Use of plant growth regulators for reduced pass harvesting of cauliflower and broccoli

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Department of Agriculture & Food Western Australia

Project Number: VG06013

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This report is published by Horticulture Australia Ltd to pass on information concerning horticultural research and development undertaken for the vegetables industry.

The research contained in this report was funded by Horticulture Australia Ltd with the financial support of:
Warren Cauliflower Group (Inc)
the vegetables industry

ISBN 0 7341 2396 5

Published and distributed by:
Horticulture Australia Ltd
Level 7
179 Elizabeth Street
Sydney NSW 2000
Telephone: (02) 8295 2300
Fax: (02) 8295 2399

Department of Agriculture and Food
GOVERNMENT OF WESTERN AUSTRALIA

USE OF PLANT GROWTH REGULATORS FOR REDUCED PASS HARVESTING OF CAULIFLOWER AND BROCCOLI

HORTICULTURE AUSTRALIA PROJECT VG06013
(14 JUNE 2010)

Rachel Lancaster and Helen Ramsey
Department of Agriculture and Food
Western Australia

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USE OF PLANT GROWTH REGULATORS FOR REDUCED PASS HARVESTING OF CAULIFLOWER AND BROCCOLI

Horticulture Australia Limited
Final report project VG06013

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FUNDING SOURCES
Funding for research and development conducted by this project was provided by Horticulture Australia Limited (HAL) and the Australian vegetable industry through its National Vegetable Levy, the Department of Agriculture and Food, Western Australia and the Warren Cauliflower Group (Inc.).

PURPOSE OF THE REPORT
This final report provides information on research to determine if plant growth regulators could be used to reduce the spread of crop maturity in cauliflower and broccoli. The direction of the research expanded in the later stages of the project to investigate the role of uniformity of seed germination on the rate of crop maturity. The project was conducted from September 2006 to March 2010.

Project VG06013 investigated:

- The use of the plant growth regulators, gibberellic acid (GA_{4+7}) and ethephon, to assist in the synchronisation of crop maturity in cauliflower and broccoli.
- The influence of uniformity of seed germination on the spread of crop maturity in cauliflower and broccoli.

ACKNOWLEDGEMENTS
The authors of this report wish to thank Horticulture Australia, the Australian vegetable industry and the Warren Cauliflower Group (Inc.) for funding this work through the national levy and by voluntary contribution. The Department of Agriculture and Food Western Australia provided support for salaries, operating and infrastructure. The substantial in-kind support provided by members of the brassica growing sector of the vegetable industry is acknowledged with thanks.

The authors thank in particular the following people of who provided valuable assistance to the project: management and staff at of the Department of Agriculture and Food research stations at Manjimup and Medina, Jane Speijers, Biometrician, Department of Agriculture and Food, South Perth, and the Committee and Executive Officer of the Warren Cauliflower Group (Inc.).

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DATE OF REPORT: 14 June 2010

This project has been funded by HAL using the vegetable levy and voluntary contributions from industry with matched funds from the Federal Government

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1 Media Summary

The primary purpose of this project was to assess the influence of the plant growth regulators (PGR's), ethephon and gibberellic acid (GA_{4+7}) on the uniformity of maturity for the vegetable brassicas, cauliflower and broccoli. The influence of seed germination date on crop maturity was also examined.

Reducing the spread of crop maturity in cauliflower and broccoli will provide savings to growers as less labour is required to remove the crop. Typically, broccoli requires at least two harvests and cauliflower at least three harvests to remove an entire crop. The costs associated with the harvest are both direct as wages and indirect, with the sourcing and training of labour becoming increasingly difficult.

The use of the PGR's, ethephon and gibberellic acid (GA_{4+7}) to influence the spread of crop maturity and reduce the number of harvests is not recommended. The experiments conducted in this project demonstrated that generally the PGR's had little influence on the uniformity of crop harvest. Where an effect on crop uniformity or yield was found, the results were not repeatable at different times of year. There is also no practical commercially viable method for determining when the PGR's should be applied with the technique used to determine floral initiation in these experiments being time consuming and cumbersome.

The PGR studies highlighted that uneven seed germination was a potential factor contributing to a lack of uniformity in crop maturity. In a preliminary study, there was a small reduction in the spread of crop maturity when using uniformly germinated seed and an increase in the marketable yield. Currently, there is no practical method that allows seedlings that all germinate on the same day to be easily selected in a commercial seedling nursery.

Further research is required to fully investigate the role of uniformly germinating seed on harvest period. This should include the role of short term methods such as seed priming and seed scouring on the spread of crop maturity, in addition to long term plant breeding, where seed germination date should be included as an additional criterion to assess when developing new varieties.

2 Technical Summary

The vegetable brassicas cauliflower (*Brassica oleracea* var. *botrytis*) and broccoli (*Brassica oleracea* var. *italica*) are mainly hand harvested in Australia, as crops tend to mature unevenly. This requires several passes over a single crop, removing the cauliflower curd or broccoli head at their optimum maturity for high quality. Passing over a crop more than once causes increased labour costs for growers both as wages and as increased costs associated with sourcing and training labour. Several passes also contribute to a decrease in quality of later maturity curds and heads as physical damage can occur to plants as people move through the crop.

The length of the maturity period for cauliflower and broccoli is determined by the floral initiation period. Floral initiation only occurs after a period of vegetative juvenility. Once the juvenile stage is completed, the correct environmental factors, such as a period of vernalisation, are required to start floral initiation. The primary purpose of this project was to assess if the plant growth regulators (PGR's), ethephon and gibberellic acid (GA_{4+7}) could substitute for natural environmental factors, promoting uniform floral initiation and consequently more uniform crop maturity. Within this project, the experiments conducted highlighted that uneven seed germination was a potential factor contributing to a lack of uniformity in crop maturity. The effect of uniformity in seed germination on harvest maturity was also investigated.

In each experiment, the period of floral initiation was identified in cauliflower and broccoli and the PGR's ethephon and GA_{4+7} were applied either prior to, at or post floral initiation. This was repeated at different times of year and at different locations, where the mean air temperature was different. Depending upon the experiment, the PGR's were also applied at different rates and / or in combination.

The use of the PGR's, ethephon and gibberellic acid (GA_{4+7}) to influence the spread of crop maturity and reduce the number of harvests is not recommended as overall the PGR's had little influence on the uniformity of crop harvest. In some experiments on broccoli, a positive effect on time to harvest and crop yield was found however the results were not repeatable at different times of year. Currently there is no practical, commercially viable method for determining when the PGR's should be applied with the technique used to determine floral initiation in these experiments being time consuming and cumbersome. For leaf number to be used as an indicator of floral initiation, studies would be required on individual varieties, which are constantly changing as new varieties are introduced by commercial seed companies.

In a preliminary study, there was a small reduction in the spread of crop maturity when using uniformly germinated seed and an increase in the marketable yield. Seedlings that germinated earlier, also tended to be larger at transplanting than those that germinated three or four days later. Currently, there is no practical method that allows seedlings that all germinate on the same day to be easily selected in a commercial seedling nursery.

No further research on the use of PGR's to influence floral initiation date in the vegetable brassicas is recommended. Further research is required to fully investigate the role of uniformly germinating seed on harvest period. This should include the role of short term methods such as seed priming and seed scouring on the spread of crop maturity, in addition to long term plant breeding, where seed germination date should be included as an additional criterion to assess when developing new varieties.

3 General Introduction

This project investigated the plant growth regulators, ethephon and gibberellic acid, to determine if they reduced the spread of harvest of broccoli and cauliflower crops. The influence of application rate and time of application on the spread of harvest was also investigated. If successful, reducing the spread of harvest will allow growers to make savings in their harvesting costs, lowering overall input costs and providing for a more cost competitive product.

Improving the competiveness of the Australian brassica industry is a major factor for increasing growth in the sector. A large cost incurred by growers is for labour with approximately 40% of the variable production costs being for labour associated with harvesting (P. Gartrell, personal communication).

The production of vegetable brassicas, in particular cauliflower, has fallen recently, largely due to the impact of low cost produce from China in the traditional Australian export markets of Singapore and Malaysia. Australian producers need to improve their cost competiveness to be able to compete in these markets. It is likely that even with improvements in costs competitiveness, Australian produce will not be priced as low as Chinese produce however Australia producers are looking to expand sectors of export markets such as restaurants, foreign supermarkets and the food service sector where safe, high quality food may attract a price premium.

Although higher prices are paid in these market sectors, compared to the traditional wet markets, Australian produce must still not be priced excessively high as products from other countries, such as the USA become increasingly attractive to local buyers.

Selective harvesting of cauliflower and broccoli crops is labour intensive as up to six passes over the crop may be required before it is completely removed. A reduction in the number of passes required to only one or two would substantially reduce labour costs and in suitable production areas, enable the introduction of mechanical harvesting. Mechanisation of harvest would further reduce labour costs, improving the competitiveness of Australian grown brassicas on the international market.

For mechanisation to be technically and financially viable, the majority of the crop must be mature at the one time. The length of the maturity period of a cauliflower crop is strongly correlated with the duration of the curd initiation period (Salter, 1969) and after initiation the time taken for individual curds to grow to maturity is relatively uniform (Booij, 1987). Therefore, if curd initiation could be synchronised, it may improve the uniformity of crop maturation and allow for mechanised harvesting.

Floral initiation occurs in cauliflower and broccoli plants after a period of vegetative growth. The vegetative period consists of a juvenile phase during which the plant is unable to initiate reproduction, even if environmental conditions are correct and a mature phase when plants can initiate reproduction, given correct environmental conditions. The duration of juvenility is determined primarily by genotype and environment (Wien and Wurr, 1997). The rate at which initiation occurs after juvenility is determined by the same factors plus a vernalisation response (Atherton *et al*., 1987, Booij, 1987). This means that environmental and cultural conditions operating at a very early stage of plant growth, as well as climatic conditions during the actual initiation period can influence the maturity characteristics of a crop.

Plant growth regulators (PGR's) such as ethephon and gibberellic acid are used to influence the process of floral initiation in a number of different crops. Ethephon can be used in crops such as pineapple to artificially induce floral initiation. When applied, the product increases the

production of endogenous ethylene within the plant resulting in the start of floral differentiation. By artificially inducing plants, rather than allowing natural floral initiation to occur, initiation is synchronised resulting in a more uniform and shorter flowering period.

In an initial investigation, Salter and Ward (1972) found that ethylene had no effect on curd maturity characteristics. This result was confirmed by Booij (1989) who found that ethylene had no effect on curd initiation and hence the maturity period. The varieties tested are likely to have an influence on the success of this product. A greater effect of ethylene may be seen with varieties normally grown during the winter period, since the application of ethylene in conjunction with high temperatures has been shown to increase bracting (Booij, 1990). The most effective rate and time of ethephon application are not known.

Gibberellic acid has been demonstrated to effectively substitute for the vernalisation requirement of a number of different plant species including some brassicas (Leshem and Steiner, 1968). During summer and autumn, environmental conditions are often inadequate to completely satisfy the vernalisation requirement of cauliflower and broccoli crops. The application of gibberellic acid to these crops may aid synchronisation of floral initiation, reducing the period of crop maturity and the spread of harvest.

The type of gibberellin used to influence flowering in cauliflower and broccoli should be considered. Success at improving cauliflower curd maturation uniformity using GA_3 has been variable (Guo *et al*., 2004; Booij, 1989; Leshem. and Steiner, 1968), however research conducted by Booij (1989) found the application of GA_{4+7} resulted in earlier curd initiation. For PGR application to be effective, the product must be applied when plants have completed juvenility and are receptive to external stimuli. Leaf number was found by to be an effective and reliable method for marking the developmental stages of cauliflower (Booij, 1987; Salter, 1969).

This method was utilised to determine the time of curd/head initiation in a number of cauliflower and broccoli varieties cultivated in Australia as part of this project. The number of leaves present at curd/head initiation varies significantly between varieties and therefore was established for each individual variety tested. The final number of leaves present at curd/head initiation remains fixed for each variety and is not altered by environmental influences. However the time taken for the number of leaves to form is influenced by external influences such as temperature. By determining the final leaf number at curd/head initiation and the time taken to reach initiation it may be possible to apply PGR's to the crop at a time when it was likely to have the greatest influence on curd/head initiation.

4 Research Program

The experiments in the project were conducted from November 2006 to September 2007 on a clay loam soil type at Manjimup Horticultural Research Institute, which is located 300 km south west of Perth. From September 2007 to December 2009, the experiments were conducted on a sandy soil type at the Medina Research Station, located approximately 50 km south of Perth.

4.1 Plant Growth Regulator Experiments

The plant growth regulators, gibberellic acid and ethephon were investigated within the project experimental program. Gibberellic acid in the form of GA_{4+7} was used as the literature (Booij, 1989) indicated this is a more active form, compared to GA_3. The source of GA_{4+7} used varied during the project. Initially, GA_{4+7} was applied in a diluted form with no other carriers in the mixture apart from water. As the project progressed, it became increasingly difficult to source this form of GA_{4+7} and a decision was made to concentrate on products containing GA_{4+7} that would be easily available to commercial growers. From August 2008, the GA_{4+7} was applied using the commercially available product 'Cytolin'. Ethephon was applied throughout the project as the commercially available product 'Ethrel'.

4.1.1 Experimental program (Year 1)

4.1.1.1 Gibberellic Acid, Summer 2006, Manjimup

Introduction

The experiment was conducted to examine using gibberellic acid in the form of GA_{4+7} to induce curd initiation in both broccoli (cv. Viper) and cauliflower (cv. Monarch). The experiment was transplanted at the Manjimup Horticultural Research Institute on 7 November 2006.

Methods

There were 10 treatments, which are listed in Table 4–1. The experiment was designed as three rates of GA_{4+7} by three times of application factorial plus additional control, in a restricted randomised block design with three replicates. The restriction in the design allowed treatments for each application date to be placed together to reduce the risk of spray drift between treatments.

Cauliflower and broccoli were planted using a mixture of Summit Spud at 1400 kg/ha and AllPhos at 150kg/ha as basal fertiliser, applied in an incorporated strip. Cauliflower and broccoli seedlings were purchased from a commercial nursery at 6 weeks of age and transplanted into a three rows per bed configuration with 50 cm between plants within a row and 45 cm between rows. Normal commercial practice for the maintenance of the plants was conducted, with insect, weeds and diseases being controlled as necessary. Post-transplant fertiliser to maintain growth was applied as required, reflecting normal commercial practice.

The GA_{4+7} was applied at three different application times. The application times were determined by the physiological age of the plant, with application time one (AT1) being immediately prior to natural floral initiation, application time two (AT2) coinciding with the time of natural floral initiation and application time three (AT3) being after natural floral initiation had occurred. The timing was determined from previous studies into curd initiation in cauliflower

and broccoli where the number of leaves at curd / head initiation was counted and by assessment of changes in the apical meristem of the plants. The apical meristem was observed under a dissecting microscope for morphological changes (Tan *et al*., 1998), which indicate the commencement of floral initiation. The number of leaves on a sample of ten untreated plants from each of the broccoli and cauliflower crops were counted at transplanting. Plants were sampled from the field twice a week, monitoring leaf number and morphological changes to the meristem, until floral initiation had occurred on 100% of plants sampled.

At each application time, the total rate of GA_{4+7} to be applied was halved and applied to the plants as a split application with at least three days between each split application. Multiple applications of GA_{4+7} have been found to be more effective then a single application (Booij, 1989).

Table 4–1: Application time and date for GA_{4+7} applied to cauliflower and broccoli

Treatment number	Application rate (mg active ingredient /plant)	Cauliflower application time (DAT)*	Broccoli application time (DAT)*
1	Nil (control)		
2	1.44	AT1 (20 and 24)	AT1 (7 and 11)
3	2.16	AT1 (20 and 24)	AT1 (7 and 11)
4	2.88	AT1 (20 and 24)	AT1 (7 and 11)
5	1.44	AT2 (23 and 27)	AT2 (10 and 14)
6	2.16	AT2 (23 and 27)	AT2 (10 and 14)
7	2.88	AT2 (23 and 27)	AT2 (10 and 14)
8	1.44	AT3 (27 and 31)	AT3 (14 and 18)
9	2.16	AT3 (27 and 31)	AT3 (14 and 18)
10	2.88	AT3 (27 and 31)	AT3 (14 and 18)

* DAT = Days after transplanting. Each application was split into two applications for each stage of growth.

At each spray application time, the required amount of GA_{4+7} solution was mixed with 29 L of water. This was applied to each treatment using a tractor mounted boom spray. There were substantial buffers between each plot and low drift nozzles were used on the boom spray to help reduce the risk of spray drift between plots.

A single pass harvest was conducted across the experiment. To determine the optimum time for harvest, a sample of 20 plants was assessed daily as the curds / heads approached maturity. When 80% of the sample plants were mature, a single pass harvest was conducted. The harvest date for broccoli was 4 January 2007 and for cauliflower was 30 January 2007. Data collected at harvest included curd / head weight, harvest date, curd / head quality and curd / head density. The marketable yield was determined by removing all curds / heads from the analysis which did not meet the specifications for either the domestic or export markets.

Data was analysed in Genstat (Windows v 9.1). The data was analysed twice; the first time included all the treatments and the control, allowing differences between the treatments and control and the rate and time of application across all plots to be determined. The second data analysis did not include the control, to determine if there was a linear effect of rate of GA_{4+7} and time of application. Uniformity of curd/head maturation was determined by analysing standard deviation of head/curd weight from the mean of the harvest sample, with a greater standard deviation indicating that curd/head initiation was not synchronised.

Results and Discussion

Leaf counts and floral initiation

Natural floral initiation for the cauliflower variety Monarch occurred between 20 days (0% initiated) and 24 days (20% initiated) after transplanting, when the plant had 27 leaves (Table 4–2). Natural floral initiation for the broccoli variety Viper, occurred between 11 days (0% initiated) and 16 days (40% initiated) after transplanting, when the plant had 22 leaves (Table 4–3).

Table 4–2: Cauliflower leaf counts and floral initiation

Days after transplant	Average leaf number	Curd floral initiation (%)
20	24.9	0
24	28.4	20
28	33.3	50
34	39.5	70
40	44.7	90
42	47.6	100
48	48	100

Table 4–3: Broccoli leaf counts and floral initiation

Days after transplant	Average leaf number	Curd floral initiation (%)
7	14.3	0
11	18.2	0
16	22.5	40
20	25.9	80
28	30.4	100

Harvest results

The application of GA caused a significant reduction in the yield when the untreated control was compared to the GA treated plants (Table 4–4). This was due to the GA causing damage to the plants by burning the leaves although this appears to have been influenced by the application time. Within the GA treated plants, the time of application caused a significant difference in the yield however this was not consistent for each of the application times. Plants to which 1.44 mg GA/plant was applied produced the greatest total yield at the second application time for GA. In contrast, for the rates 2.16 mg GA/plant and 2.88 mg GA / plant, the lowest total yield occurred when the plants were treated with GA at the second application time. The second application time coincided with what was assessed to be the stage at which floral initiation was occurring. If the rate of GA was too high, the process of floral initiation may have been affected, reducing the overall yield as fewer plants successfully set a curd.

The average weight of each curd was significantly higher in the control plants compared to those treated with GA for all curds and marketable curds. However this was not reflected in the marketable yield where there was no significant difference by applying GA compared to the untreated plants. Despite having the highest average curd weight, the marketable yield of the untreated plants was lower than the best yield from the treated plants, suggesting there were more non-marketable curds in the untreated plants. Causes of unmarketable curds can range from being over mature, very under mature or displaying symptoms of diseases, insect damage or poor growth. There was also no significant difference within the GA treated plants when the marketable yield was analysed (Table 4–4).

Table 4–4: Harvest data after treatment of cauliflower plants with three rates of GA_{4+7} by three application times

Application time	Application rate (mg/plant)	Total yield (t/ha)	Total curd weight (g)	Marketable yield (t/ha)*	Marketable curd weight (g)*
0	0	35.59	1015.77	27.59	1032.42
1	1.44	31.25	903.91	26.82	945.42
1	2.16	32.30	941.27	29.60	957.87
1	2.88	33.91	966.40	29.10	997.52
2	1.44	32.35	935.71	28.46	967.67
2	2.16	29.39	873.83	25.60	921.33
2	2.88	29.11	836.06	23.71	889.01
3	1.44	30.64	904.85	27.29	938.41
3	2.16	32.33	948.12	26.97	963.40
3	2.88	32.65	931.82	27.21	946.17
All treatments (lsd 5%)		0.002 (2.3)	0.004 (63.3)	ns	0.01 (62.2)
Rate effect (lsd 5%)		ns	ns	ns	ns
Time effect (lsd 5%)		0.05 (2.5)	ns	ns	ns

* Marketable yield, weight and diameter are determined after all curds that do not meet specifications for either the export or domestic markets are removed.

The application of GA at all rates and times caused a significant increase in the percentage of smaller curds at harvest compared to the control (Table 4–5). This was reflected by the greater percentage of curds from the control treatment being in the 'greater than 1100 g' weight category. The increase in the percentage of lower weight curds among the treated plants is largely due to the negative effects of the GA on the plants after application. Burning of the plant leaves occurred after application of the GA, which is likely to have reduced the growth of the plants, preventing them from reaching their full potential at maturity.

Table 4–5: Percentage of cauliflower curds in different weight categories

Application time	Application rate (mg/plant)	Curds less than 900g (%)	Curds between 900 g and 1100 g (%)	Curds greater than 1100 g (%)
0	0	32.00	28.00	40.00
1	1.44	46.64	27.03	26.33
1	2.16	42.74	33.36	23.90
1	2.88	40.10	29.37	30.53
2	1.44	48.61	22.34	29.05
2	2.16	53.47	25.69	20.83
2	2.88	58.45	27.47	14.08
3	1.44	51.02	22.68	26.30
3	2.16	38.38	36.98	24.65
3	2.88	44.67	30.67	24.67
All treatments (lsd 5%)		<0.001 (8)	ns	0.004 (10)
Rate effect (lsd 5%)		ns	0.02 (7.8)	ns
Time effect (lsd 5%)		0.005 (8.8)	ns	ns

Factors which caused the GA to burn the cauliflower leaves have not been identified. It is believed that atmospheric conditions at the time of application may have contributed. At the first application time, the maximum air temperature was 28.7°C. At the second (spray 2) and third application time (spray 1), there was a sudden increase in temperature to 27.4°C, which was up to 9°C warmer than the two previous and two subsequent days. Treatment application occurred during the late afternoon and the plants were in full sun at the time of GA spray application. A combination of the full sun on the leaves and the warmer air temperatures may have led to the burn marks being present on the leaves. To avoid this in future trials, the GA was only applied when the plants were not in the full sun and in the cool of the early evening.

The standard deviation of the curd weight from the mean was significantly lower in plants treated with GA compared to the control (Table 4–6). Although not significant, the standard deviation from the mean was also lower in the treated plants for the marketable yield. This suggests that the GA may have reduced the spread of curd initiation however it is more likely to

be a reflection of the negative effect of the GA. Plants which were slightly larger at the time of treatment, may have taken relatively longer to recover from the GA, causing the overall rate of growth to slow. This would have allowed the smaller plants to 'catch up', allowing the range of curd weights at maturity to be reduced.

Table 4–6: Standard deviation of curd weight for all and marketable curds

Application time	Application rate (mg/plant)	Standard deviation of curd weight (total)	Standard deviation of curd weight (marketable)
0	0	369.50	308.98
1	1.44	293.42	269.07
1	2.16	258.05	221.68
1	2.88	325.64	300.08
2	1.44	337.43	278.55
2	2.16	295.08	273.34
2	2.88	359.75	293.13
3	1.44	301.50	278.70
3	2.16	271.74	238.76
3	2.88	264.21	235.97
All treatments (lsd 5%)		0.05 (68.95)	ns
Rate effect (lsd 5%)		ns	ns
Time effect (lsd 5%)		ns	ns

Gibberellic acid applied to broccoli did not influence the yield when the untreated control was compared to the treatments. Within the treatments there was a significant reduction in marketable yield as the rate of gibberellic acid applied increased (Table 4–7). The probable cause of this was a reduction in growth of the plants due to the high rate of gibberellic acid causing extensive burning to the leaves of the plants.

The crop was removed in a one pass harvest, with there being no significant difference in the head weight ranges between untreated and treated plants (Table 4–8). This suggests that gibberellic acid did not promote floral initiation in the broccoli, with plants maturing at the same rate regardless of treatment. If the crop was harvested as the heads reached maturity, instead of in a one pass harvest, it is likely at least two harvests would have been required to remove the entire crop.

Table 4–7: Harvest data after treatment of broccoli plants with three rates of GA_{4+7} by three application times

Application time	Application rate (mg/plant)	Total yield (t/ha)	Total head weight (g)	Marketable yield (t/ha)	Marketable head weight (g)
0	0	11.97	272.38	10.39	316.59
1	1.44	12.28	285.70	10.37	307.64
1	2.16	11.95	279.16	10.27	303.01
1	2.88	10.79	241.02	6.75	280.50
2	1.44	11.59	265.54	9.92	298.24
2	2.16	11.55	267.02	9.07	298.84
2	2.88	10.20	234.68	7.19	295.73
3	1.44	11.69	271.54	9.65	305.16
3	2.16	13.06	304.70	10.92	328.64
3	2.88	12.39	284.44	9.54	315.77
All treatments (lsd 5%)		ns	ns	ns	ns
Rate effect (lsd 5%)		ns	ns	0.006 (2.0)	ns
Time effect (lsd 5%)		ns	ns	ns	ns

Table 4–8: Percentage of broccoli heads in different weight categories

Application time	Application rate (mg/plant)	Heads less than 250 g (%)	Heads between 250 g and 650 g (%)	Heads greater than 650 g (%)
0	0	39.96	60.04	0.00
1	1.44	38.03	58.02	0.52
1	2.16	39.44	60.56	0.00
1	2.88	54.12	45.88	0.00
2	1.44	45.30	54.70	0.00
2	2.16	44.46	54.98	0.56
2	2.88	57.55	42.45	0.00
3	1.44	41.44	58.56	0.00
3	2.16	31.46	68.54	0.00
3	2.88	42.14	57.86	0.00
All treatments (lsd 5%)		ns	ns	ns
Rate effect (lsd 5%)		ns	ns	ns
Time effect (lsd 5%)		ns	ns	ns

Within the treated plants, there was again no significant difference in head weight range between the rate and application times although there was a trend of more low weight heads to be produced at the highest rate of gibberellic acid, for application times one and two. This suggests that vegetative damage was caused to the plants when the gibberellic acid was applied at a high rate, either before or at floral initiation. This may have caused the growth of the plants to be reduced, resulting in the broccoli not reaching its potential maximum head weight at maturity. At application time three which was after floral initiation, this trend did not occur suggesting the plants were more tolerant of the gibberellic acid and less damage to leaf material occurred.

There was no significant difference in the standard deviation of the head weight from the mean for all heads and marketable heads, indicating that GA did not have an influence on the uniformity of crop maturity in broccoli. The failure of GA to affect broccoli crops may have been due to the product being applied too late to the crop with natural head initiation having already commenced prior to application times two and three. At application time one, the crop may have been too immature (that is; still in the juvenile phase) for the GA to be effective.

Figure 4–1: Application of PGR's to cauliflower by tractor mounted boom sprayer

4.1.1.2 Gibberellic Acid and Ethephon, Autumn 2007, Manjimup

This experiment investigated the effect of applying ethephon and GA_{4+7} at three different application rates at three different application times to broccoli (cv. Ironman) and cauliflower (cv Monarch). The experiment was planted in the field at the Manjimup Horticultural Research Institute on the 13 March 2007 (broccoli) and 14 March 2007 (cauliflower).

Methods

Cauliflower and broccoli were planted using a mixture of Summit Spud at 1500 kg/ha and AllPhos at 150kg/ha as basal fertiliser, applied in an incorporated strip. Both broccoli and cauliflower crops were machine transplanted three rows to a bed, with 45 cm between rows and 50 cm between plants within rows. Seedlings for this experiment were sourced from a commercial vegetable seedling nursery and were six weeks of age at transplanting. Normal commercial practice for the maintenance of the plants was conducted, with insect, weeds and diseases being controlled as necessary. Post-transplant fertiliser to maintain growth was applied as required, reflecting normal commercial practice.

The experiment was a restricted randomised block design of ten treatments with three replicates for each of the two types of plant growth regulator, ethephon and GA_{4+7} (Table 4–9), giving a 60 plot experiment. These treatments were applied to both broccoli and cauliflower. The restricted block design allowed treatments for each application date to be placed together to reduce the risk of spray drift between treatments.

Table 4–9: Treatments applied to cauliflower and broccoli

Treatment*	Application time	Ethephon treatments (mg/ethephon/plant)**	GA_{4+7} treatments (mg/GA_{4+7}/plant)**
1	Nil	Nil	Nil
2	AT1	3.6 mg	1.44 mg
3	AT1	10.8 mg	2.16 mg
4	AT1	18.0 mg	2.88 mg
5	AT2	3.6 mg	1.44 mg
6	AT2	10.8 mg	2.16 mg
7	AT2	18.0 mg	2.88 mg
8	AT3	3.6 mg	1.44 mg
9	AT3	10.8 mg	2.16 mg
10	AT3	18.0 mg	2.88 mg

*For each treatment the ethephon and GA were applied on separate plots. They were not applied on the same plot.
**Application rates are reported as milligrams (mg) of active ingredient applied per plant.

The ethephon and GA_{4+7} were applied at three different application times (Table 4–10). The application times were determined by the physiological age of the plant, with application time one (AT1) aimed to be immediately prior to natural floral initiation, application time two (AT2) coinciding with the time of natural floral initiation and application time three (AT3) being after natural floral initiation had occurred.

The timing was determined from previous studies into curd initiation in cauliflower and broccoli where the number of leaves at curd / head initiation was counted and by assessment of changes in the apical meristem of the plants. The apical meristem was observed under a dissecting microscope for morphological changes (Tan *et al*., 1998), which indicate the commencement of floral initiation. The number of leaves on a sample of ten untreated plants from each of the broccoli and cauliflower crops were counted at transplanting. Plants were sampled from the field twice a week, monitoring leaf number and morphological changes to the meristem, until floral initiation had occurred on 100% of plants sampled.

Table 4–10 shows application times according to the days after transplant for the different treatments. GA_{4+7} treatments were applied in split applications, with half of the total amount of GA_{4+7} being applied at each application time. The first application time, 'a' was determined by plant sampling for apical meristem changes and the second GA_{4+7} application time, 'b' was four days after the 'a' application. All of the required ethephon was applied at a single application time.

At each spray application time, the required amount of GA_{4+7} or ethephon solution was mixed with 29 L of water. This was applied to each treatment using a tractor mounted boom spray. There were substantial buffers between each plot and low drift nozzles were used on the boom spray to help reduce the risk of spray drift between plots.

Table 4–10: Application times for cauliflower and broccoli treatments

Application time	Cauliflower		Broccoli	
	GA_{4+7} (DAT)*	Ethephon (DAT)	GA_{4+7} (DAT)	Ethephon (DAT)
AT1a	23	23	9	8
AT1b	28		14	
AT2a	29	30	14	15
AT2b	34		22	
AT3a	36	37	22	29
AT3b	41		30	

* DAT = days after transplanting

Both crops were harvested in a single pass when 70 to 80 per cent of heads / curds were ready for harvest. Harvest data was analysed separately for both crops using Genstat (Windows version 9.1). Harvest characteristics assessed included yield, head / curd weight, head / curd diameter, head / curd marketability, head / curd density, quality rejection reason and harvest date. Uniformity of head / curd maturation was determined by analysing standard deviation of head / curd weight from the mean of the harvest sample.

Results and Discussion

Leaf counts and floral initiation

Natural floral initiation for the cauliflower variety Monarch occurred between 16 days (0% initiated) and 20 days (20% initiated) after transplanting (Table 4–11). Natural floral initiation for the broccoli variety Ironman occurred between 15 days (0% initiated) and 20 days (20% initiated) after transplanting (Table 4–12). The timing of the PGR treatments on the cauliflower was late, partly caused by poor weather which hindered spray application attempts. The broccoli seedlings had the PGR treatments applied at the correct time.

Table 4–11: Cauliflower leaf counts and floral initiation

Days after transplant	Average leaf number	Curd floral initiation (%)
9	15.9	0
16	18	0
20	29	20
26	32.9	40
30	34.5	50
34	38.4	70
42	45.1	100

Table 4–12: Broccoli leaf counts and floral initiation

Days after transplant	Average leaf number	Head floral initiation (%)
8	11.3	0
15	14.6	0
20	17.8	20
24	22	50
28	26	80
33	31.5	100

Harvest results

The application of GA to cauliflower in this trial had no significant effect on total and marketable yield or total and marketable curd weight (Table 4–13). GA application also did not influence the percentage of curd in each weight category. As the standard deviation of curd weight about the mean was not significantly different for any treatment, the GA application was not effective

in reducing the spread of harvest by improving the uniformity of the crop growth (Table 4–14). The GA was applied late at AT1 and was not effective, possibly due to plants being exposed to a period of cooler weather. In the previous four days prior to curd initiation being observed, the average minimum temperature was 7.1°C, while the average maximum temperature was 16.4°C. At these temperatures, vernalisation may have been sufficient for natural curd initiation to occur, without the need for an induced vernalisation requirement from the GA. The lack of variation in the weight of the curds for both the untreated control and plants treated with GA suggests all plants underwent floral initiation curd at a similar time.

Table 4–13: Total and marketable yield for cauliflower treated with GA_{4+7}

Application time	Application rate (mg/ plant)	Total yield (t/ha)	Total curd weight (g)	Marketable yield (t/ha)	Marketable curd weight (g)
Nil	0	36.08	1001.67	33.95	1023.26
AT1	1.44	33.17	920.71	31.53	980.91
AT1	2.16	33.37	926.25	31.08	956.31
AT1	2.88	35.10	974.51	33.35	999.54
AT2	1.44	34.03	944.59	31.69	964.40
AT2	2.16	32.44	900.47	30.04	952.17
AT2	2.88	33.65	934.02	32.06	960.12
AT3	1.44	34.62	961.14	31.96	980.93
AT3	2.16	32.36	904.71	29.30	936.50
AT3	2.88	32.67	918.62	27.94	895.23
Control (main effect)		ns	ns	ns	ns
Time (main effect)		ns	ns	ns	ns
Rate (main effect)		ns	ns	ns	ns
Control x time x rate interaction		ns	ns	ns	ns

Table 4–14: Standard deviation of cauliflower curd weight for all and marketable heads, treated with GA_{4+7}

Application time	Application rate (mg/ plant)	Standard deviation of curd weight (total)	Standard deviation of curd weight (marketable)	Curds which weigh below 900 g (%)	Curds which weigh between 900 g and 1100 g (%)	Curds which weigh above 1100g (%)
Nil	0	242.99	197.92	32.47	35.37	38.19
1	1.44	295.93	235.26	47.61	29.59	30.67
1	2.16	266.68	218.17	44.23	34.17	27.13
1	2.88	245.88	207.57	41.17	34.68	34.29
2	1.44	252.12	219.00	41.03	36.67	29.51
2	2.16	297.20	236.42	45.75	33.24	25.84
2	2.88	235.75	206.10	44.38	37.63	25.32
3	1.44	283.48	241.80	46.59	27.36	33.31
3	2.16	295.19	249.03	45.54	31.56	25.51
3	2.88	254.03	216.86	47.98	33.56	24.76
Control		ns	ns	ns	ns	ns
Control x time interaction		ns	ns	ns	ns	ns
Linear time effect		ns	ns	ns	ns	ns

The application of ethephon to cauliflower in this trial did have significant impacts on harvest characteristics (Table 4–15), although they are primarily negative effects, causing a reduction in yield.

The total yield of untreated plants was significantly higher compared to plants treated at the second application time at all rates and the first application time at medium and high rates of ethephon. The reduction in yield was not significantly different at the third ethephon application time. It is likely that the total yield reductions, and corresponding reductions in curd weight, is due to the ethephon causing damage to the plants, reducing their potential to reach maximum yield. The reduction in marketable yield for plants treated with ethephon indicates that many curds from all those assessed were rejected as being suitable for sale. Damage caused by the application of ethephon to the plants may have contributed to the reduction in marketable curds. There was a significant linear effect on ethephon application on total yield, marketable yield and curd weight. As the rate of ethephon increased, the total yield was decreased an average by 1.42 t/ha. The time of application did influence the final yield within the treated plants as the linear time by rate interaction indicates that as the time of application became later, there was an increase in total yield of 1.45 t/ha. The third application time was after curd initiation had

occurred and it is likely that curd growth was not affected by application of ethephon at this time.

Table 4–15: Total and marketable yield for cauliflower treated with ethephon

Application time	Application rate (mg/plant)	Total yield (t/ha)	Total curd weight (g)	Marketable yield (t/ha)	Marketable curd weight (g)
Nil	0	36.45	1040.30	35.63	1052.05
1	1.44	34.56	959.36	31.95	984.91
1	2.16	33.36	926.12	31.67	941.15
1	2.88	30.78	889.01	29.42	949.45
2	1.44	31.06	862.19	27.66	888.94
2	2.16	32.48	901.65	28.73	947.49
2	2.88	24.32	683.18	21.36	766.96
3	1.44	34.96	970.45	31.95	1023.32
3	2.16	37.14	1031.03	34.05	1057.74
3	2.88	36.97	1026.25	30.01	1066.74
Control (main effect)		0.013 (2.7)	0.001 (67)	0.001 (3.2)	0.012 (70.1)
Time (main effect)		0.005 (3.0)	0.007 (73.4)	0.003 (3.5)	ns
Rate (main effect)		<0.001 (3.0)	<0.001(73.4)	<0.001 (3.5)	<0.001(76.8)
Control x time x rate interaction		0.013 (3.7)	0.005 (89.8)	ns	0.025 (94)
Linear rate effect		0.013 (-1.42)	0.022 (-32)	0.007 (-1.79)	ns
Linear time effect		0.004 (1.73)	0.004 (42)	ns	0.004 (45)
Linear rate x time effect		0.03 (1.45)	ns	ns	ns

The GA did not affect the uniformity of crop maturity as there was no significant difference in the standard variation of the curd weight for all curds. There was a significant difference in the standard deviation of marketable curd weight although this was only for the time of application. It is likely the variation in the curd weight about the mean is due to damage caused to the plants by the GA application.

Table 4–16: Standard deviation and curd weight categories for cauliflower, treated with ethephon

Application time	Application rate (mg/plant)	Standard deviation of curd weight (total)	Standard deviation of curd weight (marketable)	Curds which weigh below 900 g (%)	Curds which weigh between 900 g and 1100 g (%)	Curds which weigh above 1100 g (%)
Nil	0	245.70	223.36	26.52	32.87	42.68
1	1.44	283.39	233.07	36.39	32.62	39.20
1	2.16	271.07	249.20	46.48	35.33	24.70
1	2.88	270.62	209.54	52.96	32.97	21.64
2	1.44	333.69	267.39	58.29	25.87	23.76
2	2.16	295.56	240.85	49.63	29.30	26.01
2	2.88	285.15	195.58	83.52	14.46	7.64
3	1.44	312.98	245.38	43.32	22.92	41.75
3	2.16	304.46	243.25	27.59	33.15	42.72
3	2.88	330.20	233.92	32.86	25.92	51.63
Control (main effect)		ns	ns	0.002 (12.3)	ns	0.04 (11.1)
Time (main effect)		ns	0.034 (40.46)	0.01 (13.5)	ns	ns
Rate (main effect)		ns	ns	<0.001 (13.5)	ns	<0.001 (12.2)
Control x time x rate interaction		ns	ns	0.01 (16.6)	ns	0.03 (14.9)
Linear rate effect		ns	0.012 (-17.8)	0.04 (5.2)	ns	ns
Linear time effect		ns	ns	0.04 (-5.3)	ns	0.001 (8.4)
Linear rate x time effect		ns	ns	0.03 (-6.8)	ns	0.02 (6.9)

The application of GA to broccoli had no significant effect on the marketable yield (Table 4–17). Treated plants did produce significantly heavier heads and a higher total yield than untreated plants. There was a linear rate effect where head weight and total yield increased as the rate increased for all application times. There was a significant time effect where plants which received GA at the second application time produced heavier heads and a higher total yield than plants at the first and third application times. There was no significant difference in marketable curd weight between treated and untreated plants. There was a linear rate effect where head weight was observed to increase with increasing rates of GA at all application times. This may be an indicator that the GA did have an effect on floral initiation. If initiation occurred slightly earlier in those seedlings treated with higher rates of GA, they would have had

longer to produce a head. At the third application time, the effect of increasing head weight as the applied rate increases is not as pronounced, however this was applied after natural floral initiation occurred.

Table 4–17: Total and marketable yield for broccoli treated with GA_{4+7}

Application time	Application rate (mg/plant)	Total yield (t/ha)	Total head weight (g)	Marketable yield (t/ha)	Marketable head weight (g)
Nil	0	11.77	328.70	15.78	328.70
1	1.44	13.35	370.57	15.54	370.57
1	2.16	14.93	417.05	14.69	417.05
1	2.88	15.66	440.52	9.54	440.52
2	1.44	15.37	429.84	14.92	429.84
2	2.16	16.30	455.67	15.88	455.67
2	2.88	16.76	465.39	16.19	465.39
3	1.44	14.07	393.41	16.73	393.41
3	2.16	15.68	435.33	15.31	435.33
3	2.88	15.01	422.41	11.04	422.41
Control (main effect)		<0.001 (1.1)	<0.001 (30.7)	ns	ns
Time (main effect)		0.002 (1.2)	0.002 (33.7)	ns	0.029 (58.8)
Rate (main effect)		0.003 (1.2)	0.005 (33.7)	ns	0.028 (58.8)
Control x time x rate interaction		ns	ns	ns	ns
Linear rate effect		0.002	0.001	ns	0.020
Linear time effect		ns	ns	ns	ns
Linear rate x time effect		ns	ns	ns	ns

There was a reduced percentage of lower weights broccoli heads for the GA treated plants suggesting that more of the plants initiated together, producing larger heads at the end of the growing period (Table 4–18). However, this is not supported by the standard deviation of the head weights, which shows greater variation in the head weights for the GA treated plots. Only plants that had GA applied at the third application time had a standard deviation similar to the untreated plants. The greater variation indicates the GA is not likely to have had an effect on the uniformity of head maturity. In cauliflower, the time from initiation to maturity is relatively

uniform (Booij, 1987) and it is assumed that a similar process occurs in broccoli. If some heads were greater in weight than others at harvest, this suggests that the head initiation dates were not the same.

Table 4–18: Standard deviation and head weight categories for broccoli, treated with GA_{4+7}

Application time	Application rate (mg/plant	Standard deviation of head weight (total)	Standard deviation of head weight (marketable)	Heads which weigh below 250 g (%)	Heads which weigh between 250 g and 650 g (%)	Heads which weigh above 650 g (%)
Nil	0	111.03	92.92	19.44	80.49	0.00
1	1.44	136.97	120.75	14.67	82.00	3.33
1	2.16	145.51	106.81	12.00	83.86	4.00
1	2.88	136.39	110.14	6.67	88.53	4.67
2	1.44	122.03	104.83	7.33	86.61	6.00
2	2.16	145.67	109.88	8.00	83.78	8.00
2	2.88	159.07	114.48	10.67	79.33	10.00
3	1.44	113.75	92.84	7.33	90.61	2.00
3	2.16	111.69	99.45	4.67	92.67	2.67
3	2.88	117.50	95.68	6.67	89.82	3.33
Control (main effect)		ns	ns	<0.001 (5.4)	ns	ns
Time (main effect)		ns	ns	ns	ns	ns
Rate (main effect)		0.015 (28.1)	0.05 (19.9)	ns	ns	ns
Control x time x rate interaction		ns	ns	ns	ns	ns

The application of ethephon to broccoli in this trial had no significant effect on total yield and total and marketable head weight (Table 4–19). There was an interaction between the application of ethephon at different rates and times. At the first and third application time marketable yield decreased with increasing rates of ethephon. This suggests the ethephon had a negative effect, causing damage to the plants which reduced the marketable yield. However, at the second application time marketable yield increased with increasing rates of ethephon.

The reason for this is unknown but it may be linked to the application of the ethephon on the day floral initiation occurred.

Table 4–19: Total and marketable yield for broccoli treated with ethephon

Application time	Application rate (mg/plant)	Total yield (t/ha)	Total head weight (g)	Marketable yield (t/ha)	Marketable head weight (g)
Nil	0	17.47	488.19	15.78	486.95
1	1.44	18.30	508.15	15.54	504.92
1	2.16	17.54	486.85	14.69	489.36
1	2.88	17.19	477.27	9.54	493.09
2	1.44	17.40	483.13	14.92	523.30
2	2.16	17.64	489.81	15.88	523.83
2	2.88	16.49	457.86	16.19	491.91
3	1.44	18.83	522.80	16.73	528.51
3	2.16	18.24	506.41	15.31	523.35
3	2.88	17.93	497.81	11.04	503.45
Control (main effect)		ns	ns	ns	ns
Time (main effect)		ns	ns	0.002 (2.6)	ns
Rate (main effect)		ns	ns	ns	ns
Control x time x rate interaction		ns	ns	0.02 (3.3)	ns
Linear rate effect		ns	ns	0.002 (-1.7)	ns
Linear time effect		ns	ns	ns	ns
Linear rate x time effect		ns	ns	ns	ns

There was no significant difference in the weight categories for the heads (Table 4–20) and also in the standard deviations for total yield and marketable yield (Table 4–21). This indicates that the application of the ethephon had no effect on crop uniformity as the spread of harvest was not different in the treated plants compared to the untreated plants.

Table 4–20: Percentage of broccoli heads treated with ethephon in different weight categories

Application time	Application rate (mg/plant)	Head weight < 250 g (%)	Head weight 250 g - 650 g (%)	Head weight > 650 g (%)
Nil	0	6.05	79.86	10.73
1	1.44	6.67	76.67	16.67
1	2.16	4.67	83.33	12.00
1	2.88	7.33	81.33	16.00
2	1.44	8.00	80.00	20.67
2	2.16	5.33	82.67	13.33
2	2.88	8.00	84.67	5.33
3	1.44	4.00	74.67	13.33
3	2.16	4.67	82.67	9.33
3	2.88	6.67	80.00	15.33
Control (main effect)		ns	ns	ns
Time (main effect)		ns	ns	ns
Rate (main effect)		ns	ns	ns
Control x time x rate interaction		ns	ns	ns
Linear rate effect		ns	ns	ns
Linear time effect		ns	ns	ns
Linear rate x time effect		ns	ns	ns

Table 4–21: Standard deviation of broccoli head weight for all and marketable heads, treated with ethephon

Application time	Application rate (mg/plant)	Standard deviation of head weight (total)	Standard deviation of head weight (marketable)
Nil	0	152.56	124.47
1	1.44	169.94	118.16
1	2.16	139.72	111.86
1	2.88	148.56	116.29
2	1.44	166.68	122.48
2	2.16	245.77	234.28
2	2.88	141.50	113.64
3	1.44	163.22	133.23
3	2.16	280.85	278.54
3	2.88	155.50	124.91
Control (main effect)		ns	ns
Time (main effect)		ns	ns
Rate (main effect)		ns	ns
Control x time x rate interaction		ns	ns
Linear rate effect		ns	ns
Linear time effect		ns	ns
Linear rate x time effect		ns	ns

There was no evidence in this experiment that the PGR's, ethephon and GA_{4+7} had a beneficial effect on improving crop uniformity in cauliflower and broccoli. After application of the PGR's, there was either no effect compared to the untreated plants or a negative influence as a result of crop damage. Some of the lack of results may have been due to the time of year as cooler temperatures may have assisted natural floral initiation to occur making treatment with PGR's superfluous. This experiment was the first time the PGR's had been investigated during the autumn period and the rates and application times may not have been ideal. Further studies into suitable rates and application times is required before the usefulness of PGR's for influencing brassica crop uniformity is assessed.

4.1.1.3 Ethephon, Winter 2007, Manjimup

Two separate experiments were conducted to examine using ethephon to induce curd initiation in both broccoli (cv. Ironman) and cauliflower (cv. Virgin). Ethephon was applied at three different rates, at three different application times to the broccoli. A more extensive range of ethephon concentrations were applied to the cauliflower plants at the one application date to determine if current rates being used were effective. The experiments were transplanted at the Manjimup Horticultural Research Institute on 15 May 2007.

Methods

Cauliflower and broccoli were planted using a mixture of Summit Spud at 1500 kg/ha and AllPhos at 150kg/ha as basal fertiliser, applied in an incorporated strip. Cauliflower and broccoli seedlings were purchased from a commercial nursery at six weeks of age and transplanted into a three row per bed configuration with 60 cm between plants within a row and 45 cm between rows. Normal commercial practice for the maintenance of the plants was conducted, with insect, weeds and diseases being controlled as necessary. Post-transplant fertiliser to maintain growth was applied as required, reflecting normal commercial practice.

Both experiments were designed as a randomised block. The broccoli experiment had 10 treatments which were replicated three times (Table 4–22). The cauliflower had six treatments which were replicated five times (Table 4–23). Ethephon was only applied at one time to the cauliflower, at 36 DAT, which was immediately prior to natural floral initiation. For broccoli, the three ethephon application dates were chosen according to the physiological age of the crop. The first application time (AT1) was well before natural floral initiation occurred, AT2 was immediately prior to natural floral initiation and AT3 was applied when most of the plants had already achieved natural floral initiation. For the broccoli, AT1 was applied at 10 days after transplanting (DAT), AT2 was applied at 22 DAT and AT3 was applied at 36 DAT.

At each spray application time, the required amount of ethephon solution was mixed with 29 L of water. This was applied to each treatment using a tractor mounted boom spray. There were substantial buffers between each plot and low drift nozzles were used on the boom spray to help reduce the risk of spray drift between plots.

The timing was determined from previous studies into curd initiation in cauliflower and broccoli where the number of leaves at curd / head initiation was counted and by assessment of changes in the apical meristem of the plants. The apical meristem of ten untreated seedlings was also observed under a dissecting microscope for morphological changes (Tan *et al*., 1998), which indicate the commencement of floral initiation. The number of leaves on a ten plant sample from each of the broccoli and cauliflower crops were also counted at transplanting. Plants were sampled from the field twice a week, monitoring leaf number and morphological changes to the meristem, until floral initiation had occurred on 100% of plants sampled.

Table 4–22: Ethephon treatments applied to broccoli

Treatment	Application time*	Application rate (mg ai per plant)**
1	Nil	0
2	AT1	3.6 mg
3	AT1	10.8 mg
4	AT1	18.0 mg
5	AT2	3.6 mg
6	AT2	10.8 mg
7	AT2	18.0 mg
8	AT3	3.6 mg
9	AT3	10.8 mg
10	AT3	18.0 mg

* AT1 was 10 days after transplanting (DAT), AT2 was 22 DAT and AT3 was 36 DAT.
**Application rates are reported as mg of active ingredient applied per plant.

Table 4–23: Ethephon treatments applied to cauliflower

Treatment	Application rate (mg ai per plant)*
1	0
2	3.6 mg
3	10.8 mg
4	18.0 mg
5	72 mg
6	144 mg

*Application rates are reported at mg of active ingredient applied per plant. Applied at 36 DAT.

Both crops were harvested in a single pass when 70 to 80 per cent of heads / curds were ready for harvest. Harvest data was analysed separately for both crops using analysis of variance in Genstat (Windows version 9.1). Harvest characteristics assessed included yield, head / curd weight, head / curd marketability, head / curd density, quality rejection reason and harvest date.

Uniformity of head / curd maturation was determined by analysing the standard deviation of head/curd weight from the mean of the harvest sample, with a greater deviation indicating that curd initiation was not synchronised.

Results and Discussion

Leaf counts and floral initiation

Average leaf counts, the standard deviation of the leaf counts, percentage of plants with floral initiation and the timing of ethephon applications are shown for broccoli (Table 4–24) and cauliflower (Table 4–25).

Table 4–24: Broccoli leaf counts and floral initiation

Days after transplant (DAT)	Average leaf number	Head floral initiation (%)	Ethephon application time
9	9.9	0	AT1 (10 DAT)
16	12.4	0	
22	15.3	0	AT2
26	17.9	30	
29	21	50	
33	23.4	70	
37	27.2	100	AT3 (36 DAT)

Table 4–25: Cauliflower leaf counts and floral initiation

Days after transplant (DAT)	Average leaf number	Curd floral initiation (%) *
9	13.8	0
16	16.6	0
37	25.6	30

* Ethephon was applied to cauliflower at 36 DAT

Harvest results

There was no significant difference in the broccoli total yield, marketable yield and head weights between the untreated control and the ethephon treated plants (Table 4–26). Within the ethephon treatments there was also no significant difference except in the marketable yield where there was an interaction between the time and rate of ethephon application. This was a linear affect, which was noticeable in the third application time, where a decrease in yield occurred as the rate of ethephon applied increased.

Table 4–26: Harvest characteristics of broccoli treated with three rates of ethephon by three application times

Treatment	Applic. time	Rate of ethephon (mg ai / plant)	Total yield (t/ha)	Mkt yield (t/ha) *	Average head weight (g)	Mkt head weight (g) *	Standard deviation of total head weight	Standard deviation of mkt head weight *
1	Nil	0	9.15	8.67	288.52	307.61	80.33	59.31
2	AT1	3.6	9.69	9.02	305.47	315.59	70.33	59.18
3	AT1	10.8	8.95	7.94	283.96	309.59	85.85	60.97
4	AT1	18.0	9.19	8.61	285.87	298.81	74.42	60.98
5	AT2	3.6	9.86	9.32	312.89	323.58	75.96	66.68
6	AT2	10.8	9.08	8.03	288.16	313.37	83.84	53.26
7	AT2	18.0	9.44	8.71	299.69	321.29	87.07	71.59
8	AT3	3.6	9.87	8.54	313.41	327.35	75.85	66.68
9	AT3	10.8	10.28	8.28	326.14	343.52	82.67	70.49
10	AT3	18.0	9.69	4.56	305.51	310.11	74.57	67.62
Control			ns	ns	ns	ns	ns	ns
Control x rate effect			ns	0.05 (1.9)	ns	ns	ns	ns
Control x time effect			ns	0.05 (1.9)	ns	ns	ns	ns
Control x rate x time effect			ns	0.05 (2.3)	ns	ns	ns	ns
Linear rate effect			ns	0.02 (-0.8)	ns	ns	ns	ns
Linear time effect			ns	0.05 (-0.7)	ns	ns	ns	ns
Linear rate x time effect			ns	0.04 (-0.9)	ns	ns	ns	ns

* mkt = marketable

There was no significant difference in the standard deviation from the mean of the total head weight and the marketable head weight. This indicates that the uniformity in crop maturity is not affected by ethephon application. The overall lack of difference between the treatments and the untreated control suggests that ethephon does not promote floral initiation in broccoli during the winter months.

An increasing rate of ethephon on cauliflower caused a reduction in the total yield, marketable yield and curd weights (Table 4–27). Within the ethephon treatments, there was a strong linear relationship between the rate applied and the marketable yield, particularly when the rate applied was greater than 10.8 mg per plant. The negative influence of ethephon is evident in the percentage of curds in different weight categories (Table 4–28). There was an increasing percentage of curds in the low weight categories as the rate of ethephon applied increased. It is likely that the ethephon caused damage to the plants, causing their growth to be reduced and preventing the maximum potential yield being reduced. In future experiments, a maximum ethephon rate of 3.6 mg active ingredient per plant is suggested to prevent damage to the plants.

Table 4–27: Harvest characteristics of cauliflower, treated with ethephon

Treatment	Rate of ethephon (mg ai / plant)	Total yield (t/ha)	Mkt yield (t/ha) *	Total curd weight (g)	Mkt curd weight (g) *	Standard deviation of total curd weight	Standard deviation of mkt curd weight *
1	0	23.04	19.31	737.47	801.00	276.81	225.39
2	3.6	23.75	19.51	753.83	791.59	291.19	198.64
3	10.8	22.38	18.00	710.36	770.91	257.27	181.82
4	18.0	21.75	17.50	690.26	756.13	254.75	178.36
5	72	17.00	6.21	537.34	657.97	279.65	154.32
6	144	11.12	2.14	360.96	610.84	251.63	186.53
Control		<0.001 (1.6)	<0.001 (2.1)	<0.001 (49.1)	<0.001 (33.3)	ns	0.005 (30.5)
Control x rate effect		<0.001 (2.1)	<0.001 (2.7)	<0.001 (63.3)	<0.001 (43)	ns	ns
Linear rate effect (contrast)		<0.001 (-3.0)	<0.001 (-4.4)	<0.001 (-94.2)	<0.001 (-51.7)	ns	ns

* mkt = marketable

There was no significant difference in the standard deviation for the total curd weight, again suggesting the ethephon did not a have an influence on the initiation of curds (Table 4–27). The significant difference in the standard deviation for marketable curds is likely to be a reflection of the poor growth of the curds at high ethephon application rates rather than an indication of synchronised curd initiation.

Table 4–28: Percentage of curds from cauliflower treated with ethephon in different weight categories

Treatment	Rate of ethephon (mg ai / plant)	Curd weight < 900 g (%)	Curd weight 900 g – 1100 g (%)	Curd weight >1100 g (%)
1	0	72.15	16.50	11.35
2	3.6	72.42	18.18	9.40
3	10.8	79.20	14.40	6.40
4	18.0	76.80	17.60	5.60
5	72	89.24	7.17	3.59
6	144	95.50	3.68	0.82
Control		<0.001 (5.2)	ns	<0.001 (3.3)
Control x rate effect		<0.001 (6.7)	0.003 (8.0)	0.007 (4.3)
Linear rate effect (contrast)		<0.001 (5.6)	<0.001 (-3.6)	<0.001 (-2.0)

The application of ethephon at greater than 10.8 mg active ingredient per plant reduced cauliflower vegetative vigour and marketable yield. The ethephon also had no influence on improving the uniformity of crop maturity in cauliflower indicating that it is not a suitable product to use during the winter months when natural initiation caused by vernalisation at cool temperatures is likely to have occurred. Broccoli plants also displayed little response to this product and therefore commercial application of ethephon for improving maturation uniformity in broccoli and cauliflower during winter is not recommended.

4.1.2 Experimental program (Year 2)

Field experiments for the second year of the project were conducted at the Medina Research Station located approximately 50 km south of Perth, Western Australia. The experimental program was moved to this site due to the higher ambient temperatures, relative to the Manjimup experimental site, which can make production of high quality cauliflower and broccoli during summer difficult. The application of gibberellic acid to substitute for vernalisation at this location may be more effective due to a reduction in naturally occurring chilling temperatures.

4.1.2.1 Gibberellic Acid, Summer 2008, Medina

This experiment investigated the effect of applying gibberellic acid (GA_{4+7}) at three different application times to broccoli (cv. Ironman) and cauliflower (cv. Lisbon). The experiment was planted in the field at the Medina Research Station on 30 January 2008.

Methods

Both broccoli and cauliflower crops were machine transplanted three rows to a bed, with 60 cm between rows of cauliflower and 50 cm between rows of broccoli. Seedlings were planted 60 cm apart within rows. Seedlings for this experiment were sourced from a commercial vegetable nursery and were transplanted at six weeks of age. Apart from the treatments, the cauliflower and broccoli were grown according to normal commercial practice for brassica production on sandplain. This included supplying fertiliser both as a basal prior to transplanting and regularly post-transplanting, as well as controlling insects, diseases and weeds.

The experiment was a randomised block design of four treatments with seven replicates for cauliflower and eight replicates for broccoli. At each spray application time, the required amount of GA_{4+7} solution was mixed with 29 L of water. This was applied to each treatment using a handheld boom spray. There were substantial buffers between each plot and low drift nozzles were used on the boom spray to help reduce the risk of spray drift between plots.

The GA_{4+7} treatments were applied at three different application times (Table 4–29). The GA was applied prior to natural curd initiation to examine if early applications of GA would have an influence on plant growth. GA treatments were applied in split applications, with half of the total amount of GA being applied at each split application time. The first application time, 'a' was determined from the plant sample. The second half of the split application 'b' was 3 days after the 'a' application.

The timing was determined by assessment of changes in the apical meristem of the plants. The apical meristem was observed under a dissecting microscope for morphological changes (Tan *et al*., 1998), which indicate the commencement of floral initiation. The number of leaves on a sample of ten untreated plants from each of the broccoli and cauliflower crops were also counted at transplanting. Plants were sampled from the field twice a week, monitoring leaf number and morphological changes to the meristem, until floral initiation had occurred on 100% of plants sampled.

Table 4–29: Treatments and application times for cauliflower and broccoli treatments

Treatment	Application time	Cauliflower		Broccoli	
		GA_{4+7} (DAT)	Application rate (mg ai per plant	GA_{4+7} (DAT)	Application rate (mg ai per plant
1	Control		Nil		Nil
2	AT1a	9	2.16	2	2.16
	AT1b	12		5	
3	AT2a	16	2.16	9	2.16
	AT2b	18		12	
4	AT3a	23	2.16	14	2.16
	AT3b	24		16	

Two replicates of cauliflower and broccoli were harvested on a selective basis, as the heads/curds matured (as per current industry practice). The remaining five replicates of cauliflower and six of broccoli were harvested in one pass. To determine the optimum time for a one pass harvest, a sample of 20 plants was assessed daily as the curds / heads approached maturity. When 75% of the sample plants were mature, a single pass harvest was conducted for each plot. The first harvest date for the broccoli was 10 April 2008 for treatments one to three, however treatment four in the broccoli was harvested on 7 April 2008. Treatments one, two and four on cauliflower were harvested on 15 April 2008, while treatment three was harvested on 10 April 2008. Data collected at harvest included curd / head weight, harvest date, curd / head quality and curd / head density. The marketable yield was determined by removing all curds / heads from the analysis which did not meet the specifications for either the domestic or export markets.

All treatments were applied to both broccoli and cauliflower crops and the two crops were analysed separately using analysis of variance in Genstat (Windows, version 11). Uniformity of curd / head maturation was determined by analysing standard deviation of curd / head weight from the mean of the harvest sample, with a greater standard deviation indicating that curd / head initiation was not synchronised.

Results and Discussion

Leaf counts and floral initiation

Average leaf counts, the standard deviation of the leaf counts, percentage of plants with floral initiation and the timing of GA_{4+7} applications are shown for broccoli (Table 4–30) and cauliflower (Table 4–31).

Table 4–30: Broccoli leaf counts and floral initiation

Days after transplant	Average leaf number	Standard deviation (leaf number)	Head floral initiation (%)	GA application time
0	10.7	0.5	0	
2	11.5	0.7	0	AT1a
5	12.8	0.6	0	AT1b
7	14.3	0.7	0	
9	15.2	0.8	0	AT2a
12	16.8	0.8	0	AT2b
14	17.9	0.7	0	AT3a
16	19.1	0.7	30	AT3b
19	21.5	0.7	90	
21	24.2	1.5	90	

Table 4–31: Cauliflower leaf counts and floral initiation

Days after transplant	Average leaf number	Standard deviation (leaf number)	Curd floral initiation (%)	GA application time
0	11.4	1.6	0	
2	11.9	1.5	0	
5	14.7	1.1	0	
7	16.1	0.9	0	
9	17.5	0.8	0	AT1a
12	18.7	0.7	0	AT1b
14	20.0	0.7	0	
16	21.4	1.1	0	AT2a
19	23.8	1.1	0	AT2b (at 18 DAT)
21	25.2	1.2	0	AT3a
23	29.4	1.0	30	AT3b (at 24 DAT)
26	32.7	1.6	60	
28	35.9	2.1	100	

Harvest results

There was a significant effect of the application time of GA on broccoli yield, which is reflected in the head weights (Table 4–32). The yield and head weight increased as the application time of GA was delayed. For every day delay in application time, head weight increased by 4.9 g. AT3 was applied as curd initiation was occurring. This was an ideal time to apply the GA and it may have substituted for the natural floral initiation process. GA can be used as a substitute for vernalisation (Leshem and Steiner, 1968), which would have taken longer in the warmer summer temperatures when this experiment was conducted. If more of the plants treated at AT3 were subject to initiation at the same time, they would have had more time to produce a larger head compared to the plants where the initiation did not occur uniformly.

The actual number of harvests conducted for plants treated at AT3 was not significantly different from the untreated plants. The distribution of head weights for the one pass harvest indicates there was not a major difference between any of the treatments (Table 4–33) however the plants treated at AT3 were harvested in one pass three days before the other treatments. In the selectively harvested plants, the AT3 plants were also ready for harvest three days earlier compared to the other treatments and the untreated control. This is reflected in the higher percentage of crop removed at the first harvest (Table 4–34).

Table 4–32: Broccoli harvest results

Treatment	Application time	Total yield (t/ha)	Head weight (g)	Number of harvests
1	Not applied	21.38	405.8	3.5
2	AT1	20.84	397.8	4
3	AT2	22.65	424.0	4
4	AT3	23.73	432.8	3.5
Application time effect (5% lsd)		<0.001 (1.65)	0.002 (17.6)	ns

Table 4–33: Percentage of broccoli heads treated with GA in different weight categories (one pass harvest)

Treatment	Application time	% removed in each weight category		
		< 250 g	250 g- 650 g	> 650 g
1	Not applied	11.70	83.82	4.47
2	AT1	12.69	84.02	3.30
3	AT2	10.08	86.88	3.04
4	AT3	10.94	85.56	3.50

Table 4–34: Percentage of broccoli heads treated with GA removed at each harvest time (selective harvest)

Treatment	Application time	% removed at each harvest			
		Harvest 1	Harvest 2	Harvest 3	Harvest 4
1	Not applied	6.96	25.43	58.70	8.91
2	AT1	33.02	18.08	38.40	10.50
3	AT2	21.96	37.13	37.69	3.22
4	AT3	74.66	14.29	9.15	1.90

The application of GA had no influence on the yield or number of harvests in cauliflower (Table 4–35). For a one pass harvest, the distribution of the weight of cauliflower curds was similar across all weight categories (Table 4–36) indicating that floral initiation is likely to have occurred at a similar time, regardless of treatment. However, the plants treated at AT2 were ready for a one pass harvest five days earlier than plants treated at other application times. AT2 was close to floral initiation. In the selective harvest, the percentage of curds removed at each harvest time was not highly different (Table 4–37) however AT2 plants still commenced harvest five days earlier than the other treatments.

Table 4–35: Cauliflower harvest results

Treatment	Time of Application	Total yield (t/ha)	Curd weight (g)	Number of harvests
1	Not applied	35.90	821.8	4
2	AT1	34.36	789.0	4
3	AT2	29.90	677.0	4
4	AT3	36.37	810.8	3.5
Application time effect (5% lsd)		ns	ns	ns

Table 4–36: Percentage of cauliflower curds treated with GA in different weight categories (one pass harvest)

Treatment	Application time	% removed in each weight category		
		< 900g	900 - 1100g	> 1100g
1	Not applied	62.75	17.38	19.87
2	AT1	66.80	17.90	15.30
3	AT2	79.51	15.25	5.24
4	AT3	64.56	19.24	16.20

Table 4–37: Percentage of cauliflower curds treated with GA removed at each harvest time (selective harvest)

Treatment	Application time	% removed at each harvest			
		Harvest 1	Harvest 2	Harvest 3	Harvest 4
1	Not applied	45.16	5.64	38.11	11.08
2	AT1	29.32	17.52	36.95	16.22
3	AT2	26.88	22.56	37.79	12.78
4	AT3	40.12	15.22	40.69	3.97

The affect GA had on the broccoli and cauliflower days to harvest indicates it may be useful for manipulating harvest date during the summer months however it may not be possible to replicate this effect at other times of year. The application of GA to broccoli at AT3 provided for an increase in yield and allowed the crop to be harvested three days earlier. Likewise the application of GA to cauliflower at AT2 allowed the crop to be harvested five days earlier. This would be of commercial benefit however it is not currently possible to use this method in a commercial situation. The timing of the GA application is critical and it is very difficult to assess a crop to determine if it is becoming responsive for floral initiation. It is highly likely that a commercial operator would not have sufficient time to correctly determine the application time for GA and at best, no response to the GA application would be achieved.

4.1.2.2 Ethephon and Gibberellic Acid, Winter 2008, Medina

This experiment investigated the effect of applying ethephon and GA individually (GA at one constant rate and ethephon at two rates) and in combination at two different application times to broccoli (cv. Ironman) and cauliflower (cv. Aviron). The experiment was planted in the field at the Medina Research Station on 19 June 2008.

Methods

Broccoli and cauliflower seedlings were machine transplanted three rows to a bed, with 45 cm between rows and 60 cm between plants within a row. Seedlings for this experiment were sourced from a commercial vegetable nursery and were transplanted at eight weeks of age. Apart from the treatments, the cauliflower and broccoli were grown according to normal commercial practice for brassica production on sandplain. This included supplying fertiliser both as a basal prior to transplanting and regularly post-transplanting, as well as controlling insects, diseases and weeds.

The cauliflower and broccoli were treated as separate experiments. The design was a randomised block design of eleven treatments with four replicates for both cauliflower and for broccoli. At each spray application time, the required amount of GA_{4+7} or ethephon solution was mixed with 29 L of water. This was applied to each treatment using a hand held boom spray. There were substantial buffers between each plot and low drift nozzles were used to reduce the risk of spray drift between plots.

Experimental treatments are shown in Table 4–38. AT1 indicates an application time prior to floral initiation at a time determined by leaf number (12 leaves for broccoli and 21 leaves for cauliflower). AT2 indicates an application time at early floral initiation where, based on sample, 30% of plants had changes to the apical meristem.

Table 4–38: Treatments of GA_{4+7} and ethephon applied to cauliflower and broccoli

Treatment number	Application time *	Treatment applied
1	AT1	3.6 mg ai/plant Ethephon
2	AT2	3.6 mg ai/plant Ethephon
3	AT1	6 mg ai/plant Ethephon
4	AT2	6 mg ai/plant Ethephon
5	AT1a,b	2.16 mg ai/ plant GA_{4+7}
6	AT2a,b	2.16 mg ai/ plant GA_{4+7}
7	AT1a,b	3.6 mg ai/plant Ethephon plus 2.16 mg ai/plant GA_{4+7}
8	AT2a,b	3.6 mg ai/plant Ethephon plus 2.16 mg ai/ plant GA_{4+7}
9	AT1a,b	6 mg ai/plant Ethephon plus 2.16 mg ai / plant GA_{4+7}
10	AT2a,b	6 mg ai/plant Ethephon plus 2.16 mg ai/ plant GA_{4+7}
11	Nil	Control – no PGR applied

* Where there are multiple application times for a treatment, the ethephon was only applied at the ‘a’ application time. The GA was applied in a split application at the ‘a’ and ‘b’ application time.

The timing for the AT2 application was determined by assessment of changes in the apical meristem of the plants. The apical meristem was observed under a dissecting microscope for morphological changes (Tan *et al*., 1998), which indicate the commencement of floral initiation. The number of leaves on a sample of ten untreated plants from each of the broccoli and cauliflower crops were counted at transplanting. Plants were sampled from the field twice a week, monitoring leaf number and morphological changes to the meristem, until floral initiation had occurred on 100% of plants sampled.

GA_{4+7} treatments were applied in split applications, with half of the total amount of GA_{4+7} being applied at each split application time (Table 4–39). The first part of a split application, 'a' was determined from either the leaf number (AT1) or the floral initiation in the plant samples (AT2). The second half of the split application 'b' was 5 to 7 days after the 'a' application, depending upon weather conditions, which delayed application for some treatments. All of the required ethephon was applied in one application for each application time. For treatments 7, 8, 9 and 10, the ethephon was applied at the first application time 'a' with half of the GA_{4+7}.

Table 4–39: Application times of GA_{4+7} and ethephon for cauliflower and broccoli treatments

Application time	Cauliflower		Broccoli	
	GA_{4+7} (DAT)	Ethephon (DAT)	GA_{4+7} (DAT)	Ethephon (DAT)
Control	Nil	Nil	Nil	Nil
AT1a	11		13	
		11		13
AT1b	18		18	
AT2a	25		24	
		25		24
AT2b	32		32	

All treatments were applied to both broccoli and cauliflower crops and the two crops were analysed separately using analysis of variance in Genstat (Windows, version 11). Uniformity of curd / head maturation was determined by analysing standard deviation of curd / head weight from the mean of the harvest sample, with a greater standard deviation indicating that curd / head initiation was not synchronised.

The cauliflower and broccoli were harvested as the curds / heads became mature. The cauliflower was removed in three harvests and the broccoli was removed in a single harvest as all heads were mature at a similar time. Data collected at harvest included curd / head weight, harvest date, curd / head quality and curd / head density. The marketable yield was determined by removing all curds / heads from the analysis which did not meet the specifications for either the domestic or export markets.

Results and Discussion

Leaf counts and floral initiation

Average leaf counts, the standard deviation of the leaf counts, percentage of plants with floral initiation and the timing of the GA_{4+7} and ethephon applications are shown for broccoli (Table 4–40) and cauliflower (Table 4–41).

Table 4–40: Broccoli leaf counts and floral initiation

Days after transplant	Average leaf number	Standard deviation (leaf number)	Head floral initiation (%)	PGR application time
6	11.3	0.7	0%	
8	12.4	0.7	0%	
11	12.8	0.8	0%	AT1a (at 13 DAT)
14	12.3	0.8	0%	
15	13.5	1.1	0%	AT1b (at 18 DAT)
20	16.4	0.8	10%	
22	17.9	0.9	40%	AT2a (at 24 DAT)
25	19.3	1.1	90%	
27	20.6	0.8	100%	AT2b (at 32 DAT)
32			100%	

Changes to the apical meristem, indicating the beginning of floral initiation, were first noted in broccoli at 16 leaves and in cauliflower at 25 leaves. These were the first incidences of initiation noted, not all plants with these leaf numbers or greater necessarily showed signs of initiation. Broccoli plants were slightly quicker to initiate than cauliflower, with initiation occurring naturally over a shorter period of time, with less variation in leaf number. In the sample analysed cauliflower plants were seen to commence initiation from 26 leaves up to 29 leaves; some but not all plants with 29 leaves had initiated. Plants sampled with over 29 leaves had all commenced initiation. Broccoli plants were seen to commence initiation from 16 to 18 leaves. Again, not all plants with 18 leaves had initiated but all plants with more than 18 leaves had commenced floral initiation.

Table 4–41: Cauliflower leaf counts and floral initiation

Days after transplant	Average leaf number	Standard deviation (leaf number)	Curd floral initiation (%)	PGR application time
6	20.1	1.5	0	
8	21.4	1.8	0	
11	21.2	1.5	0	AT1a
14	19.4	1.2	0	
15	22.4	1.6	0	AT1b (at 18 DAT)
20	24.8	1.2	0	
22	25.6	1.4	30	
25	27.1	1.3	50	AT2a
27	30.4	1.1	80	
32	33.3	1.3	100	AT2b

Harvest results

Neither ethephon nor GA had a significant effect on the yield or the marketable yield (Table 4–42). All treatments including the untreated control were removed in one harvest indicating that GA and ethephon were not effective in improving the uniformity of crop maturity. Within the ethephon treatments, there was a significant difference in head weight of all broccoli harvested and the marketable head weight related to the rate of ethephon applied. The average head weight was reduced by at least 28g when ethephon was applied at the high rate however this was not sufficient to cause a significant difference in the overall yield. The marketable head weight was reduced by 49.2 g when ethephon was applied at the high rate at AT2. The reduction in head weight suggests that ethephon had an undesirable effect on the growth of the broccoli although it was not sufficient to cause a marketed reduction in the yield. Despite this the application of ethephon to broccoli could not be recommended due to a potentially increased risk for a reduction in yield and the lack of influence of the PGR on crop uniformity.

Table 4–42: Harvest characteristics of broccoli heads harvested

Treatment	PGR	Application rate (mg ai/plant)	Applic. time	Total yield (t/ha)	Total mkt yield (t/ha) *	Average head weight (g)	Average mkt head weight (g) *
1	Ethephon	3.6	AT1	24.23	22.50	549.3	568.5
2	Ethephon	3.6	AT2	24.91	23.54	547.2	569.4
3	Ethephon	6	AT1	23.95	22.39	521.3	566.0
4	Ethephon	6	AT2	23.69	22.35	500.0	520.2
5	GA_{4+7}	2.16	AT1a,b	23.21	21.47	516.5	551.9
6	GA_{4+7}	2.16	AT2a,b	24.50	23.28	528.9	545.0
7	Ethephon + GA_{4+7}	3.6 + 2.16	AT1a,b	24.99	22.91	541.4	573.2
8	Ethephon + GA_{4+7}	3.6 + 2.16	AT2a,b	24.50	22.98	543.1	575.0
9	Ethephon + GA_{4+7}	6 + 2.16	AT1a,b	23.60	22.72	523.6	544.7
10	Ethephon + GA_{4+7}	6 + 2.16	AT2a,b	23.45	22.37	528.8	560.3
11	Control	Nil	Nil	24.11	23.08	535.0	563.7
lsd (5%), between PGR treatments and control				ns	ns	ns	ns
P value (5% lsd, main effect of time within ethephon treatments)				ns	ns	ns	ns
P value (5% lsd, main effect of ethephon rate within ethephon treatments)				ns	ns	0.018 (22.7)	0.027 (22.7)
P value (5% lsd, main effect of GA within ethephon treatments)				ns	ns	ns	ns
P value (5% lsd, interaction of time and GA application				ns	ns	ns	ns

* mkt = marketable

There was no significant difference in the cauliflower yield or curd weights between the PGR treatments and the untreated control (Table 4–43). Within the ethephon treatments, there was an interaction between the gibberellic acid and the time of its application, with a reduction in yield when GA was applied at AT1. A reduction in yield was also noted when GA was applied on its own at AT1 however there was no reduction in yield when ethephon was applied on its own at either application time.

Table 4–43: Harvest characteristics of cauliflower curds harvested

Treatment	PGR	Application rate (mg ai/plant)	Applic. time	Total yield (t/ha)	Total mkt yield (t/ha) *	Average curd weight (g)	Average mkt curd weight (g) *
1	ethephon	3.6	AT1	30.32	23.83	960	974.4
2	ethephon	3.6	AT2	31.24	23.04	985	993.9
3	ethephon	6	AT1	29.38	20.99	907	942.5
4	ethephon	6	AT2	29.23	20.91	956	991.6
5	GA_{4+7}	2.16	AT1a,b	25.61	20.54	852	948.6
6	GA_{4+7}	2.16	AT2a,b	29.31	21.48	947	988.7
7	ethephon + GA_{4+7}	3.6 + 2.16	AT1a,b	24.45	16.66	794	886.3
8	ethephon GA_{4+7}	3.6 + 2.16	AT2a,b	28.43	20.01	902	960.4
9	ethephon GA_{4+7}	6 + 2.16	AT1a,b	22.52	14.75	751	892.3
10	ethephon GA_{4+7}	6 + 2.16	AT2a,b	29.09	21.89	919	974.0
11	control	Nil	Nil	29.43	21.96	943	962.6
lsd (5%), between PGR treatments and control				ns	ns	ns	ns
P value (5% lsd, main effect of time within ethephon treatments)				0.004 (1.81)	0.025 (2.04)	<0.001 (39.3)	0.001 (31.8)
P value (5% lsd, main effect of ethephon rate within ethephon treatments)				ns	ns	<0.001 (39.3)	ns
P value (5% lsd, main effect of GA within ethephon treatments)				<0.001 (1.81)	<0.001 (2.04)	ns	0.005 (31.8)
P value (5% lsd, interaction of time and GA application)				0.011 (3.63)	0.009 (4.08)	0.014 (55.6)	ns

* mkt = marketable

The PGR's did have an effect on the spread of harvest (Table 4–44) although it was primarily a negative one. When ethephon and GA were applied together at AT1, the percentage of curds removed at the third harvest was significantly higher compared to the other PGR treatments. Alternatively, the percentage of curds removed at AT1 was significantly lower for the ethephon/GA/AT1 treatment, with an interaction occurring between the time of application and a

GA and ethephon dual application. Despite there being a difference in the percentage removed at each harvest time, the overall number of harvests required for each treatment was three.

The combination of ethephon and GA, applied at AT1 is detrimental to the growth of the plants. As there was a reduction in yield when GA was applied on its own, it is suggested the GA is mainly contributing to the reduced plant growth in the combined PGR treatments, when they were applied at AT1. The growth of the plants was delayed by the PGR application, causing a reduction in the weight of curds and subsequent overall yield. Yield may have increased if the plants were left slightly longer prior to the third harvest, although this may not have been possible as the curds still need to be removed when they are at their premium quality.

Table 4–44: Percentage of marketable yield removed at each harvest for cauliflower

Treatment	PGR	Application rate (mg ai/plant)	Application time	Harvest 1	Harvest 2	Harvest 3
1	Ethephon	3.6	AT1	36.8	32.7	30.5
2	Ethephon	3.6	AT2	36.1	29.1	34.8
3	Ethephon	6	AT1	32.7	31.3	36.0
4	Ethephon	6	AT2	33.5	37.7	28.8
5	GA_{4+7}	2.16	AT1a,b	31.4	28.9	39.7
6	GA_{4+7}	2.16	AT2a,b	41.4	32.7	25.9
7	Ethephon + GA_{4+7}	3.6 + 2.16	AT1a,b	12.4	31.8	55.8
8	Ethephon GA_{4+7}	3.6 + 2.16	AT2a,b	34.1	38.9	27.0
9	Ethephon GA_{4+7}	6 + 2.16	AT1a,b	25.1	26.5	48.4
10	Ethephon GA_{4+7}	6 + 2.16	AT2a,b	52.5	38.2	9.3
11	Control	Nil	Nil	32.2	37.1	30.7
P value (5% lsd, between PGR treatments and control)				ns	ns	ns
P value (5% lsd, main effect of time)				0.001 (7.38)	ns	<0.001 (9.4)
P value (5% lsd, main effect of ethephon rate)				0.013 (7.38)	ns	ns
P value (5% lsd, main effect of GA)				ns	ns	ns
P value (5% lsd, interaction of time and GA application)				0.003 (14.7)	ns	0.002 (18.9)

Ethephon caused a reduction in cauliflower yield and weight when it was examined during the first year of the experiment on loam soils. There was no comparative treatment where ethephon and GA were combined in the previous year's experiment, however as the rate of ethephon increased, the amount by which the curd weight and yield was reduced, also became greater. This indicates that ethephon is not suitable to use in winter as a plant growth regulator on cauliflower, with a deleterious effect on plants and no affect on reducing the spread of harvest. There was no effect on broccoli of ethephon in the winter 2007 loam soil experiment and only a small effect on curd weight and head diameter in the 2008 experiment conducted on sandy soils. This indicates that ethephon is also not effective on broccoli for reducing the spread of harvest or improving yield.

Gibberellic acid did not reduce the number of harvests required however did cause a delay in the growth of plants when applied at AT1. A reduction in the percentage of heavy curds, suggesting a late maturation time, was noted in the first experiment conducted on the loam soils (Section 4.1.1.1). Damage to the plants was caused by the GA at all application times and rates in the first experiment. In this experiment, there was little effect of GA at AT2, however this application time was after natural floral initiation had commenced and the GA was unlikely to have had an influence.

4.1.2.3 Ethephon and Gibberellic Acid, Spring 2008, Medina

This experiment investigated the effect of applying ethephon and GA at two rates by three different application times to broccoli (cv. Ironman) and cauliflower (cv. Aviron). The experiment was planted at the Medina Research Station on 30 September 2008.

Methods

Broccoli and cauliflower seedlings were machine transplanted three rows to a bed, with 45 cm between rows and 60 cm between plants within a row. Seedlings for this experiment were sourced from a commercial vegetable nursery and were transplanted at eight weeks of age. Apart from the treatments, the cauliflower and broccoli were grown according to normal commercial practice for brassica production on sandplain. This included supplying fertiliser both as a basal prior to transplanting and regularly post-transplanting, as well as controlling insects, diseases and weeds.

The cauliflower and broccoli were treated as separate experiments. The design was a randomised block design of ten treatments with four replicates each for both cauliflower and broccoli. All treatments were applied to both broccoli and cauliflower crops. At each spray application time, the required amount of PGR for each treatment was mixed into a solution with 29 L of water. This was applied to each plot using a handheld boom spray. There were substantial buffers between each plot and low drift nozzles were used on the boom spray to help reduce the risk of spray drift between plots.

Treatments are shown in Table 4–45. AT1 indicates an application time prior to floral initiation at a time determined by leaf number (14 leaves for broccoli and 18 leaves for cauliflower). AT2 indicates an application time at early floral initiation where, based on sample, 30% of plants had changes to the apical meristem. AT3 indicates an application time late in floral initiation where, based on a sample, at least 90% of plants had changes to the apical meristem.

The timing for the AT2 and AT3 applications were determined by leaf number and assessment of changes in the apical meristem of the plants. The approximate time of floral initiation was determined by counting the number of leaves, including those still forming, at planting on a sample of 10 untreated plants each of broccoli and cauliflower. The apical meristem was observed under a dissecting microscope for morphological changes (Tan *et al.*, 1998), which indicate the commencement of floral initiation. Plants were sampled from the field twice a week, monitoring leaf number and morphological changes to the meristem, until floral initiation had occurred on 100% of plants sampled.

GA_{4+7} treatments were applied in split applications, with half of the total amount of GA_{4+7} being applied at each split application time. The first part of a split application, 'a' was determined from either the leaf number (AT1) or the floral initiation in the plant samples (AT2 and AT3). The second half of the split application 'b' was three days after the 'a' application, depending upon weather conditions, which shortened application time for some treatments. All of the required ethephon was applied in one application for each application time.

Table 4–45: Treatments of GA_{4+7} and ethephon applied to cauliflower and broccoli

Treatment	Application time	Treatment applied
1	AT1	6 mg ai/plant Ethephon
2	AT2	6 mg ai/plant Ethephon
3	AT3	6 mg ai/plant Ethephon
4	AT1a,b	2.16 mg ai/plant GA_{4+7}
5	AT2a,b	2.16 mg ai/plant GA_{4+7}
6	AT3a,b	2.16 mg ai/plant GA_{4+7}
7	AT1a,b	4.32 mg ai/plant GA_{4+7}
8	AT2a,b	4.32 mg ai/plant GA_{4+7}
9	AT3a,b	4.32 mg ai/plant GA_{4+7}
10	Nil	Control – no PGR applied

Table 4–46: Application times of GA_{4+7} and ethephon for cauliflower and broccoli treatments

Application time	Cauliflower		Broccoli	
	GA_{4+7} (DAT)	Ethephon (DAT)	GA_{4+7} (DAT)	Ethephon (DAT)
Control	Nil	Nil	Nil	Nil
AT1a	10	10	3	3
AT1b	13		6	
AT2a	20	20	10	10
AT2b	23		13	
AT3a	29	29	13	13
AT3b	30		15	

The broccoli and cauliflower were analysed separately using analysis of variance in Genstat (Windows, version 11). Uniformity of curd / head maturation was determined by analysing standard deviation of curd / head weight from the mean of the harvest sample, with a greater standard deviation indicating that curd / head initiation was not synchronised.

The cauliflower and broccoli were harvested as the curds / heads became mature. The cauliflower was removed in three harvests and the broccoli was removed in a single harvest as all heads were mature at a similar time. Data collected at harvest included curd / head weight, harvest date, curd / head quality and curd / head density. The marketable yield was determined by removing all curds / heads from the analysis which did not meet the specifications for either the domestic or export markets.

Results and Discussion

Leaf counts and floral initiation

Changes to the apical meristem, indicating the beginning of floral initiation, were first noted in broccoli at 16 leaves (Table 4–47) and in cauliflower at 21 leaves (Table 4–48). Broccoli plants were quicker to initiate than cauliflower, with initiation occurring naturally over a shorter period of time and within a smaller range of leaf number.

Table 4–47: Broccoli leaf counts and floral initiation

Days after transplant	Average leaf number	Standard deviation (leaf number)	Head floral initiation (%)	PGR application time
1	12.4	0.8	0%	
3	13.3	0.5	0%	AT1a
6	14.6	0.5	0%	AT1b
8	14.5	0.8	0%	
10	16	0.5	20%	AT2a
13	17.7	0.7	80%	AT2b & AT3a
15	19.5	1.1	100%	AT3b (16 DAT)

Cauliflower plants commenced initiation from 21 leaves up to 32 leaves. Broccoli plants were seen to commence initiation from 16 to 17 leaves. Not all plants with 17 leaves had initiated but all plants with more than 17 leaves had started floral initiation.

Table 4–48: Cauliflower leaf counts and floral initiation

Days after transplant	Average leaf number	Standard deviation (leaf number)	Curd floral initiation (%)*	PGR application time
1	13.7	0.8	0	
3	15.4	1.1	0	
6	15.8	0.6	0	
8	15.6	2.0	0	
10	17.2	0.6	0	AT1a
13	19.6	1.1	0	AT1b
15	20.8	0.9	0	
17	22.2	1.0	20	
20	25.7	2.5	10	AT2a
22	28.3	1.3	50	AT2b (23 DAT)
24	29.8	1.7	60	
27	32.9	1.9	100	
29			100	AT3a
30			100	AT3b

* Initiation was very uneven across the crop. A reduction in initiation appeared to occur due to the small sample size analysed for curd floral initiation. This would not have occurred if the sample size was larger.

Harvest results

There was no significant difference between the untreated control and any of the PGR treatments for total and marketable yield and head weight in the broccoli (Table 4–49). There was a significant difference in the total yield within the PGR treatments at each time of PGR application. The highest yield was obtained when ethephon and GA were applied at AT2, an application time which corresponded with the start of floral initiation. An increase in broccoli yield was also noted when GA was applied at the start of floral initiation during the summer planted experiment (section 4.1.2.1). All the treatments were removed in one harvest, with the PGR's having no effect on reducing the spread of harvest.

Table 4–49: Broccoli harvest results

Treatment	PGR	Applic. rate (mg ai/plant)	Applic. time	Total yield (t/ha)	Total marketable yield (t/ha)	Average head weight (g)	Average marketable head weight (g)
1	Ethephon	6	AT1	21.11	17.42	714.2	699.0
2	Ethephon	6	AT2	21.43	14.58	691.2	684.1
3	Ethephon	6	AT3	19.79	17.13	654.5	656.0
4	GA_{4+7}	2.16	AT1a,b	20.32	15.90	688.7	671.4
5	GA_{4+7}	2.16	AT2a,b	22.24	17.22	714.4	705.7
6	GA_{4+7}	2.16	AT3a,b	20.14	15.79	685.4	674.2
7	GA_{4+7}	4.32	AT1a,b	22.18	18.96	741.0	756.6
8	GA_{4+7}	4.32	AT2a,b	22.68	16.91	731.9	703.4
9	GA_{4+7}	4.32	AT3a,b	20.39	15.37	696.7	690.8
10	Control	0	0	21.43	16.76	687.4	686.8
P value (5% lsd, all treatments)				ns	ns	ns	ns
P value (5% lsd, PGR type main effect)				ns	ns	ns	ns
P value (5% lsd, time main effect)				0.026 (1.41)	ns	ns	ns
P value (5% lsd, chemical rate main effect)				ns	ns	ns	ns
P value (5% lsd, PGR type and application time interaction)				ns	ns	ns	ns
P value (5% lsd, chemical rate and time interaction)				ns	ns	ns	ns

The PGR's again showed no significant difference in the yield and curd weight compared to the untreated control (Table 4–50). There was also no difference between the ethephon and GA treatments when they were compared against each other. The percentage of curds removed at each harvest was similar for all treatments (Table 4–51), indicating that PGR applications were not effective at reducing the spread of curd maturity.

Table 4–50: Cauliflower harvest results

Treatment	PGR	Applic. rate (mg ai/plant)	Applic. time	Total yield (t/ha)	Total marketable yield (t/ha)	Average curd weight (g)	Average marketable curd weight (g)
1	Ethephon	6	AT1	21.50	16.16	698	901
2	Ethephon	6	AT2	22.73	17.42	726	878
3	Ethephon	6	AT3	20.89	16.20	711	858
4	GA_{4+7}	2.16	AT1a,b	22.82	18.38	734	900
5	GA_{4+7}	2.16	AT2a,b	22.35	16.94	714	863
6	GA_{4+7}	2.16	AT3a,b	20.08	15.46	670	866
7	GA_{4+7}	4.32	AT1a,b	22.14	17.50	708	861
8	GA_{4+7}	4.32	AT2a,b	21.36	16.53	711	904
9	GA_{4+7}	4.32	AT3a,b	20.58	14.62	665	839
10	Control	0	0	21.44	15.87	701	875
P value (5% lsd, all treatments)				ns	ns	ns	ns
P value (5% lsd, PGR type main effect)				ns	ns	ns	ns
P value (5% lsd, time main effect)				ns	ns	ns	ns
P value (5% lsd, chemical rate main effect)				ns	ns	ns	ns
P value (5% lsd, PGR type and application time interaction)				ns	ns	ns	ns
P value (5% lsd, chemical rate and time interaction)				ns	ns	ns	ns

Table 4–51: Percentage of cauliflower marketable yield removed at each harvest

Treatment	PGR	Applic. rate (mg ai/plant)	Applic. time	Harvest 1 (%)	Harvest 2 (%)	Harvest 3 (%)
1	Ethephon	6	AT1	35	61	4
2	Ethephon	6	AT2	24	66	10
3	Ethephon	6	AT3	24	68	8
4	GA_{4+7}	2.16	AT1a,b	31	54	15
5	GA_{4+7}	2.16	AT2a,b	40	55	5
6	GA_{4+7}	2.16	AT3a,b	28	64	8
7	GA_{4+7}	4.32	AT1a,b	22	69	9
8	GA_{4+7}	4.32	AT2a,b	21	73	6
9	GA_{4+7}	4.32	AT3a,b	22	67	11
10	Control	0	0	24	72	5
P value (5% lsd), between treatments and control				ns	ns	ns
P value (5% lsd), within PGR treatments				ns	ns	ns

The results from this experiment confirm results from other experiments in this project; that is the PGR's had very little or no effect on cauliflower and it would not be commercially viable to use the PGR's ethephon or GA_{4+7} to influence harvest period or yield.

4.1.3 Conclusion - PGR Studies

The application of the plant growth regulators, ethephon and GA_{4+7} did not have a positive influence on the spread of crop maturity for cauliflower and broccoli. Throughout the experiments conducted there was little difference in crop uniformity between the PGR treated plants and the untreated controls, apart from one experiment where the GA applied at floral initiation caused a reduced time to harvest but not reduced harvest number. Gibberellic acid did have an affect on broccoli, where it slightly increased yield. The benefits of the increase in yield are not likely to be sufficient to offset the increased cost of monitoring the crop to determine when to apply the GA. Ethephon had no beneficial effect on broccoli and neither ethephon or GA_{4+7} had a positive influence in cauliflower. Booij (1989) also found that ethephon had no effect on curd initiation.

Other plant growth regulators, such as different forms of gibberellic acid may have an effect on the uniformity of brassica crop harvest. However, based on these projects results, the extensive testing of other PGR's could not be currently recommended as the benefits may be small for the research costs involved. Difficulties in determining the time of PGR application would also be problematic in a commercial situation.

Determining the application time for the PGR's was a time consuming and cumbersome process. It would not be practical in a commercial situation to use the method outlined in this project. It was difficult to determine the exact initiation time, particularly if initiation was occurring unevenly across a crop. The number of sample plants that would need to be assessed for floral initiation across a commercial crop would be large making the technique unviable. Leaf number has been found in other studies (Booij, 1987; Salter, 1969) to be an accurate indicator of floral initiation however this was not the case in these experiments. Floral initiation for both broccoli and cauliflower varied across a range of leaf numbers and each range was different depending upon the variety. If leaf number was to be used to determine PGR application time, individual varieties would have to be analysed to determine the correlation between leaf number and floral initiation. This would have to be constantly repeated as new varieties of cauliflower and broccoli are regularly released to the market.

4.2 Uniform seed germination and plant growth regulator experiments

Introduction

Previous experiments conducted in this project found the application of gibberellic acid (GA_{4+7}) was not effective at making crop maturity more uniform in cauliflower and broccoli. The leaf count data that was gathered from the plant growth regulator experiments indicated the seedlings within a particular experiment were at slightly different stages of growth despite all being seeded on the same day. This may have provided a random factor to the experiments which could have contributed to the PGR's being mainly ineffective at inducing floral initiation. Since initiation can only occur after a stage of juvenility, which is partially governed by seedling age, the seedlings may have been too variable in age for applications of PGR to have an impact.

To investigate this, two trials were conducted to compare the uniformity of floral initiation and harvest characteristics between seedlings that germinated on the same day and seedlings that germinated over a number of days. The spread of crop maturity was examined, comparing uniformly and non-uniformly germinated cauliflower and broccoli seedlings treated with two rates of gibberellic acid (GA_{4+7}) as the commercially available product 'Cytolin' at two application times.

4.2.1 Uniform seed / Gibberellic Acid, Autumn 2009, Medina

Cauliflower (cv. Liberty) was seeded on 6 March 2009 and broccoli (cv. Ironman) on 13 March 2009. The seedlings were transplanted in the field at the Medina Research Station on 24 April 2009.

Methods

Pre-plant seedling treatment

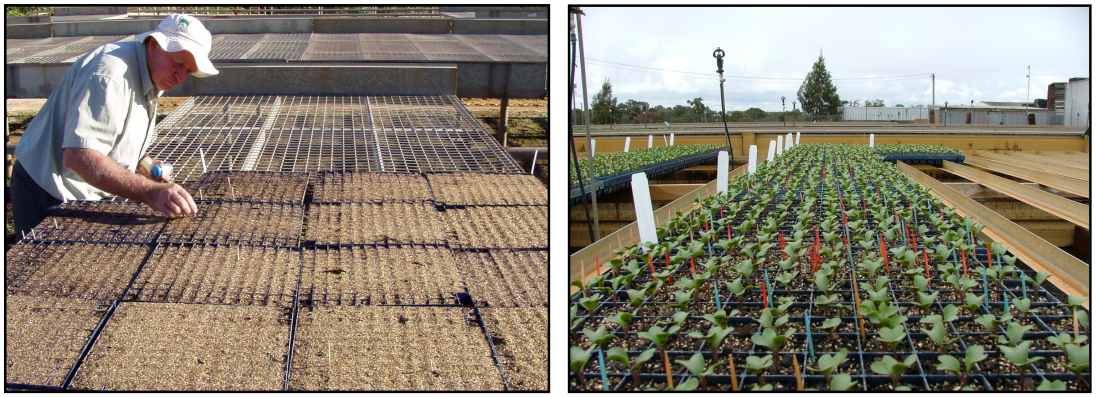
The germination studies were conducted at a commercial vegetable seedling nursery. The commercial nursery reflected industry standards for seedling production and post germination, standard commercial practices for the handling and management of seedlings occurred.

Figure 4–2: Experimental seedlings being grown in a commercial nursery

Fifty six trays of cauliflower seedlings and sixty trays of broccoli seedlings containing 144 seedlings per tray formed the uniform seedling component of the experiment. Seedling numbers germinated were double that required in the field to allow for the correct number of seedlings to be selected to represent uniform germination. A further seven trays of cauliflower and eight trays of broccoli, also with 144 seedlings per tray, formed the industry standard (non-uniform) seedling component of the experiment. Industry standard trays were selected randomly from the total group of trays available (63 cauliflower trays and 68 broccoli trays).

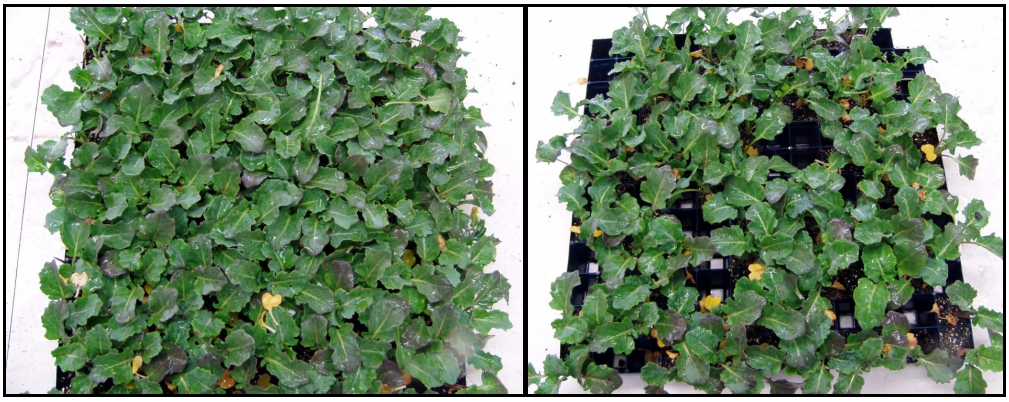
After seeding, the trays were placed in a dark growth chamber as per commercial practice for two days. Seedling emergence was monitored in the nursery daily from the day trays were seeded. Emergence of the first broccoli seedlings was noted the day after removal from the growth chamber. The first cauliflower seedlings emerged three days after removal from the growth chamber. Monitoring occurred once a day at approximately the same time each day. Seedlings were said to be emerged when the first shoot broke the soil surface. Emergence was monitored in trays selected for the uniform seedling treatments daily, until the number of uniform seedlings required to fill the plots was reached. Uniform seedlings were considered to be those seedlings that germinated within 24 hours of each other. Trays selected for the industry standard (non-uniform) plots were monitored daily until 90 percent of seedlings had emerged. Seedlings were tagged with a toothpick as they emerged and emergence dates were mapped for each tray (Figure 4–3).

Figure 4–3: Cells were tagged daily as seedlings emerged (left); toothpicks were colour coded according to the day of emergence (right)



On the day of planting, seedlings in the uniform seedling treatment trays were sorted so only seedlings that germinated on the one day were selected for planting (Figure 4–4). All other seedlings in these trays were discarded. Seedlings in the industry standard trays were planted according to normal practice using all seedlings in the tray. Blind and double seedlings were not included in the experiment.

Figure 4–4: Broccoli seedling trays before (left) and after (right) sorting for uniform seedling treatments



Experimental design in the field

Cauliflower seedlings were planted by hand in the field at two rows per bed with 80 cm between rows and 40 cm between plants within a row. Broccoli seedlings were planted by hand in the field at three rows per bed with 45 cm between rows and 50 cm between plants within a row. Apart from the treatments applied, the seedlings were grown using standard commercial practice. Pre and post transplant fertiliser was provided to all seedlings and weeds, insects and diseases were controlled as required throughout the experiment.

A randomised complete block design of eight treatments with three replicates was used for both the cauliflower and broccoli experiments. All treatments were applied to the cauliflower and broccoli and the two crops were analysed separately using analysis of variance in Genstat (Windows version 12). Both crops were harvested on a selective basis, as the curds / heads matured as per current industry practice. Harvest characteristics assessed included yield, curd / head weight, curd / head marketability, curd / head density, quality rejection reason number of harvests and percentage removed at each harvest.

Post-plant gibberellic acid treatments

The GA_{4+7} treatments were applied to both broccoli and cauliflower crops (Table 4–52). AT1 indicates an application time at early floral initiation where, based on a random sample of seedlings, at least 10% of plants had changes to the apical meristem. AT2 indicates an application time during floral initiation where, based on a random sample of seedlings, at least 50% of plants had changes to the apical meristem.

The approximate timing of floral initiation was determined by counting the number of leaves at planting on a sample of 20 plants, 10 of the uniform and 10 of the industry standard (non-uniform) seedlings. Leaf number can be used as a guide to when the juvenile period of vegetative growth will end. Once the required leaf number was reached, plants were sampled from the field twice a week, monitoring leaf number and morphological changes to the apical meristem (Tan *et al.*, 1998), until floral initiation had occurred on 100% of plants sampled. Twenty plants, 10 of the uniform and 10 of the industry standard seedlings were sampled each time, on both cauliflower and broccoli treatments.

Cytolin is a commercially available form of GA_{4+7}. 1X Cytolin treatments contained GA_{4+7} at 80 mg/L (1.44 mg per plant), 10X Cytolin treatments contained GA_{4+7} at 800 mg/L (14.4 mg per plant). Treatments were applied in a single application.

Table 4–52: Treatments applied to cauliflower and broccoli seedlings

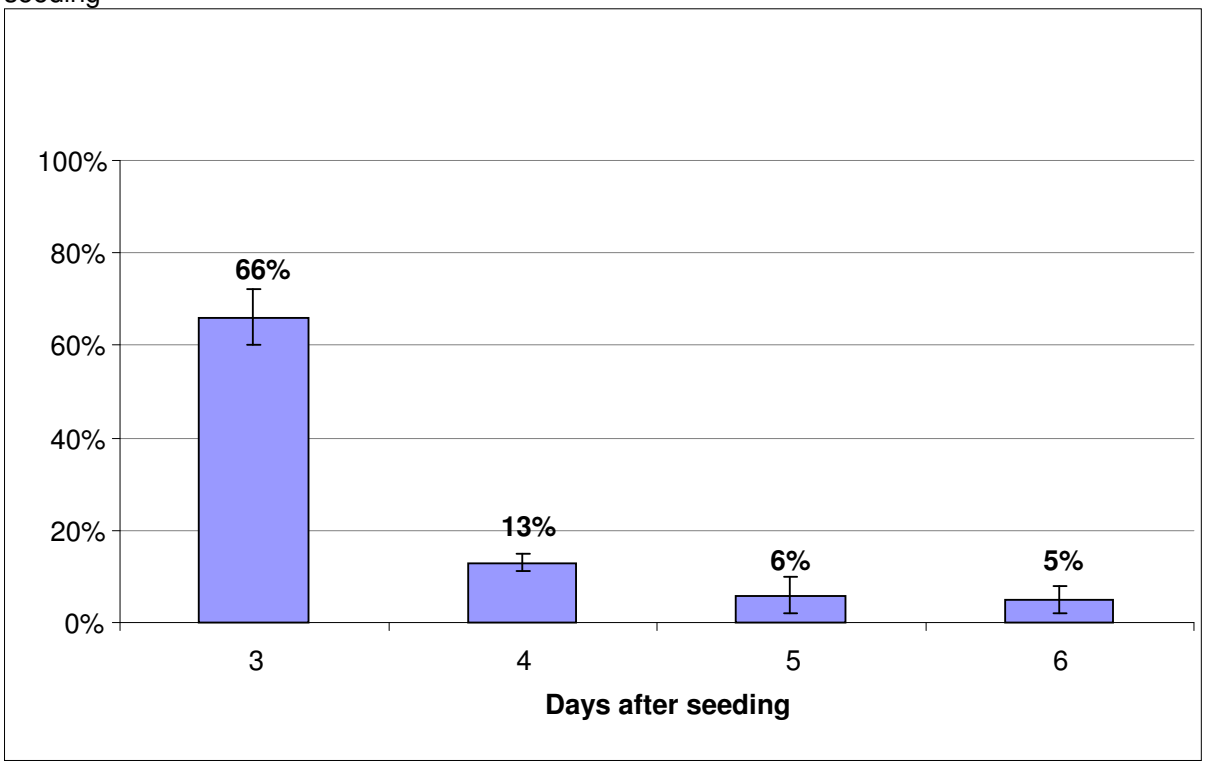
Treatment number	GA application time	Seedling type	Treatment applied (mg GA/plant)
1	AT1	Uniform	1X Cytolin (1.44)
2	AT2	Uniform	1X Cytolin (1.44)
3	AT1	Industry standard	1X Cytolin (1.44)
4	AT1	Uniform	10X Cytolin (14.4)
5	AT2	Uniform	10X Cytolin (14.4)
6	AT2	Industry standard	10X Cytolin (14.4)
7	Nil	Uniform	Nil
8	Nil	Industry standard	Nil

Results and Discussion

Uniformity of seedling emergence

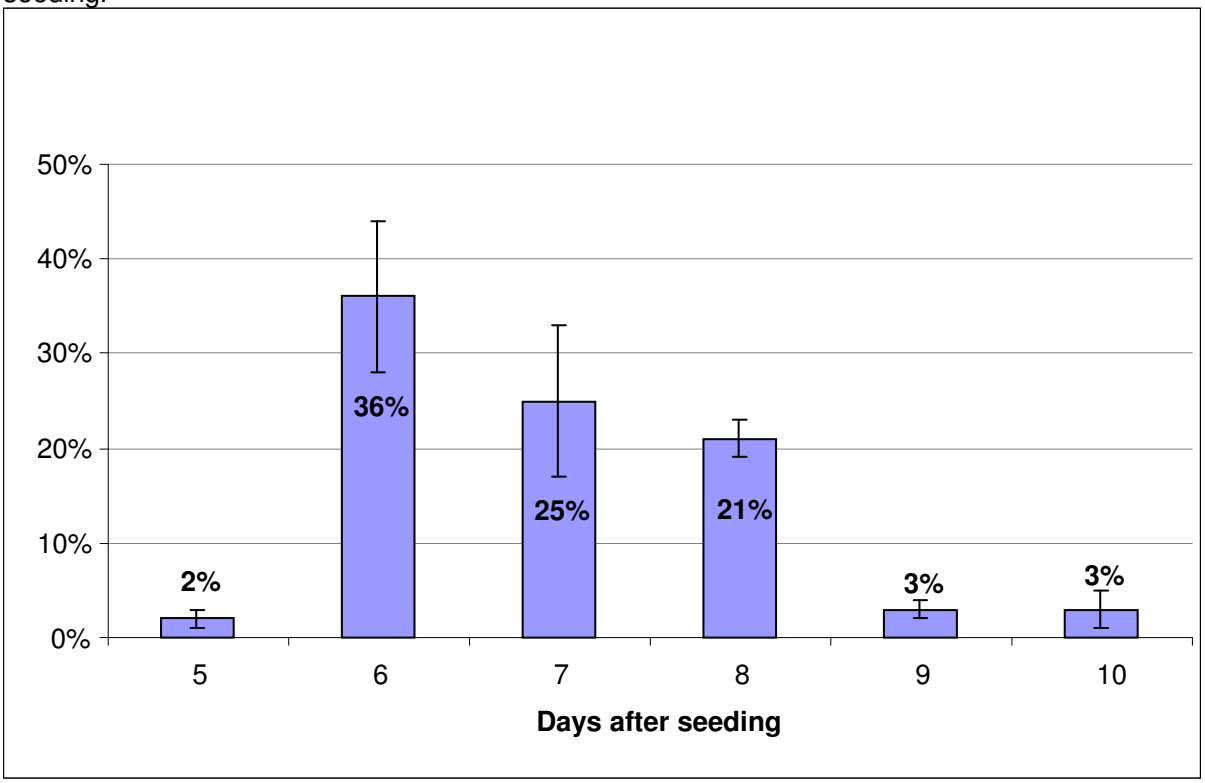
The average daily emergence rate of seedlings in trays used to plant out industry standard (non-uniform) treatments are shown for broccoli (Figure 4–5) and cauliflower (Figure 4–6). Error bars show the standard deviation in emergence date amongst the trays sampled (seven trays of cauliflower and eight of broccoli).

Figure 4–5: Percentage of broccoli (cv. Ironman) seedlings emerged up to six days after seeding



Note: No seedlings emerged on days one and two after seeding.

Figure 4–6: Percentage of cauliflower (cv. Liberty) seedlings emerged up to ten days after seeding.



Note: No seedlings emerged on days one to four after seeding.

The rate of seedling emergence was distinctly different between cauliflower and broccoli crops. The majority of broccoli seedlings emerged on one day with an average of 66 per cent emerging three days after seeding (DAS). A further 13 per cent emerged four DAS and 11 per cent over five and six DAS. Standard deviations show that the patterns of broccoli seedling emergence were similar between trays. The bulk of cauliflower germination was spread over three days with an average of 82 per cent of seedlings emerging between six and eight DAS. This general pattern was reflected in all trays however variation in the pattern of emergence between trays was greater for cauliflower than for broccoli.

Overall the pattern of seedling emergence in broccoli trays was more consistent and concentrated than that of the cauliflower. 90 per cent of all broccoli seedlings emerged within four days of the first seedling emergence, while cauliflower seedlings took six days to reach 90 per cent emergence.

Broccoli seedlings that emerged three DAS and cauliflower seedlings that emerged six DAS were used to plant out uniform seedling treatments.

The date a seedling emerged had significant impact on its physical size and strength. Figure 4–7 shows an example of broccoli seedlings that emerged on different dates. The first two seedlings pictured on the left emerged three DAS and are representative of the 66 per cent of broccoli seedlings used in uniform seedling treatments. The two seedlings in the centre emerged four DAS. These seedlings appeared larger and stronger than those that emerged three DAS. The two seedlings on the right emerged five and six DAS and were typical of the smaller, less vigorous seedlings that emerged on those days.

Figure 4–7: Broccoli seedlings that emerged three, four, five and six days after seeding (left to right)

In addition to the variation in seedling size and vigour caused by emergence date, there were variations caused by tray positioning and edge effects (Figure 4–8). Trays with severe variations in seedling size not attributable to emergence date were omitted from the trial.

Figure 4–8: Variations in seedling size and vigour caused by tray positioning and edge effects

Leaf counts and floral initiation

Average leaf number, the standard deviation between leaf number, the percentage of plants with floral initiation and GA_{4+7} application times are shown for broccoli (Table 4–53) and cauliflower (Table 4–54). Uniform and industry standard seedlings were assessed and reported separately for each crop.

Table 4–53: Broccoli leaf counts and floral initiation

Days after transplant	Industry standard seedlings			Uniform seedlings*			GA applic. time
	Average leaf number	Standard deviation (leaf number)	Head floral initiation (%)	Average leaf number	Standard deviation (leaf number)	Head floral initiation (%)	
4	12.3	0.9	0	12.2	0.6	0	
6	12.2	0.4	0	13	0	0	
10	15.1	0.9	0	14.1	0.3	0	
13	16	0.8	30	15.8	0.4	60	AT1
17	18.2	0.6	100	18.4	0.5	100	AT2 (18 DAT)
20	21.5	3.1	100	20.8	0.4	100	
24	24.6	0.9	100	24.3	0.5	100	

* The uniform seedlings were from those that germinated 3 days after seeding

AT1 was applied to broccoli treatments 13 days after transplant (DAT) when the sampled uniform plants had an average of 15.8 leaves and 60% of plants sampled showed signs of initiation. AT2 was applied 18 DAT when uniform plants sampled had an average of ≥18.4 leaves and 100% of the sample showed signs of initiation.

The broccoli uniform and industry standard seedlings both had floral initiation occur when they had approximately 16 leaves however the uniform plants had 30% more seedlings with morphological changes to the apical meristem. By 17 DAT, both types of seedlings had 100% floral initiation. The initial higher percentage of initiated seedlings in the uniform plants may be a useful indicator for reducing the spread of crop harvest. The time taken for individual cauliflower curds to grow to maturity is relatively uniform (Booij, 1987) and it is assumed that a similar pattern occurs in broccoli. As a greater percentage of broccoli seedlings became initiated earlier, compared to the industry standard seedlings, the uniform plants should be removed in fewer harvests. That is, if there was less variation in the floral initiation period, there should be less variation in the harvest period. This study was continued through to harvest to determine if this occurred.

AT1 was applied to cauliflower treatments 14 DAT when uniform plants sampled had an average of 24.7 leaves and none of the plants sampled showed signs of initiation. AT2 was applied 20 DAT when uniform plants sampled had an average of 29.5 leaves and 90% of the sample showed signs of initiation.

There was no difference between the uniform and industry standard cauliflower seedlings in the rate of curd initiation. This suggests there should be no difference in the harvest period or the number of harvests required to remove the crop.

Table 4–54: Cauliflower leaf counts and floral initiation

Days after transplant (DAT)	Industry standard seedlings			Uniform seedlings*			GA applic. time
	Average leaf number	Standard deviation (leaf number)	Curd floral initiation (%)	Average leaf number	Standard deviation (leaf number)	Curd floral initiation (%)	
4	21.1	1.1	0	21.7	0.8	0	
6	21.2	3	0	22.7	0.9	0	
10	23.1	3.3	0	22.2	1	0	
13	24.7	2.1	0	24.7	1.5	0	
17	26.8	2.7	30	26.5	1.6	30	AT1 (14 DAT)
20	30.4	3.2	90	29.5	2.6	90	AT2
24	31.6	3.7	100	34.2	2.6	100	

* The uniform seedlings were from those that germinated 6 days after seeding

Harvest results

There was no significant difference in the broccoli total yield however there was a significant difference in the marketable yield (Table 4–55). This is particularly evident when the uniform and industry standard plants that had not been treated with GA were compared, with the marketable yield being 5.54 t/ha greater from the uniform seedlings. The weight of broccoli heads from the uniform seedlings was generally lower than those from the industry standard seedlings. Despite this, the uniform seedlings had the higher marketable yield, indicating that the industry standard plants did not have as many high quality heads, with the percentage of waste being higher. Some of the reduction in yield was due to damage from rodents, however misshapen heads were also recorded regularly as a cause of poor quality heads. The misshapen heads were generally more prevalent in the industry standard plants.

Table 4–55: Broccoli harvest results

Treatment	Seedling type	GA rate	Applic. time	Total yield (t/ha)	Total mkt yield (t/ha)*	Average total head weight (g)	Average mkt head weight (g) *
1	Uniform	1x	AT1	17.57	14.57	433	451
2	Uniform	1x	AT2	16.39	13.54	417	442
3	Industry standard	1x	AT1	17.69	13.68	446	473
4	Uniform	10x	AT1	17.06	13.75	433	453
5	Uniform	10x	AT2	17.24	13.33	454	467
6	Industry standard	10x	AT2	18.88	13.86	459	478
7	Uniform	Nil	Nil	18.29	16.18	447	432
8	Industry standard	Nil	Nil	16.88	10.64	452	475
lsd (5%), between GA treatments and control				ns	0.028 (1.36)	ns	0.015 (20.24)
lsd (5%), between GA treatments				ns	ns	0.030 (4.17)	ns

* mkt = marketable

There was a significant difference between the uniform and industry standard seedlings in the percentage of heads removed (Table 4–56), with more heads being harvested at the second harvest in the uniform plants, apart from when 10X GA was applied at AT2. Although not significant, the marketable yield harvest time reflected this result with a greater percentage of heads from uniform plants being removed at the second harvest compared to the industry standard plants.

The high percentage of heads removed in the uniform broccoli plants may have occurred because of greater head initiation occurring at a similar time in the uniform plants. Selection of plants with the same germination day is likely to have contributed to the uniformity in the head initiation as they would have had a similar period of vegetative juvenility. As not all uniform seedlings had floral initiation at the same time, there is likely to be some natural variation due to genetics. To confirm this, a detailed study into the interaction between seed germination day and floral initiation would be required and this would have to be examined across different species of brassicas and for different cultivars within species.

Table 4–56: Broccoli yield removed at each harvest

Treatment	Seedling type	GA rate	Applic. time	Total yield harvest 1 % removed	Total yield harvest 2 % removed	Mkt yield harvest 1 % removed *	Mkt yield harvest 2 % removed *
1	Uniform	1x	AT1	11.41	88.59	9.64	90.36
2	Uniform	1x	AT2	13.85	86.15	13.8	86.25
3	Industry standard	1x	AT1	22.28	77.72	23.36	76.64
4	Uniform	10x	AT1	23.67	76.33	18.41	81.58
5	Uniform	10x	AT2	31.49	68.51	27.87	72.13
6	Industry standard	10x	AT2	29.67	70.33	21.61	78.38
7	Uniform	Nil	Nil	11.58	88.42	10.91	89.08
8	Industry standard	Nil	Nil	28.24	71.76	21.63	78.36
lsd (5%), between GA treatments and control				0.029 (7.36)	0.029 (7.36)	ns	ns
lsd (5%), between GA treatments				ns	ns	ns	ns

* mkt = marketable

There was a significant difference in the total yield when the uniform and industry standard seedlings were compared as the industry standard seedlings produced a greater yield (Table 4–57). Within the seedlings treated with GA, there was no significant difference in the yield. The marketable yield was much lower for all treatments however the industry standard seedlings produced a significantly higher marketable yield compared to the uniform seedlings. This was also reflected by the curd weights, where although there was no significant difference between the treatments, the uniform seedlings tended to have lower curd weights. The lower yields in the uniform seeds may have occurred as the further grading of the seedlings has removed the 'outliers' of plants which would have produced either very light or very heavy curds.

There was no significant difference between the treatments in the percentage of cauliflower curds removed at each harvest time (Table 4–58 and Table 4–59). The lack of variation in the cauliflower may be related to the lack of difference in the initiation period for the cauliflower. Both the uniform and industry standard plants started floral initiation at 17 days after transplanting when they had about 17 leaves each. This is in contrast to the broccoli where there was a difference in the initiation date, which may have led to the difference in percentage of heads removed at each harvest time.

Table 4–57: Cauliflower harvest results

Treatment	Seedling type	GA rate	Applic. time	Total yield (t/ha)	Total mkt yield (t/ha) *	Average total curd weight (g)	Average mkt curd weight (g) *
1	Uniform	1x	AT1	23.80	20.68	729	776
2	Uniform	1x	AT2	22.11	16.68	678	735
3	Industry standard	1x	AT1	27.81	24.38	733	791
4	Uniform	10x	AT1	23.52	18.22	676	789
5	Uniform	10x	AT2	23.93	21.58	737	777
6	Industry standard	10x	AT2	28.12	22.83	746	795
7	Uniform	Nil	Nil	25.20	20.98	727	768
8	Industry standard	Nil	Nil	29.42	23.46	739	770
lsd (5%), between GA treatments and control				0.019 (1.204)	0.033 (1.197)	ns	ns
lsd (5%), between GA treatments				ns	0.006 (2.318)	ns	ns

* mkt = marketable

Table 4–58: Percentage of cauliflower total yield removed at each harvest

Treatment	Seedling type	GA rate	Applic. time	Total yield harvest 1 (%)	Total yield harvest 2 (%)	Total yield harvest 3 (%)
1	Uniform	1x	AT1	30.61	57.09	12.31
2	Uniform	1x	AT2	34.73	43.12	22.15
3	Industry standard	1x	AT1	33.94	59.64	6.42
4	Uniform	10x	AT1	35.60	62.99	1.41
5	Uniform	10x	AT2	23.62	61.75	14.63
6	Industry standard	10x	AT2	35.95	57.45	6.60
7	Uniform	Nil	Nil	34.35	52.04	13.61
8	Industry standard	Nil	Nil	38.39	53.60	8.01
lsd (5%), between GA treatments and control				ns	ns	ns
lsd (5%), between GA treatments				ns	ns	ns

Table 4–59: Percentage of cauliflower marketable yield removed at each harvest

Treatment	Seedling type	GA rate	Applic. time	Mkt yield harvest 1 (%) *	Mkt yield harvest 2 (%) *	Mkt yield harvest 3 (%) *
1	Uniform	1x	AT1	30.87	56.85	12.28
2	Uniform	1x	AT2	40.32	40.45	19.22
3	Industry standard	1x	AT1	32.99	51.00	16.01
4	Uniform	10x	AT1	37.94	62.06	0.00
5	Uniform	10x	AT2	23.61	65.10	11.30
6	Industry standard	10x	AT2	31.01	53.38	15.62
7	Uniform	Nil	Nil	33.08	55.10	11.83
8	Industry standard	Nil	Nil	32.72	45.90	21.38
lsd (5%), between GA treatments and control				ns	ns	ns
lsd (5%), between GA treatments				ns	ns	ns

* mkt = marketable

The broccoli experimental results suggest that seed characteristics, in particular the day of germination do influence the harvest period. It is currently impractical to implement selection in a commercial seedling nursery to identify seedlings by germination day however future breeding programs by commercial organisations could focus on germination day as a desirable factor to be considered when developing new broccoli cultivars.

As breeding program are a long term prospect for influencing seed germination day, future research should concentrate on existing methods for promoting uniformity in geminating seed. This could include seed priming or pre-germination, scouring of seeds, vernalisation treatment and storage conditions.

4.2.2 Uniform seed / Gibberellic Acid, Spring 2009, Medina

This was the second of two uniform seedling experiments. The experiment commenced in a commercial vegetable seedling nursery on the 7 August 2009 and the seedlings were transplanted into the field at Medina Research Station on 24 September 2009 (broccoli) and 30 September 2009 (cauliflower).

Methods

The same general methods used in the autumn uniform seed experiment were used for this experiment. These are listed in section 4.2.1. Sixty six trays each of broccoli seedlings (cv. Bridge) and cauliflower seedlings (cv. Scudo) were seeded using normal commercial seeding machinery. Thirteen trays each of cauliflower and broccoli were randomly selected from the total number of trays to be the industry standard treatments. Seed emergence dates were recorded for all seedlings in all 66 trays of both cauliflower and broccoli. All trays of seedlings were grown together in the nursery.

The seedlings in the industry standard trays were sorted prior to transplanting in the field and only broccoli and cauliflower seedlings that germinated on the same day were transplanted. The industry standard trays were not sorted and all plants, except those which were deformed, blind or double were transplanted.

Broccoli seedlings that emerged six days after transplanting and cauliflower seedlings that emerged eight days after transplanting were used to plant out uniform seedling treatments.

The GA_{4+7} was applied as the commercial available product 'Cytolin' at two different rates (one times and ten times the first rate). Treatments applied to the cauliflower and broccoli seedlings are listed in Table 4–60. These treatments are the same as those applied in the first uniform seedling experiment and they were repeated to determine if cooler weather conditions had any impact.

Table 4–60: Treatments applied to cauliflower and broccoli seedlings

Treatment number	GA application time	Seedling type	Treatment applied (mg GA/plant)
1	AT1	Uniform	1X Cytolin (1.44)
2	AT2	Uniform	1X Cytolin (1.44)
3	AT1	Industry standard	1X Cytolin (1.44)
4	AT1	Uniform	10X Cytolin (14.4)
5	AT2	Uniform	10X Cytolin (14.4)
6	AT2	Industry standard	10X Cytolin (14.4)
7	Nil	Uniform	Nil
8	Nil	Industry standard	Nil

Results and Discussion

Uniformity of seedling emergence

For all trays used in the experiment, the percentage of seedlings which emerged each day are shown for broccoli (Figure 4–9) and cauliflower (Figure 4–10). Error bars show the standard deviation amongst the trays for each emergence date.

Rates of seedling emergence between cauliflower and broccoli crops showed similar patterns with the majority of seedlings emerging on the second day of emergence. Rates of emergence were slower than in the previous trial due to colder weather conditions. An average of 25 per cent of broccoli seedlings emerged five days after seeding (DAS) and a further 62 percent six DAS. On average, just nine percent of cauliflower seedlings emerged on the first day of emergence (7 DAS) and 81 percent at eight DAS. Standard deviations show that variation in the pattern of emergence between trays was slightly greater for cauliflower than for broccoli.

Figure 4–9: Average rate of broccoli seedling emergence and standard deviation between trays for each day after seeding

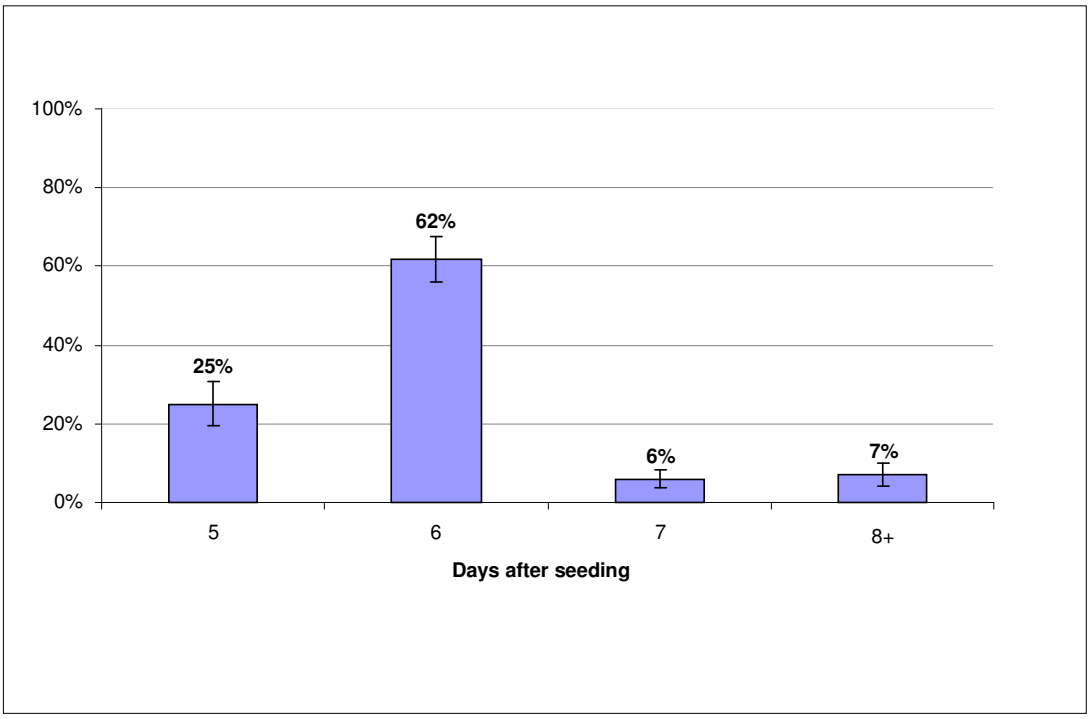
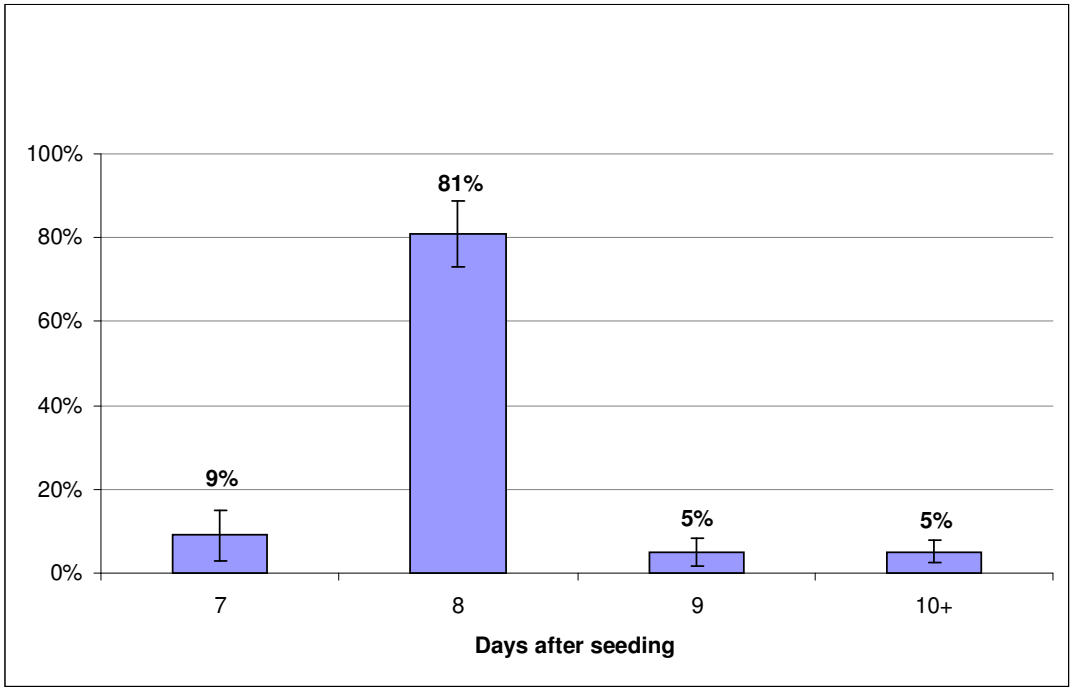


Figure 4–10: Average rate of cauliflower seedling emergence and standard deviation between trays for each day after seeding



Leaf counts and floral initiation

Changes to the apical meristem indicate the beginning of floral initiation. Uniform and industry standard broccoli and cauliflower seedlings were assessed for changes to the apical meristem which marks the start of floral initiation. Both the uniform and industry standard broccoli seedlings started floral initiation at 18 days after transplanting (Table 4–61), when the plants had approximately 24 leaves.

AT1 was applied to broccoli treatments 14 days after transplant (DAT) when uniform plants sampled had an average of ≥17.6 leaves and none of the plants sampled showed signs of initiation. AT2 was applied 18 DAT when uniform plants sampled had an average of 23.7 leaves and 60% of the sample showed signs of initiation.

Both the uniform and industry standard cauliflower seedlings started floral initiation at 7 days after transplanting (Table 4–62), when the plants had approximately 27 leaves. AT1 was applied to cauliflower treatments 8 days after transplant (DAT) when uniform plants sampled had an average of ≥26.6 leaves and 20% of plants sampled showed signs of initiation. AT2 was applied 12 DAT when uniform plants sampled had an average of 35.4 leaves and 100% of the sample showed signs of initiation.

Floral initiation for cauliflower in this experiment was at seven days after transplanting, which is ten days earlier than cauliflower floral initiation in the autumn uniform seed experiment. The short time to floral initiation provided an early indication that the cauliflower was developing abnormally. Curds were formed four weeks after transplant when there was insufficient plant frame to support curd development. The cauliflower experiment was discontinued at this stage as no reliable yield data could be obtained. It is unknown why the curd initiation started early in the cauliflower. Only the broccoli crop was harvested and assessed according to standard methods.

Table 4–61: Broccoli leaf counts and initiation

Days after transplant	Industry standard seedlings			Uniform seedlings germinated 6 days after seeding			GA applic. time
	Average leaf number	Standard deviation (leaf number)	Floral initiation (%)	Average leaf number	Standard deviation (leaf number)	Floral initiation (%)	
0	12.1	0.9	0	12.3	0.7	0	
6	13.3	0.5	0	13	0.5	0	
8	14.1	0.6	0	14.1	0.6	0	
11	14.9	0.6	0	15.3	1.1	0	
13	16.7	0.7	0	17.6	0.9	0	AT1 (14 DAT)
18	24.6	2.7	60	23.7	1.3	60	AT2
22	30.3	4.5	90	30	0.9	100	

Table 4–62: Cauliflower leaf counts and initiation

Days after transplant	Industry standard seedlings			Uniform seedlings germinated 8 days after seeding			GA applic. time
	Average leaf number	Standard deviation (leaf number)	Floral initiation (%)	Average leaf number	Standard deviation (leaf number)	Floral initiation (%)	
0	19.3	0.9	0	18.5	1.4	0	
2	20	1.3	0	21.3	1.4	0	
5	22.7	2.2	0	23.9	2.3	0	
7	27	2.2	20	26.6	2	20	AT1 (8 DAT)
12	33.5	2.4	90	35.4	0.8	100	AT2

Harvest results

There was no significant difference in the yield or head weight for the broccoli between any of the treatments (Table 4–63). The application of the GA to the seedlings also did not have an impact on these harvest characteristics. Using uniform or industry standard seedlings did not influence when the broccoli heads matured (Table 4–64). As there was no difference in the floral initiation time between the two types of seedlings, a difference in the uniformity of harvest was not expected.

Table 4–63: Broccoli harvest results

Treatment	Seedling Type	GA rate	GA applic. Time	Total yield (t/ha)	Total marketable yield (t/ha)	Average total head weight (g)	Average marketable head weight (g)
1	Uniform	1x	AT1	20.6	17.9	605	601
2	Uniform	1x	AT2	20.9	19.1	607	614
3	Industry standard	1x	AT1	19.0	17.7	577	582
4	Uniform	10x	AT1	19.6	17.3	592	609
5	Uniform	10x	AT2	19.8	17.1	632	611
6	Industry standard	10x	AT2	20.0	17.2	592	600
7	Uniform	Nil	Nil	20.1	18.5	590	597
8	Industry standard	Nil	Nil	20.6	17.3	464	623
P value (5% lsd), between GA treatments and control				ns	ns	ns	ns
P value (5% lsd), between GA treatments				ns	ns	ns	ns

There was a significant difference at the first harvest time. GA, applied to industry standard seedlings at the 10 times rate at AT2 had 46% of the curds in that treatment removed at the first harvest. This was not repeated for the other treatments where industry standard seedlings were used suggesting the application time, the GA or an interaction of the two factors contributed to the large first harvest.

Table 4–64: Percentage of broccoli marketable yield removed at each harvest

Treatment	Seedling type	GA rate	Application time	Harvest 1 (%)	Harvest 2 (%)	Harvest 3 (%)
1	Uniform	1x	AT1	17	31	52
2	Uniform	1x	AT2	25	31	45
3	Industry standard	1x	AT1	27	32	41
4	Uniform	10x	AT1	30	26	44
5	Uniform	10x	AT2	36	37	27
6	Industry standard	10x	AT2	46	33	20
7	Uniform	Nil	Nil	20	32	47
8	Industry standard	Nil	Nil	27	30	43
P value (5% lsd), between GA treatments and control				ns	ns	ns
P value (5% lsd), between GA treatments				0.019 (14.06)	ns	ns

4.2.3 Conclusion – Uniform Seed and Gibberellic Acid Studies

Although these are initial studies, there is some indication particularly for broccoli, that seed germination day does have an impact on the spread of harvest. The role of seed germination day on the evenness of crop growth warrants further investigation however very detailed studies would be required. Future studies should include using short term treatments to promote uniformity in seed germination such as seed priming and seed scouring. Long term methods such as plant breeding should be investigated as potential mechanisms for improving the uniformity of seed germination. Additionally the 'freshness' of seed, in relation to when the seal on a seed packet is broken, should be included in these studies as anecdotal evidence suggests that seed which has been opened and stored in a refrigerator for some time may be subject to an increase in seed germination variability.

5 Recommendations

The primary purpose of this project was to assess the influence of the plant growth regulators (PGR's), ethephon and gibberellic acid (GA_{4+7}) on the uniformity of maturity for the vegetable brassicas, cauliflower and broccoli. The experiments conducted in this project demonstrated that both ethephon and GA_{4+7} had little influence on the uniformity of crop harvest. A slightly reduced harvest period was recorded for both ethephon and GA in different experiments, however this was not repeatable at different times of year and at different locations. The crop yield was improved in some experiments, although this was also inconsistent throughout the project. It was difficult to determine why the PGR's were ineffective at influencing crop maturity although it is likely that natural floral initiation often occurred prior to application of the PGR's as the process to determine when the plants were ready to start initiation was very cumbersome, time consuming and not practical in a commercial situation. Based on the poor outcome for improving crop uniformity, the inconsistent results in influencing yield and the difficulty associated with determining the correct application time, the PGR's ethephon and GA_{4+7} are not recommended to be applied to cauliflower and broccoli.

The experiments conducted to assess the PGR's highlighted that uneven seed germination was a potential factor contributing to a lack of uniformity in crop maturity. Experiments were conducted to assess the role of seed germination time on crop maturity and there is potentially a link between the two factors. It is recommended this potential link be investigated in detail as this could have a major impact both on the spread of crop maturity and on the potential marketable yield of crops, especially broccoli. For broccoli and cauliflower the following factors should be investigated:

- role of seed germination time on the length of the juvenile vegetative period and the start of floral initiation
- influence of the seed germination date on the spread of harvest and yield
- methods for improving the uniformity of seed germination day, including seed modification techniques (eg: seed priming, seed scouring) and plant breeding,
- the impact of seed modification techniques on the uniformity of harvest and yield

Plant breeding is likely to be a key factor to influence seed germination date although this will not provide a short term solution for growers and nurseries who want to source more uniformly germinating seed. If further research conclusively indicates that seed germination date impacts on the crop maturity, it is recommended that plant breeders include seed germination date as an additional criterion to assess when developing new varieties.

6 Extension and Technology Transfer

There were no field walks held on this work as it was not possible to visually examine any differences between the treatments while the crop was growing. It would have been wasteful of time and money to have asked growers to attend a field walk. The project results were presented at various seminars, grower meetings and in written form instead. These are noted below.

6.1 Publications

- Farm Weekly newspaper, 'Ripe' supplement, Less work in seed uniformity. 24 June 2010, p. 18
- Countryman newspaper, Uniformity head start. 1 July 2010, p. 57
- Good Fruit and Vegetables, Seedling selection saves time. July 2010, Volume 22, Number 1, p. 20

6.2 Newsletters

- 'Better Brassica' no. 10 (March 2007), 'Plant growth regulators'

6.3 Meetings / seminars / workshops

Presentations on the general scope of the project and updates of project results occurred at:

- Regional brassica workshop in Manjimup (July 2007)
- Manjimup Horticulture Research Institute Field Day (March 2007)
- Vegetables WA regional meeting in Manjimup (August 2007)

6.4 Radio Interviews

- ABC Local Radio – South West Rural Report. Aired on 10 June 2010
- ABC State Radio – Country Hour Program. Aired on 10 June 2010

6.5 On-farm grower groups

Regular updates on the progress of this project were provided during on-farm grower group meetings which were held every 2 months (2006 – 2010)

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