J Plant Growth Regul (1997) 16:21–25

Journal of Plant Growth Regulation

Gibberellic Acid$_3$ Modifies Some Growth and Physiologic Effects of Paclobutrazol (PP_{333}) on Wheat

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Received May 22, 1996; accepted November 14, 1996

Abstract. Gibberellic acid$_3$ (GA_3) modification of some growth and physiologic effects of paclobutrazol (PP_{333}) was studied by applying PP_{333} alone and in combination with GA_3 at the tillering stage of wheat. Results showed that GA_3 weakened the effect of PP_{333} on tillering and shortening the plant, increased the dry matter accumulation of different tillers, improved plant nitrogen metabolism by favoring nitrogen translocation into tillers at late growth stage, and stimulated tiller development. All of these reduced the difference in spike weight among tillers and the main stem. Compared with control, there were more spikes per plant and fewer grain per spike in the PP_{333} treatment, but all yield components developed positively in the treatment consisting of the mixture of GA_3 and PP_{333}.

Key Words. *Triticum aestivum*—Plant growth regulator—Tiller—Dry matter—Yield component

Lodging is one of the factors limiting high yields of wheat. Although achievement of modern semidwarf breeding has improved the lodge resistance of wheat varieties by reducing plant height (Gale 1985), some varieties now being used in production still, to some extent, lodge under conditions of high nitrogen fertilizer, especially in areas with too much rainfall and in soils waterlogged during the growing season. To avoid possible lodging, application of some growth retardants such as CCC (cycocel) and PP_{333} (paclobutrazol) is recommended because of their effect on inhibiting internode elongation and shortening the plant. In wheat production these retardants are generally applied just before the stem begins elongating, at which time the plant is in the period of spikelet differentiation and extension of the three or four uppermost functional leaves. Therefore ear development and establishment of the photosynthetic area will be inhibited, resulting in a reduction of sink and source capacity. In practice, whether or not the application of growth retardants has a positive effect on grain yield is dependent on lodge status. Yield loss may result when retardants are applied in the fields where there is little or no lodging.

It was considered that the effect of retardants in reducing plant height was a result of their action in modifying GA metabolism in plants because retardants and GA are generally physiologic antagonists (Treharne et al. 1995). However, Konanteng and Matthews (1982) and Hutley-Bull and Schwabe (1982) suggested that the above mentioned plant growth regulators (PGRs) do not show simple antagonism in their effect on the morphology and development of yield components if low concentrations of GA_3 (20 ppm) and CCC or PP_{333} were applied simultaneously at an early stage of barley or wheat development. Zhang (1992) showed that application of the mixture GA_3 and CCC or PP_{333} modified the effect of a single retardant in inhibiting growth, dry matter accumulation, and nitrogen metabolism of wheat plants. Thus the development of each yield component was favored. This experiment was carried out to study the effect of applying a mixture of PP_{333} and GA_3 on tiller initiation and development, dry matter accumulation, and nitrogen absorption and translocation, and yield components. With all of these, the modification of GA_3 on the physiologic and growth effects of retardants can be better understood.

Materials and Methods

The experiment was carried out on the experimental farm of Zhejiang Agricultural University (Hangzhou). Winter wheat variety ZAU 105 was sown December 5 at a rate of 225 seeds m^{-2}. Compound fertilizer (N:P:K = 15:15:15) was applied before sowing at a rate of 225

Abbreviations: CCC, cycocel; PP_{333}, paclobutrazol; GA, gibberellic acid; PGR, plant growth regulator.

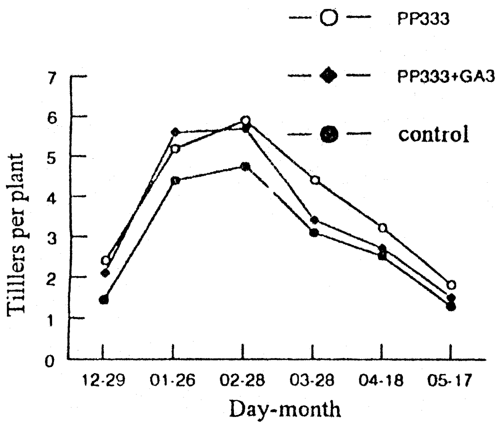

Fig. 1. Effect of different growth regulator treatments on tillering.

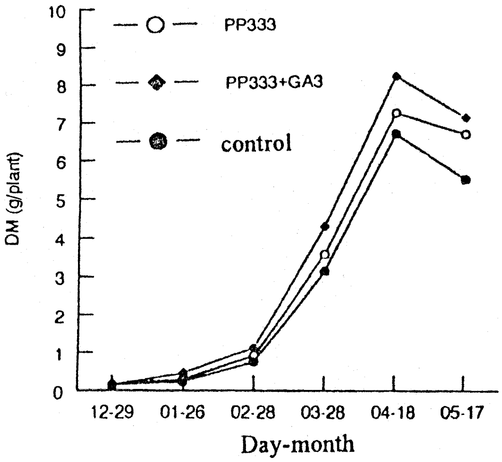

Fig. 2. Effect of different growth regulator treatments on dry matter accumulation.

$kg \cdot ha^{-1}$, and 75 $kg \cdot ha^{-1}$ urea was side dressed when the second internode in the base of the plants began elongating. Weeds were controlled by herbicides. When plants began tillering, three treatments, i.e. 30 ppm GA_3 + 150 ppm PP_{333}, 150 ppm PP_{333}, and water (control) were applied. All solutions were sprayed on foliar surfaces at a rate of 375 $kg \cdot ha^{-1}$. A randomized complete block design was used with four replications. The plot area was 6.6 m^2. At the main development stages (tillering, elongating, booting, heading, and ripening stages) 20 plants were harvested randomly in each treatment, their tiller composition was examined, and plant height was measured. Different tillers were assessed for dry matter accumulation after being oven dried for 0.5 h at 105°C and for 48 h at 85°C. Nitrogen content was determined by wet ashing (H_2SO_4-H_2O_2 method) and Kjeldehl methods. The length of two internodes in the base of mature plants was measured, as were some economic characters.

Results and Discussion

Initiation and Growth of Tillers

Under local conditions, the seedling number at the end of December is correlated closely with spike number because all tillers at that time will have more than three leaves when plants begin elongating, and they can absorb nutrients and water independently, with the potential of developing further into spike-bearing shoots. The observation of tiller number/plant showed that both treatments, PP_{333} alone and its mixture with GA_3, stimulated tiller initiation. On December 29, the tiller number/plant was 1.45, 2.50, and 2.25 for control, PP_{333} alone, and the GA_3 + PP_{333} mixture, respectively. It can be seen from Fig. 1 that the treatment of PP_{333} had the greatest, and the control had the fewest tillers and spike numbers/plant. This suggests that the positive effect PP_{333} has on tiller initiation can be reduced by adding GA_3 to the PP_{333} solution. This effect was not overcome totally by GA_3 as there was still a difference between the treatment mixture and the control in tillering.

Dry Matter Accumulation

There was little difference between the two PGR treatments and the control in dry matter weight before the plants reached the elongating stage (February 28). The dry matter increased gradually, being greatest in the mixture treatment and smallest in the control. At booting stage (March 28), the dry matter weight/plant in the mixture treatment was 1.1 and 2.0 g greater than that in the treatment with PP_{333} and the control, respectively. At heading stage (April 18), when the wheat plant dry matter weight was maximum in all three treatments, the weight of the mixture treatment was 1.2 and 2.1 g greater than those of the PP_{333} treatment and control, respectively. Although the dry matter weight/plant for all treatments fell after heading, there were still some differences in the degree of decrease. At mature stage (May 17), the dry matter weight/plant was similar for treatments with PP_{333} and the mixture, but they were 26.3 and 27.5%, respectively, greater than that of the control (Fig. 2.).

Although the two PGR treatments had effects on the absolute quantity of dry matter, the accumulation pattern did not change. Both treatments, PP_{333} and the mixture, showed the same pattern as the control, in that the dry matter weight/plant increased slowly before stem elongation, increased rapidly from elongating stage to flowering stage, and then fell gradually. As to the relative proportion of dry matter accumulated at different stages, all treatments had similar values: about 5% before elongating and ranging from 73.8% in the mixture treatment to 77.9% in the PP_{333} treatment from stem elongation to flowering.

There were certain differences among treatments in the dry matter accumulation pattern of different tillers (Fig. 3). Compared with the control, the PP_{333} treatment inhibited the main shoot and the first tiller but stimulated

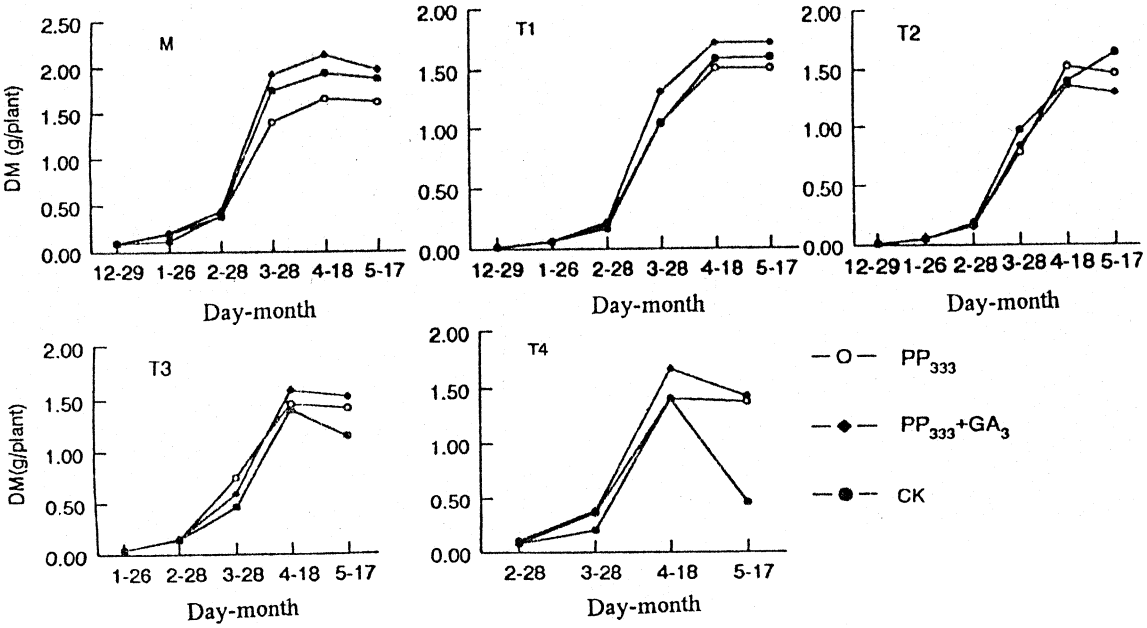

Fig. 3. Effect of different growth regulator treatments on dry matter accumulation of different tillers M, main stem; T1, the first tiller; T2, the second tiller; T3, the third tiller; T4, the fourth tiller.

other tillers in dry matter accumulation, whereas the mixture treatment exhibited the inhibiting effect of PP_{333} on dry matter accumulation of the main shoot and the first tiller and also stimulated the dry matter accumulation in the other tillers.

Plant Height and Lodge Resistance

It was shown that the plant height after PP_{333} treatment was 3.1 cm shorter than that in the control, and the first and the second basal internodes were 1.2 and 1.5 cm shorter than the corresponding internodes in the control plants, respectively (Table 1). Although plant height in the mixture treatment was shortened only by 1.1 cm, the lengths of the first and the second internodes were reduced by 1.16 and 0.61 cm, respectively, compared with the control. By observing lodging scale before harvest, it was found that about 30% of the control plants lodged, whereas plants in both the PP_{333} and the mixture treatments did not. This again suggests that GA_3 will reduce, to a certain extent, the inhibiting effect on stem elongation by PP_{333}, but it still improves lodging resistance because of its positive action on plant height and stem development.

Table 1. Effect of different growth regulator treatments on wheat plant height and internode length.

Treatment	First internode (cm)	Second internode (cm)	Plant height (cm)
PP_{333} + GA_3	3.08ab	7.19ab	97.6ab
PP_{333}	2.55b	6.33b	95.6b
Control	3.74a	7.80a	98.7a

Means with different letters at the same column are significantly different at the 0.05 probability level by the least significant difference test.

Nitrogen Content and Accumulation

There were differences in nitrogen content of the plants among the treatments at jointing and flowering stages (Table 2). For the whole plant, at jointing stage, the mixture treatment had the highest nitrogen content, followed by PP_{333} treatment, being 0.22 and 0.15% higher than that of the control, respectively. Although the PP_{333} treatment group had the highest nitrogen content at the flowering stage, there were relatively small differences among treatment groups. Consistent among treatments was the fact that the main shoot had a lower nitrogen content than tillers at both growth stages. The main shoot and all tillers except secondaries (TS) had a higher nitrogen content in both treatments than those in the controls at jointing stage, but there was little difference among treatments for nitrogen content in the main shoot and tillers at flowering stage.

There were differences in nitrogen accumulation among the treatment groups for both whole plants and each shoot. At the jointing stage, the mixture treatment had the greatest amount of nitrogen accumulation in the main shoot and the various tillers, followed by the PP_{333}

Table 2. Nitrogen content and accumulation in various tillers for different growth regulator treatments.

Treatment	Stage	M	T1	T2	T3	T4	T5	TS	Whole plant
		N content (%)							
PP_{333} + GA_3	ES	1.88	2.15	2.11	2.19	2.20	2.15	2.13	2.13
	FS	0.48	0.65	0.62	0.64	0.64	0.67		0.62
PP_{333}	ES	1.81	2.05	1.96	2.04	2.17	2.16	2.24	2.06
	FS	0.55	0.66	0.71	0.71	0.62	0.63		0.65
CK	ES	1.58	1.90	1.81	1.94	2.01	1.98	2.16	1.91
	FS	0.53	0.63	0.64	0.58	0.63			0.60
		N accumulation (g/100 plants)							
PP_{333} + GA_3	ES	0.819	0.471	0.399	0.333	0.244	0.254	0.136	2.657
	FS	1.027	1.283	0.843	1.018	1.063	1.079		6.312
PP_{333}	ES	0.695	0.355	0.312	0.192	0.184	0.115	0.094	2.002
	FS	0.913	0.430	1.086	1.037	0.806	0.788		5.753
CK	ES	0.619	0.354	0.302	0.270	0.177	0.081	0.071	1.804
	FS	1.134	0.989	0.812	0.835	0.882			4.653

ES, elongation stage; FS, flowering stage; M, main shoot; T1–T5, first tiller to the fifth tiller, respectively.

Table 3. Yield and its components in different growth regulator treatments.

Treatment	Yield ($kg \cdot ha^{-2}$)	Grains/spike and 1,000 grain weight (g)	M	T1	T2	T3	T4	Mean
PP_{333} + GA_3	4,161.90a	GS	41.42	40.42	39.62	41.52	41.61	41.42
		GW	33.91	33.22	32.04	32.61	31.83	33.00
PP_{333}	3,752.40b	GS	40.64	36.03	32.29	32.04	28.81	36.81
		GW	30.81	32.50	30.48	32.81	31.89	31.50
Control	3,696.90b	GS	43.48	36.13	33.39	32.51		38.40
		GW	30.31	31.79	31.71	32.70		31.60

GS, grains; GW, thousand grain weight.

treatment. For the whole plant, the mixture treatment and PP_{333} was 47.3 and 11.0% higher in nitrogen accumulation than the control, respectively. At the flowering stage, nitrogen accumulation in the main shoot was less in both treatments than that in the control, but various tillers showed a contrary trend, which was least obvious in the control. For the whole plant, nitrogen accumulation in the mixture and PP_{333} treatments was 38.3 and 23.8% more than that in the control, respectively. This suggests that the stimulation of nitrogen metabolism by PP_{333} in wheat plants can be improved further by applying GA_3 together with PP_{333}. In the latter case nitrogen translocation into tillers is favored. The effect of the mixture treatment on nitrogen metabolism may underlie the physiologic basis of the stimulation of tiller growth and spike development.

Grain Yield and Its Components

Analysis of yield components in all treatments (Table 3) showed that the PP_{333} treatment group had the greatest number of spikes/hectare, 3.57×10^5, i.e. 13.1% more than the control, whereas the mixture treatment was 2.63×10^5 spikes/hectare or 9.6% more than the control. The higher spike number in both treatments was attributed to the development of the fourth tiller in some shoots.

The number of grains/spike in the mixture treatment was significantly more than the controls, but the PP_{333} treatment group was lower than the controls. As for grain numbers from different tillers, in the control, the main shoot was the greatest. Although considerable variation existed among the different spikes developed from tillers, there was little difference between the main shoot and the tillers in the mixture treatment. It is likely that the higher grain numbers/spike for the plant of the mixture account for improved grain setting in tiller spikes.

For the whole plant, the mixture treatment had the highest grain weight, being 1.4 mg greater than the control. There was little difference between the PP_{333} treatment and the control groups in grain weight. In comparing different spikes, the mixture treatment had the greatest grain weight for the main shoot and the first tiller spike, which was 3.1 and 3.6 mg greater than those of the control and the PP_{333} treatment, respectively.

It can be concluded that each yield component reacted positively to the mixture treatment. As a result, its yield was significantly higher than that of control. Although the PP_{333} treatment group had more spikes/plant, the grain number/plant was reduced to some extent, and thus the latter showed no obvious increase in grain yield.

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