Biological yield (g)	Hrvest index (%)
T_1	GA_3 (30 g)	69.36**	25.70**	18.10**	190.08**	23.09**	44.67**	5.33**	22.77**	32.92	16.19**
T_2	GA_3 (45 g)	66.54**	26.10**	16.96	227.70**	29.22**	58.88**	6.14**	23.27**	41.32**	14.85**
T_3	NAA (100 g)	71.52**	25.97**	17.82**	193.38**	26.47**	54.74**	5.09**	22.25**	40.70**	12.50**
T_4	NAA (150 g)	68.39**	25.16**	17.3	198.17**	28.61**	41.21**	4.94**	18.91**	39.68**	12.44**
T_5	NAA (200 g)	67.71**	25.50**	17.91**	224.40**	20.50**	48.88**	5.14**	22.70**	37.66**	13.64**
T_6	Urea (20 g)	70.81**	24.29	15.81	199.07**	23.14**	44.90**	5.10**	21.38**	35.27**	14.45**
T_7	Boric acid (20 g)	67.08**	25.59**	17.16	178.89**	28.66**	33.58	4.63**	18.81**	36.21**	12.78**
T_8	C.C. (Urea 10 g +Boric acid 2g+ $ZnSO_4$ 2g +K_2 PO_4 2 g)	66.56**	23.01	14.58	206.78**	22.62**	45.05**	5.24**	17.99**	34.44**	19.99**
T_9	$ZnSO_4$ (20 g)	67.39**	25.67**	16.04	178.33**	19.23	33.82	3.93**	20.86**	32.68**	12.02**
T_{10}	K_2PO_4 (20 g)	63.11**	24.74**	15.84	190.31**	19.15	35.78	4.23**	16.24	34.29**	12.33**
T_{11}	GA_3 (30 g)+NAA (100 g)	64.44**	23.15	16.5	175.40**	19.18	38.25**	4.53**	16.21	32.73**	13.84**
T_{12}	GA_3 (30 g)+NAA (150 g)	70.01**	24.42**	16.24	178.55**	25.34**	41.19**	4.33**	20.91**	29.92	14.47**
T_{13}	GA_3 (30 g)+NAA	68.70**	24.29	15.81	155.73	21.81**	41.17**	4.03**	17.42**	40.23**	10.01**
T_{14}	GA_3 (45 g)+NAA (100 g)	67.45**	24.99**	14.75	184.23**	21.35**	36.66**	4.01**	19.48**	34.52**	11.61**
T_{15}	GA_3 (45 g)+NAA (150 g)	60.03**	23.05	13.2	174.03**	19.42**	27.64	3.73**	17.23**	35.50**	10.50**
T_{16}	GA_3 (45 g)+NAA (200 g)	67.26**	24.77**	16.27	183.35**	17.70	42.28**	4.04**	15.02	31.52	12.81**
T_{17}	GA_3 (30 g)+Urea (2 g)	64.01**	24.19	15.01	148.89	22.45**	38.38**	3.63	18.01**	34.60**	10.49**
T_{18}	GA_3 (45 g)+Urea (2 g)	64.24**	24.31	15.46	184.72**	19.13	39.76**	3.71**	19.24**	34.96**	10.61**
T_{19}	GA_3 (30 g)+Boric acid (2 g)	65.18**	23.76	15.84	165.53**	19.40**	40.38**	4.23**	15.84	31.24	13.54**
T_{20}	GA_3 (45 g)+Boric acid (2 g)	64.89**	24.03	15.95	167.31**	20.44**	43.71**	4.83**	18.07**	32.94**	14.66**
T_{21}	GA_3 (30 g)+$ZnSO_4$ (2 g)	66.23**	25.19**	17.15	156.42	21.85**	41.80**	4.03**	17.07**	33.55**	12.01**
T_{22}	GA_3 (45 g)+$ZnSO_4$ (2 g)	65.82**	25.31**	17.06	175.23**	22.86**	39.39**	3.83**	16.19	36.63**	10.45**
T_{23}	GA_3 (30 g)+K_2PO_4 (2 g)	66.76**	25.09**	15.76	187.11**	24.71**	43.81**	4.63**	15.82	35.48**	13.03**
T_{24}	GA_3 (45 g)+K_2PO_4 (2 g)	67.03**	24.87**	15.14	188.10**	25.87**	45.43**	5.04**	21.78**	32.25	15.62**
T_{25}	GA_3 (30 g)+C.C.	68.00**	23.18	16.65	198.00**	25.54**	45.45**	5.24**	21.09**	31.54	16.61**
T_{26}	GA_3 (45 g)+C.C.	71.47**	26.35**	18.12**	229.68**	29.52**	59.49**	8.75**	23.54**	38.08**	22.08**
T_{27}	Urea (2 g)+C.C.	68.64**	22.75	16.94	210.96**	23.72**	45.45**	5.14**	21.92**	32.43**	15.84**
T_{28}	Urea (20 g)+C.C.	69.65**	22.86	17.63	158.38	24.86**	46.13**	5.34**	18.81**	30.3	17.62**
T_{29}	Boric acid (2 g)+ K_2PO_4 (20 g)	69.65**	24.31	14.95	167.59**	25.19**	46.46**	5.24**	18.40**	35.58**	14.72**
T_{30}	$ZnSO_4$ (20g)+K_2 PO_4 (20g)	70.12**	24.38	15.74	187.11**	26.54**	46.70**	5.20**	17.50**	37.87**	13.73**
T_{31}	Boric acid (2g) +$ZnSO_4$ (20 g)	60.46**	23.3	16.63	192.06**	27.21**	46.84**	5.12**	16.42	36.56**	14.01**
T_{32}	Boric acid (2 g) +K_2PO_4 (20g)	64.65**	23.79	16.04	196.02**	26.31**	44.44**	4.94**	21.36**	31.62	15.62**
T_{33}	Urea (2g)+ $ZnSO_4$ (20 g)	66.29**	24.78**	17.23	184.14**	25.68**	43.43**	4.13**	19.38**	34.54**	11.90**
T_{34}	Urea (2 g)+K_2 PO_4 (20g)	56.63**	24.70**	17.42	196.26**	27.33**	41.41**	3.84**	21.03**	31.18	12.28**
T_{35}	Control	32.64	22.17	16.19	146.52	17.13	32.32	3.22	14.85	29.22	8.21
	SE mean	2.12	0.79	0.52	5.96	0.77	1.38	0.14	0.62	1.12	0.84
	CD (0.01%)	5.98	2.22	1.47	16.87	2.17	3.9	0.42	1.75	3.17	1.35

**Significant at 1% probability level of significance. In this table test of significance calculated by applying t test

obtain the desirable population; conventional rice relies on number of seedlings planted. About 85-90% of productive panicles of hybrid rice come from tillers. A perusal of data (Table 3) revealed that significant increase in effective tillers was ranged from 22.17 to 26.35 and highest estimate was recorded by the treatment combination T26 (26.35) followed by T2 (26.10), T3 (25.97), T1 (25.70), T9 (25.67), T7 (25.59) T5 (25.50), T22 (25.31) T21 (25.19), T4 (25.16) and T23 (25.09). Generally, larger panicle is associated with high number of grains panicle resulting into higher productivity; therefore significant increase for panicle length is desirable. The highest significant increase in panicle length were showed by the treatment T_{26} (18.12 cm) followed by T_1 (18.10 cm), T_5 (17.91 cm) and T_3 (17.82 cm). The data also revealed that some treatment combinations give the decrease in panicle length as compare to control i.e., treatment combination T_8 and T_{15}. These results were in conformity with the results of Elankavi *et al.* (2009) who also observed that the exogenous application of GA_3 significantly increases various growth characters viz., plant height, number of tillers and yield attributes in rice.

Regulating total spikelets is necessary to gain high hybrid rice yields. The number of spikelet per panicle ranged from 165 to 229. All treatment combination showed significant increase in spikelet number except T_{28}, T_{21}, T_{15} and T_{17}. The number of fertile spikelets was highest with the application of GA_3+ C.C (T_{26}). Spikelet fertility % is very important in hybrid breeding programme because this trait has a direct effect on the seed yield. The successful utilization of CMS in development of hybrids is not possible unless the effective restorer lines are identified. More number of fertile spikelets is closely associated with high yield per plant resulting in high productivity. The range of spikelet fertility varied from 27.64 to 59.49%. Twelve treatment combinations showed above 45% spikelet fertility among them T_{26} (59.49 %) had highest estimate followed by T_2 (58.88%) and T_3 (54.74 %). Similar findings in rice were also reported by Bui *et al.* (1992), Kalavathi *et al.* (2000); Yogesha *et al.* (2000). Poor development of spikelets on the basal branches resulted in a high percentage (50-60%) of degeneration and sterility and, consequently, grain yield was poor. Application of gibberellic acid (GA_3) and kinetin (6-furfuryl amino purine) improved development and grain yield on all branches (Patel and Mohapatra, 1992).

Biological yield significantly increased with the application of different combinations of growth regulators and it varied from 32.42 g to 41.31 g. The highest biological yield were recorded with the application of GA_3 (45 g) followed by NAA (100 g), GA_3 (30 g)+NAA (200 g), NAA (150 g) and GA_3 (45 g)+c.c. against control (29.22 g). Similarly the highest harvest index was recorded by the T_{26} i.e., GA_3 (45 g)+C.C. The 100 grain weight is one of the important common traits which influence the yield. All treatment combination gave the significant increase in 100 grain weight except T_{17}. The highest significant increase in 100 grain weight were showed by the treatment T_{26} (8.75 g) followed by T_2 (6.14 g), T_{28} (5.34 g) and (5.33 g). The grain yield is very complex trait. It is multiplicative end product of several basic components of yield i.e., panicle length, spikelet fertility, test weight, number of effective tillers and number of spikelets per panicle. In hybrid rice seed production seed yield mainly depends on floral traits of CMS line i.e., stigma exertion, opening angle of spikelets, panicle exertion percent, outcrossing rate and also agro-morphological traits of pollen parents. Therefore, to achieve higher yield improvements in these traits is a necessary requirement. The application of GA_3 influences panicle exertion, spikelet opening angle and other floral traits which increases outcrossing rate of CMS lines leading higher yield. Xu and Li (1988) reported 13% higher seed yield with application of GA_3 in rice. Similarly, Elankavi *et al.* (2009) observed up to 50.52% increase in grain yields over control. In present study the effect of growth regulators on grain yield showed that it was significantly increases with a range of 14.85 to 23.54 g. The treatment T_{26} i.e., GA_3 (45 g)+C.C gave highest significant increase in seed yield followed by T_2 (GA_3 45 g), T_1 (GA_3 30 g), T_5 (NAA 200 g), T_3 (NAA 100 g), T_{27} (Urea 2 g+C.C.) and T_{24} (GA_3 45 g+K_2PO_4 2 g). The increase in yield with the application of various plant growth regulators might be due to increased yield attributes, which in turn resulted from effective translocation of photosynthates. The plant growth hormones also increases mobilization of reserve food materials to the developing sink through increase in hydrolyzing and oxidizing enzyme activities and leads to yield increases (Jayachandran *et al.*, 2000). While, Zahir *et al.* (2007) observed that exogenously supplied PGRs may undergo several metabolic processes in the soil resulting in loss of their activity and reduced availability to plants and such type of behavior was only seen with IAA and Gibberellic acid. These results were in conformity with a number of workers such as Know *et al.* (1990), Risheng *et al.* (1990), Aswathanarayana and Mahadevappa (1992), Bui *et al.* (1992), Yuan and Fu (1995), Pandey *et al.* (1996), Jayaraj and Chandrasekharan (1997), Subbaih and Mittra (1997), Mao *et al.* (1998), Singh and Sahoo (1998), Liang and Zaman (1999), Kalavathi *et al.* (2000), Yogesha *et al.* (2000), Thangaraj *et al.* (2000), Shi-Hua *et al.* (2006) and Elankavi *et al.* (2009).

CONCLUSION

Plant Growth Regulators (PGRs) and various chemical combinations significantly influence agronomical, morphological and physiological traits in rice and it was observed that at limited concentrations they stimulate rapid cell division resulting faster vegetation and reproductive growth. The treatment combination T_{26} i.e., (GA_3 45 g+Urea 10 g+Boric acid 2 g+$ZnSO_4$ 2 g+K_2PO_4 2 g) gave the best effects as compared to all other treatment combinations for most of the characters and may be used as substitute of GA_3 with low cost hybrid seed production in India as well as other hybrid rice growing countries and also to achieve higher seed yield with maximum economic return.

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REFERENCES

Abel, S. and A. Theologis, 2010. Odyssey of Auxin. In: Perspectives in Biology, Estelle, M., D. Weijers, K. Ljung and O. Leyser (Eds.). Cold Spring Harbor Lab. Press, USA.

Anonymous, 2002. Standard Evaluation System for Rice. 5th Edn., IRRI, Manila, Los Banos, Philippines.

Aswathanarayana, S.S. and M. Mahadevappa, 1992. Effect of game locides in hybrid seed production of rice. J. Maharashtra Agric. Univ., 17: 14-16.

Azad, M.A.K., S. Yokota, S. Yahara and N. Yoshizawa, 2004. Effects of explant type and growth regulators on organogenesis in a medicinal tree, *Phellodendron amurense* Rupr. Asian J. Plant Sci., 3: 522-528.

Bui, B.B., F.V. Zaman, V.P. Singh, A.R. Sandanada and M.S. Swaminathan, 1992. Studies to enhance hybrid seed production in rice. Omon Rice, 2: 40-51.

Dunand, R.T., 1998. Effects of preheading applications of gibberellic acid on rice growth and production. Proceedings of the 27th Rice Tech. Working Group (RTWG'98), Reno, NV, pp: 211-211.

Elankavi, S., G. Kuppuswamy, V. Vaiyapuri and R. Raman, 2009. Effect of Phytohormones on growth and yield of rice. Oryza, 46: 310-313.

Emongor, V., 2007. Gibberellic acid (GA_3) influence on vegetative growth, nodulation and yield of cowpea (*Vigna unguiculata* (L.) walp. J. Agron., 6: 509-517.

Frankenberger, Jr. W.T. and M. Arshad, 1995. Phytohormones in Soil: Microbial Production and Function. Marcel Dekker Inc., New York, USA., ISBN: 0824794427, pp: 503.

Hedden, P. and A.L. Phillips, 2000. Gibberellin metabolism: New insights revealed by the genes. Trends Plant Sci., 5: 523-530.

Itoh, H., T. M. Ueguchi, N. Sentoku, H. Kitano, M. Matsuoka and M. Kobayashi, 2001. Cloning and functional analysis of two gibberellin 3-hydroxylase genes that are differently expressed during the growth of rice. Proc. Natl. Acad. Sci., 98: 8909-8914.

Jayachandran, M., N.O. Gopal and R. Marimuthu, 2000. Performance of hybrid rice cultures under different levels of nitrogen in combination with growth regulators. Madras Agric. J., 89: 462-465.

Jayaraj, T. and B. Chandrasekharan, 1997. Foliar fertilization to changes seed yield and quality in rice. Seed Res., 25: 50-52.

Kalavathi, O., A. Ananthakalaiselvi and J. Vijaya, 2000. Econonomization of GA_3 use in hybrid rice seed production by supplementing with other nutrients. Seed Res., 28: 10-12.

Know, O.K., K.S. Kim, Y.P. Hong and I.S. Han, 1990. Effect of day length and GA_3 on the conservation from cliestogamy to clasmogamy in *Violu mandshurica* W. Becker. J. Korean Soc. Hort. Sci., 31: 305-310.

Li, J., Y. Xin and L.P. Yuan, 2009. Hybrid rice in China in Pushing the Yield Frontier. IFPRI Discussion Paper. Hybrid Rice Technology Development: Ensuring China's Food Security. International Food Policy Research Institute, Washington D.C., pp: 77-82. http://www.ifpri.org/book-5826/millionsfed/cases/hybridrice.

Liang, M. and F.V. Zaman, 1999. Optimization of hybrid rice seed production. Seed Res., 27: 7-10.

Lopez, M.T., T. Toojinda, A. Vanavichit and S. Tragoonrung, 2003. Microsettelite markers flanking the tms 2 gene facilitated tropical TGMS rice line development. Crop Sci., 43: 2267-2271.

Mao, C.X., S.S. Virmani and I. Kumar, 1998. Technological innovations to lower the cost of hybrid rice seed production. Proceedings of the 3rd International Symposium on Hybrid Rice, Nov. 14-16, Hyderabad, India, Manila, IRRI, pp: 111-128.

Mobin, M., A.H. Rahman and K.N. Ahmad, 2007. Timing of GA_3 application to Indian mustard (*Brassica juncea* L.): Dry matter distribution, growth analysis and nutrient uptake. J. Agron., 6: 53-60.

Muthukumar, V.B., K. Velayudham and N. Thavaprakaash, 2007. Plant growth regulators and split application of nitrogen improves the quality parameters and green cob yield of baby corn (*Zea mays* L.). J. Agron., 6: 208-211.

Naeem, N., M. Ishtiaq, P. Khan, N. Mohammad, J. Khan and B. Jamiher, 2001. Effect of gibberellic acid on growth and yield of tomato Cv. Roma. J. Biol. Sci., 1: 448-450.

Nguyen, N.V., 2010. Ensuring Food Security in the 21st Century with Hybrid Rice: Issues and Challenges. In: Accelerating Hybrid Rice Development, Xie, F. and B. Hardy (Eds.). International Rice Research Institute, Los Banos, Philippines, pp: 9-24.

Olszewski, N., T. Sun and F. Gubler, 2002. Gibberellins signaling: Biosynthesis, catabolism and response pathways. Plant Cell, 14: S61-80.

Pandey, M.P., S.C. Mani, H. Singh and J.P. Singh, 1996. Hybrid Rice Seed Production. A Technology Manual. Power Printers, New Delhi, India.

Panse, V.G. and P.V. Sukhatme, 1967. Statistical Methods for Agricultural Workers. 2nd Edn., ICAR Publication, New Delhi, India, pp: 44.

Pareek, N.K., N.L. Jat and R.G. Pareek, 2000. Response of coriander (*Coriandrum sativum* L.) to nitrogen and plant growth regulators. Haryana J. Agron., 16: 104-109.

Patel, R. and P.K. Mohapatra, 1992. Regulation of spikelet development in rice by Hormones . J. Exp. Bot., 43: 257-262.

Peng, J., D.E. Richards, N.M. Hartley, G.P. Murphy and K.M. Devos *et al*., 1999. Green revolution gene encodes mutant gibberellin response modulators. Nature, 400: 256-261.

Richards, D.E., K.E. King, A.T. Ali and N.P. Harberd, 2001. How gibberellin regulates plant growth and development: A molecular genetic analysis of gibberellin signaling. Ann. Rev. Plant Physiol. Plant Mol. Biol., 52: 67-88.

Risheng, T., Z. Jinyu and W. Guangnan, 1990. Regulation of endogenous abscisic acid and indole acetic acid in rice plants by multiple effect of triazole. Jiangsu J. Agric. Sci., 6: 38-43.

Sakamoto, T., K. Miura, T. Tatsumi, M. Ueguchitanaka and K. Ishiyama *et al*., 2004. An overview of gibberellin metabolism enzyme and their related mutants in rice. Plant Physiol., 134: 1642-1653.

Sarkar, P.K., M.S. Haque and M.A. Karim, 2002. Effects of GA3 and IAA and their frequency of application on morphology, yield contributing characters and yield of soybean. J. Agron., 1: 119-122.

Schomburg, F.M., C.M. Bizzell, D.J. Lee, J.A. Zeevaart and R.M. Amasino, 2003. Overexpression of a novel class of gibberellin 2-oxidases decreases gibberellin levels and creates dwarf plants. Plant Cell, 15: 151-163.

Senthil, A., M. Djanaguiraman and R. Chandrababu, 2003. Effect of root dipping of seedlings with plant growth regulators and chemicals on yield and yield components of rice (*Oryza sativa* L.) transplanted by broadcast method. Madras Agric. J., 90: 383-384.

Shah, S.H., I. Ahmad and Samiullah, 2006. Effect of gibberellic acid spray on growth, nutrient uptake and yield attributes during various growth stages of black cumin (*Nigella sativa* L.). Asian J. Plant Sci., 5: 881-884.

Shi-Hua, Y., C. Ben-Yi, W. Jian-Li, S. Wei-Feng and C. Shi-Hua, 2006. Review and prospects on rice breeding and extension in China. Rice Sci., 13: 1-8.

Shibairo, S.I., P. Demo, J.N. Kabira, P. Gildemacher and E. Gachango *et al*., 2006. Effects of gibberellic acid (GA3) on sprouting and quality of potato seed tubers in diffused light and pit storage conditions. J. Boil. Sci., 6: 723-733.

Singh, R. and S.K. Sahoo, 1998. Evaluating hybrid seed production technology along with new hormone mangeferin. Ph.D. Thesis, Banaras Hindu University, Varanasi

Solaimalai, A., C. Sivakumar, S. Anbumani, T. Suresh and K. Arumugam, 2001. Role of plant growth regulators in rice production: A review. Agric. Rev., 22: 33-40.

Spielmeyer, W., M.H. Ellis and P.M. Chandler, 2002. Semidwarf (sd-1), green revolution rice, contains a defective gibberellin 20-oxidase gene. Proc. Natl. Acad. Sci., 99: 9043-9048.

Subbaih, G. and B.N. Mittra, 1997. Effect of foliar spray of micronutrient on growth and yield of rice. Oryza, 26: 148-151.

Sun, T., 2004. Gibberellin Signal Transduction in Stem Elongation and Leaf Growth. In: Plant Hormones; Biosynthesis, Signal Transduction, Action, Davies, P.J. (Ed.). Kluwer Academic Publ., Dordrecht, The Netherlands, pp: 304-320.

Thangaraj, M., M. Laxmiprabha and D.D. Devi, 2000. Physiological and biochemical effects of barassonalides on productivity of rice. Oryza, 87: 49-50.

Vanderhoff, L.N. and R.R. Dute, 1981. Auxin-regulated wail loosening and sustained growth in elongation. Plant Physiol., 67: 146-149.

Virmani, S.S., B.C. Viraktamath, C.L. Casal, R.S. Toledo, M.T. Lopez and J.O. Manalo, 1997. Hybrid Rice Breeding Manual. International Rice Research Institute, Philippines.

Virmani, S.S., C.X. Mao, R.S. Toledo, M. Hossain and A. Janaiah, 2007. Hybrid rice seed production technology and its impact on seed industries and rural employment opportunities in Asia. http://www.agnet.org/library/tb/156/tb156.pdf.

Woodward, A.W. and B. Bartel, 2005. Auxin: Regulation, action and interaction. Ann. Bot., 95: 707-735.

Xu, S. and B. Li, 1988. Managing hybrid rice seed production. Proceedings of the 1st International Symposium on Hybrid Rice, Oct. 6-10, International Rice Research Institute, Manila, Philippines, pp: 157-163.

Yogesha, H.S., S. Pandey and S.P. Sharma, 2000. GA_3 to obtain synchrony in hybrid seed production. Seed Res., 28: 87-89.

Yuan, L.P. and X.Q. Fu, 1995. Technolgy of Hybrid Rice Production. FAO, Rome, Italy, pp: 84.

Yuan, L.P., 2007. Proposal of implementing the planting-three-produce four high-yielding project on super hybrid rice. Hybrid Rice, 22: 1-1.

Yuan, L.P., 2010. Progress in Breeding Super Hybrid Rice. In: Accelerating Hybrid Rice Development, Xie, F. and B. Hardy (Eds.). IRRI, Los Banos, Philippines, pp: 3-8.

Zahir, A.Z., M. Iqbal , M. Arshad, M . Naveed and M. Khalid, 2007. Effectiveness of IAA, GA_3 and kinetin blended with recycled organic waste for improving growth and yield of wheat (*Triticum aestivum* L.). Pak. J. Bot., 39: 761-768.