PLANT GROWTH REGULATORS AND GRAIN LEGUMES

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ABSTRACT

The feasibility of using synthetic plant growth regulators (PGRs) for manipulating the stature, dry weight partitioning and seed yield of grain legumes is discussed. The triazole PGR's paclobutrazol and triapenthenol have been field tested and have produced positive responses.

Paclobutrazol reduced stem height in field bean (*Vicia faba*) by 13.8 %, eliminating major lodging problems. In addition there was an overall increase in yield of 42.1 % (190 to 270 g m^{-2}). All yield components were enhanced, but particularly the number of pods (+ 37.3 %). The overall increase in harvest index was highly significant (25.3 to 34.4 %). The increase in yield was linked to increases in flowering and pod retention, particularly on branches.

In lentil (*Lens culinaris*) effects were less pronounced but both paclobutrazol and triapenthenol apparently increased seed yield although not all effects were significant.

The advantages of PGR use in enhancing seed yield and improving aspects of grain legume crop management are discussed. The complex interactions between PGR treatment, soil and climate factors and the potential for improved crop production are considered.

Additional key words: *Plant growth regulator, PGR, paclobutrazol triapenthenol, grain legume, field bean,* Vicia faba, *lentil,* Lens culinaris, *yield enhancement, stature control*

INTRODUCTION

Development of synthetic plant growth regulators: Naturally occurring plant hormones are involved in the control of all plant growth and development events.

There are several endogenous hormone groups; auxins, gibberellins, cytokinins, abscisic acid and ethylene, which interact to determine the activity of physiological processes. The genetically-linked production of plant hormones can be varied by environment and these interactions result in promotion, cessation or retardation of growth and development.

Native plant hormones usually have short-lived, inconsistent effects when applied to plants and have generally not been commercially developed for improved crop performance and yield.

The most radical developments in the chemical manipulation of plant development have involved the use of chemical analogues of endogenous hormones and novel synthetic compounds. The principal objective has been to develop compounds that:

i) increase yield of specific yield components.

ii) improve plant/crop management, often in association with the use of mechanical aids to maintenance and harvesting.

iii) improve post harvest characteristics.

Clearly a major aim is to increase absolute yield or to improve the overall economic efficiency of production. With respect to improvements in yield the rational development of synthetic plant growth regulators (PGR's) has been aimed at:

i) increased net photosynthesis, with a major emphasis on reducing photorespiration.

ii) manipulation of assimilate partitioning to increase harvest index.

iii) delayed senescence to extend leaf area duration.

Unfortunately none of these processes is controlled by a single hormone or for that matter is regulated by a single gene. A conflict arises in the rational development of a PGR to influence yield-determining processes. The development of a simple PGR that mimics, stimulates or inhibits the action of a single endogenous hormone is inadequate for controlling the complex of physiological processes contributing to yield.

The increase in understanding of physiological processes is confirming the complexity of hormonal regulation, particularly if environmental and climatic factors intervene. The fact that a single PGR may only manipulate a part of the overall hormone system controlling a physiological process presumably leads, at best, to reduced or no performance, or at worst, adverse side effects.

There are virtually no examples of biorationally designed PGR's that are in commercial use. Those compounds that interfere with plant hormone production have largely been discovered by empirical methods.

The increasing knowledge of physiological processes and the controlling role of plant hormones suggests that PGR development targeted at manipulation of endogenous plant hormones is not a useful tactic. Biorational development of PGR's should be aimed first at understanding the physiology and chemistry of target processes and secondly at finding chemicals that produce desirable interference with specific enzymatic and control steps. Such an approach to PGR development should result in more specific plant responses and reduce undesirable side effects.

Triazole PGR's The triazole group of compounds that reduce gibberellin biosynthesis can have a marked effect on reducing plant stature (Dawkins, 1986).

Paclobutrazol and triapenthenol are triazole PGR's that have similar modes of action (Rademacher & Jung, 1986) but some differences in biological activity.

PGR's and grain legumes: There are few examples of PGR use in grain legume crops although the potential advantages of being able to constrain their indeterminate growth habit are considerable.

One obvious application of PGR's is the regulation of vegetative growth to prevent lodging of tall crops like field beans (*Vicia faba* L.) or to promote increased height in short stature crop such as dwarf bean (*Phaseolus vulgaris* L.) where harvesting problems, disease damage and soiling of pods borne on lower nodes is a problem.

Repartitioning of dry weight induced by PGR's may produce desirable benefits in the yield forming processes. These opportunities are discussed in relation to recent research carried on field beans and lentils (*Lens culinaris* Medick.).

FIELD BEANS

The tall stature of field bean crops, their indeterminate growth habit and their variable pod set are factors that may reduce seed yield (Newton & Hill, 1987). Spring sown crops are particularly vulnerable and yields are usually lower than from autumn sown crops in New Zealand. The contributing factors have recently been tested experimentally and the linkages between crop phenology and the environment reviewed (Husain *et al.*, 1988 a, b).

The use of PGR's to change plant stature may reduce lodging with some improvement in harvestable yield. An earlier study on field beans (Attiya *et al.*, 1983) revealed that seed yield was increased by 9.3 % and harvest index rose from 45.4 to 49.6 % following application of the PGR, paclobutrazol.

The significant increase in yield was in part attributed to higher pod production but this could not be separated from the major effects on the allocation and partitioning of dry weight, that were linked to reduced stem extension.

A later paper described a more complete analysis of paclobutrazol effects on yield promotion in field bean, (Field, *et al.*, 1989). There was particular emphasis on the formation of vegetative structures for supporting flowers and pods and a detailed analysis of direct effects of paclobutrazol on flower formation, pod development and pod retention.

LENTILS

The positive yield enhancement obtained with PGR application to field beans encouraged investigation of their effects on other grain legume species, particularly lentil.

There is considerable plasticity in the seed yield of lentils (McKenzie *et al.* ,1985, 1986) which may indicate a potential for exploitation by PGR treatments. Effendi *et al.* (1989) demonstrated some positive seed yield increases with the two triazole PGR's paclobutrazol and triapenthenol, although there were major seasonal variations in response.

MATERIALS AND METHODS

Field beans: The field bean (*Vicia faba* cv. Maris Bead) was sown on 6 October 1983 into a Wakanui silt loam soil. The experimental design was a 3 x 3 x 2 split plot with three replicates. The crop was sown in rows 10 cm apart with a precision seeder to achieve populations of 40, 80 and 100 plants m^{-2} in plots 4 x 15 m.

The three PGR treatments, were control, TIBA and paclobutrazol and plots were either irrigated or non-irrigated. Only main effect results from the control and paclobutrazol treatments are presented. There were no interactions among the variates presented.

Paclobutrazol at 1 kg a.i./ ha in 250 l water/ha was applied on 25 November 1983 to plants at the 9 leaf stage, just before flowering. Weed, disease and insect management plus details of fertilizer use and the irrigation strategy are detailed elsewhere (Attiya, 1985).

The crop was sampled at approximately two weekly intervals for analysis of dry matter accumulation by stem, leaf and pod components and for internode and stem length measurements.

Final yield was determined from harvests taken on 1-3 March 1984, both from multiple random quadrats and from a plot combine harvester.

Analysis of yield components on branches and the main stem (Table 2) was calculated from different samples to those taken for the main harvest analysis (Table 1).

For determination of flower and pod set, five plants were selected and tagged in each plot before flowering. Appearance of flowers and pods at all nodes was recorded.

Nodes 10, 13, 16 and 19 were selected and marked with wire loops and flowers and pods were counted at regular intervals to determine formation and loss.

Plants were harvested at maturity and yield components measured at all nodes. A distinction was made between mature pods with at least one fully developed seed and immature pods that had only partial or no seed development.

Lentils: The lentil (*Lens culinaris* L.) cv. Olympic was sown on 18 September 1987 into a Templeton silt loam soil.

The experimental was a 2 x 2 x 4 randomised block design with four replicates. The treatments were plant population (100 and 300 plants m^{-2}), the plant growth regulators, paclobutrazol and triapenthenol, each applied at four rates (0, 0.3, 0.6 and 0.9 kg a.i./ha), (Effendi *et al.* 1989).

The PGR treatments were applied on 11 November 1987 (54 DAS), when the plants were at the 11-12 leaf stage.

The crop was sampled prior to the final harvest taken on 5 February 1988 (136 DAS). Quadrat samples were taken for height and dry weight determinations, and yield components were determined on a sub sample of five plants.

There were no interactions between plant population and the PGR treatments. Therefore only the main effects attributable to the PGR treatments are presented.

RESULTS AND DISCUSSION

Field beans: Application of paclobutrazol did not significantly affect total shoot dry weight at final harvest (1,091 and 1,105 g/m^2, SE = 29.0).

Analysis of individual dry weight components revealed a marked reduction in stem weight which was linked to a shortening in plant height by 13.8 % (1,359 to 1,171 mm, SE = 23.3).

Shorter stature was associated with reduced internode length, particularly of those internodes formed immediately after paclobutrazol application. With paclobutrazol internodes 10, 13, 16 and 19 had a -37.7, -41.0, -21.9 and +2.2 % change in length, respectively.

The reduction in stem length may have been linked to the small but not significant reduction in the percentage of broken stems at final harvest (24.7 to 20.9 %, SE 2.55).

Previous experiments have shown a more significant effect of paclobutrazol in reducing lodging (Attiya *et al.* 1983).

At final harvest (147 days after sowing) the pod fraction in paclobutrazol treated plants contained 34.4 % of the total dry matter compared to 25.3 % in the control. This was a significant increase in harvest index.

Pods in paclobutrazol-treated plants had an increase in absolute dry weight of 37.7 % and this was the basis for a significant improvement in seed yield.

Reduced stem extension was linked to changes in the partitioning of dry weight which gave a significant improvement in harvest index. The induction of such large changes by PGR application are rare and may have been exaggerated in this instance because overall yield was lower than in other seasons (Attiya *et al.*, 1983; Husain *et al.*, 1988a,b).

Notwithstanding the low yield and harvest index, the basis of paclobutrazol-induced enhancement of yield is of major interest and involved not only a change in dry weight partitioning but also had significant effects on reproductive capacity.

Analysis of yield components of individual plants showed that all factors contributing to yield were increased by paclobutrazol (Table 1). The increase in the number of pods per plant was the most significant, increasing by 37.3 %, while the number of seeds per pod and the weight of individual seed increased by 9.5 and 6.2 % respectively.

The maximum potential increase in seed yield of 57.9 % was reduced to approximately 42.1 % because of

Table 1: Components of yield analysis in *Vicia faba* at final harvest (147 d after sowing).

	Control	Paclobutrazol	SEM	Percentage change
Pods/plant	5.1	7.0	0.20	+37.3
Seeds/pod	2.1	2.3	0.06	+ 9.5
Seed weight (mg)	354	376	6.0	+ 6.2
Seed yield (g/plant)	3.8	6.0	0.20	+57.9
Plants/m^{2*}	59	51	1.26	-13.6
Seed yield (g/m^2)	190	270	10.0	+42.1

* independent analysis. (from Field *et al.*, 1989)

a 13.6 % reduction in plant population which was associated with paclobutrazol application.

Effects on flowering and pod set were marked (Table 2). Paclobutrazol induced pod set at lower and higher nodes on the main stem and there was a 42.6 % increase in the number of podded nodes.

Pod retention of all pods was significantly improved by paclobutrazol, although many were immature and did not set seed. Paclobutrazol increased the development of immature pods resulting in no enhancement of mature pods on the main stem.

Paclobutrazol enhanced flowering and subsequent pod set by earlier and more prolonged flowering on the main stem, (Tables 1, 2).

Although pod retention was high and there was an increase in the number of podded nodes, this did not increase seed yield on the main stem.

The major increase in the number of pods per plant was linked to paclobutrazol-induced changes in both vegetative growth and the pattern of flowering.

Paclobutrazol increased the number of branches per plant from 0.8 to 0.9 (SE 0.09) while their dry weight increased from 4.9 to 6.7 g (SE 0.46). While paclobutrazol induced changes to pod production increased the yield potential on the main stem, the real benefits were associated with changes to branching.

Branch number was increased slightly by paclobutrazol and this may be linked to redistribution of dry weight and the reduction in main stem dry weight. Analysis of seed yield (Table 2) showed that paclobutrazol-induced enhancement was linked to a 118.2 % yield increase on branches.

The major effect of paclobutrazol on field beans was apparently developmental and the very large increase in mature pod production on branches may have related to earlier pod initiation, as demonstrated for the main stem (Table 2). Overall the positive effects of paclobutrazol seem to be more closely linked with developmental changes rather than gross allocation of dry weight.

The small but positive increases in the number of seeds per pod and mean seed weight could be associated with either factor while earlier developmental events such as the pattern of flowering and pod set are probably not linked directly to dry weight partitioning.

Lentils: Paclobutrazol significantly reduced plant height from 331 mm to 282, 284 and 249 mm (se 13.0) at 0.3, 0.6 and 0.9 kg a.i./ha, respectively, at 82 DAS. Significant height reductions were only found in the 0.9 kg a.i./ha treatment at 109 DAS.

In contrast reductions in height with triapenthenol were less marked, dropping from 317 mm to 307, 286 and 276 mm (SE = 13.0) at 0.3, 0.6 and 0.9 kg a.i./ha respectively, at 82 DAS. No significant differences were apparent at 109 DAS.

There was no significant effect of PGR's on total dry matter production, pod number, and seeds per pod. However, both paclobutrazol and triapenthenol affected ($P < 0.05$) seed yield with a maximum of 251.1 g/m^2, and of 239.0 g/m^2 respectively, (Table 3).

Paclobutrazol at 0.6 kg a.i./ha increased HI from 44.8 to 49.2 % ($P < 0.001$). It had no effect on the number of branches (Table 3).

Triapenthenol also affected seed yield and gave a maximum yield of 240.7 g/m^2 at 0.6 kg a.i. /ha (P <

Table 2: Pattern of pod formation and distribution of seed yield on main stem and branches of *Vicia faba*.

	Control	Paclobutrazol	SEM	Percentage change
First podded node	13.6	13.2	0.21	
Final podded node	19.0	21.0	0.27	
Number of podded nodes	5.4	7.7	0.29	+42.6
Percentage pod retention (125 - 147 DAS)	78.3	99.4	7.55	+26.9
Mature pods per main stem	3.4	3.4	0.29	0
Mature pods per branch	1.4	3.0	0.31	+114.3
Seed yield per main stem (g/stem)	2.5	2.7	0.20	+8.0
Seed yield per branch (g/branch)	1.1	2.4	0.33	+118.2

(from Field *et al.*, 1989)

Table 3: The effect of PGR treatment on dry matter production, seed yield, harvest index and yield components in lentils.

Treatment	Dry matter g/m2	Seed yield g/m2	Harvest index %	Branches/ plant	Pods/ plant	Seeds/ pod	Mean seed weight mg
Paclobutrazol (kg a.i./ha)							
0.0	480.0	215.0	44.76	13.6	30.3	1.17	65.4
0.3	505.3	243.0	47.51	16.1	28.5	1.08	70.1
0.6	507.3	253.4	49.80	15.3	33.5	1.12	70.6
0.9	479.5	235.7	49.15	16.8	32.1	1.14	67.9
Tripenthenol (kg a.i./ha)							
0.0	457.0	213.5	46.70	12.3	32.6	1.14	68.0
0.3	487.7	236.5	48.55	15.4	34.5	1.10	68.3
0.6	501.4	240.7	48.12	17.1	29.2	1.07	69.5
0.9	474.9	218.5	48.65	14.6	33.6	1.12	65.9
SEM	23.6	14.4	1.15				

0.05). Branch number increased with a maximum of 17.1 branches per plant ($P < 0.05$).

Under favourable moisture conditions paclobutrazol and triapenthenol increased ($P < 0.05$) seed yield/ha (Table 3). This was mainly due to a higher number of pods per plant, total dry matter production, and HI.

This was related to lower plant height and shorter mean internode length following PGR application (Table 3). Reduced height induced by the PGR's tended to increase assimilate partitioning to generative organs like pods, or supporting organs such as branches.

It is possible that the reduction in plant height and mean internode length increased the competitive ability of the pods for assimilate supply and aided seed formation.

The PGR effect on lentils was achieved in a season of adequate soil moisture and pronounced vegetative growth, (Effendi *et al.*, 1989). In contrast in a dry season with inadequate irrigation there was no effect of PGR's effects and thus no increase in yield (Effendi *et al.*, 1989).

Poor performance may be attributed to a low yield potential in the dry season or lack of PGR efficacy because of poor soil mobilization.

The experiment reported here involved a single time of PGR application at the 11-12 leaf stage. Earlier application at the 6-7 leaf stage was less effective in inducing increased yield (Effendi *et al.*, 1989).

Many of the triazole group of PGR's, such as paclobutrazol and triapenthenol are rate and time dependent in their effects on crop growth (Dawkins, 1986).

There is a clear need to understand the relationships between the time and rate of PGR application, lentil crop phenology, environment and soil factors and possible yield enhancement.

CONCLUSIONS

The use of triazole PGR's on grain legume crops such as field beans and lentils may confer significant yield and management advantages.

Commercial development of PGR treatments for grain legumes is likely to depend on the consistent demonstration of advantages.

The evidence suggests that the potential benefits of PGR application to legume crops with an indeterminate growth habit is considerable and greatly exceeds those found in other crops such as cereals (McLaren, 1982) and sugar beet (Stevens, 1985).

Chemical treatments that limit vegetative growth often increase flower production and fruit set by reducing competition for assimilates (Quinlan, 1982). In field beans the extension of flowering and pod formation to node 21 (Table 2) by paclobutrazol was a developmental advance that was not maintained to full pod maturity. This suggests either, that while initial assimilate supply was adequate it could not be maintained or that other regulatory factors were determining pod development. It is significant that other gibberellin synthesis inhibitors, CCC and B9 have been shown to increase flower set in field beans (El-Beltagy *et al.*, 1979), while in other species gibberellins have been closely linked with flower induction and fruit development (El-Beltagy *et al.*, 1979; Quinlan, 1982).

The present data suggests that paclobutrazol-induced changes in gibberellin biosynthesis may contribute positively to reproductive development that improves seed yield per plant.

Overall, application of triazole PGR's to field beans and lentils produced major benefits in seed yield enhancement (Tables 1, 3). In addition in a tall crop such as field bean there are potential crop management and harvesting improvements associated with reduced plant height and more robust stems (Attiya *et al.*, 1983; Field *et al.*, 1989).

While yield enhancement trends were also found in lentils any reduction in plant height in this crop may cause harvesting difficulties.

Soil residual problems with some triazole PGR's, notably paclobutrazol may create limitations to their use and influence of crop rotations. While no major post-crop problems have been experienced with paclobutrazol applications of 1 kg a.i./ha, or less, there are advantages in developing alternatives to blanket, post-emergence applications.

Dobson & Field (1987) demonstrated the possibility of incorporating paclobutrazol into a seed treatment at sowing. Retardation effects were pronounced and such an approach could provide a more cost-effective PGR treatment method for grain legume crops.

The experimental data presented here indicate the potential advantages of using PGR's to regulate the growth and development of indertiminate grain legume crops.

It is equally clear that yield and management benefits may be inconsistent and relate to seasonal changes in environment, particularly available soil water (Attiya, 1985; Effendi *et al.*, 1989).

Further research is required to determine optimum PGR treatments and to eliminate the unreliability of their response. The overwhelming conclusion is that under ideal conditions PGR treatment may dramatically enhance seed yield and produce benefits that exceed those typically attainable in a short term plant breeding programme.

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