SEED PRODUCTION IN HYBRID DAHLIA

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ABSTRACT

Seed grown dahlias lack uniformity of growth habit and are particularly erratic bloomers. This results in a wide range of seed maturities within a plant and creates major problems for seed harvest. In an attempt to reduce the spread of flowering and improve uniformity, crop manipulation by hand pinching and the application of three plant growth regulators was investigated in field grown dahlia (*Dahlia hybrida*) cvs. Unwins Dwarf Mixture and Figaro White.

In 1987/88 the effects of pinching above nodes 3, 4 and 5 on flowering pattern, flower production and seed yield of dahlia cv. Unwins Dwarf Mixture were determined. Pinching had no effect on the number of flowers per plant or total flowering period. However pinching did shorten the days from first to peak flowering because of increased uniformity of lateral branch growth. Pinching above node 4 increased harvested seed yield by 40 % and cleaned seed yield by 32 % but only the former result was significant. Although pinching above node 4 also produced more seedheads per plant and seeds per seedhead than in non-pinched plants, differences were once again non-significant.

In the following season (1988/89) two rates of three plant growth regulators (PGRs) were applied at two growth stages (i.e. paclobutrazol 0.5 and 1.0 kg a.i. ha^{-1}, daminozide 2.0 and 4.0 kg a.i. ha^{-1}, chlormequat chloride 1.5 and 3.0 kg a.i. ha^{-1} at visible terminal bud stage and stem elongation) to plants of two cultivars, Unwins Dwarf Mixture (multicolour, 70 cm tall) and Figaro White (white, 30-35 cm tall) to determine their effects on plant growth and development, flowering pattern, seed yield and yield components. Hand pinching above node 4 was also included as a treatment for comparison. In cv. Unwins Dwarf Mixture, hand pinching increased lateral branch length and promoted simultaneous flowering, but did not significantly increase seed yield or any of its components. All three PGR's retarded growth initially, but these effects mostly did not persist past first flowering. Flowering duration or flower numbers did not alter following PGR application, and so a high variation in seed maturation was still present in all plots. However two PGR treatments, paclobutrazol (1.0 kg a.i. ha^{-1}) applied at the first visible bud stage, and chlormequat chloride (1.5 kg a.i. ha^{-1}) applied at the

stem elongation stage significantly increased seed yield. The response to paclobutrazol came from an increased number of seeds per seedhead and greater uniformity of seedhead development, which reduced the seed loss during cleaning (from 44 to 11 %). The reason for the seed yield increase following chlormequat application was not clear, as yield components did not differ significantly, but more seedheads per plant were recorded. In the dwarf cultivar Figaro White, PGRs did not increase seed yield. Retardation effects were transitory. Seed yield of this cultivar was very low because of poor seed setting in all treatments and it is suggested that white petal colour is unattractive to insect pollinators.

Response to PGRs is application rate and time dependent. Results from the previous trial suggested that paclobutrazol application could be more effective if applied earlier, whereas for chlormequat chloride, later application (i.e. at or after stem elongation) may be more appropriate. However, paclobutrazol application at the vegetative stage did not affect seed yield, and as in the previous experiment, seed yield was increased following application at the visible bud stage only. Chlormequat chloride applied at stem elongation also increased harvested seed yield but not cleaned seed yield, presumably as a result of loss of immature/light seed.

Because of the diversity of seed maturation, optimum harvest time is difficult to judge in dahlia grown for seed. Reproductive growth and development were monitored in glasshouse grown plants of cv. Unwins Dwarf Mixture, and the sequence of seed development determined in flowers produced on plants growing from tubers left in the field from a previous trial. Seed yield was most strongly related to seedhead numbers rather than seed numbers or weight, and thus the uniformity of seedhead maturation is important for a high yield of quality seed. Although the total flowering period was over two months (from 66-132 days after sowing (DAS)), around 80 % of the total flowers produced were formed between 75-96 DAS. Each seedhead needed 33 days from first flower opening to reach seed physiological maturity, and seed could remain in the seedhead for a further 9 days before shedding began. Thus the optimum harvest time was between 33-42 days after first flowering (or 120-129 DAS) because during this time the maximum number of mature seedheads was recorded, seed had reached full viability, and seed shedding had not begun. Once seedheads opened, seed

moisture fell rapidly (from 40 to 14 % in 3 days) and seed was completely shed by 54 DAF.

Delaying harvest until 60 days after peak flowering (DAPF) produced the greatest harvested seed yield in untreated plants because of the continued ripening of green seedheads. However, after cleaning, seed yield at 60 DAPF did not differ from that at 42 DAPF because of greater cleaning losses (43 cf. 27 %). In addition, seed sprouting in the seedhead was observed by 54 DAPF. When harvested at 42 DAPF both paclobutrazol and chlormequat chloride significantly increased seed yield, but cleaning losses were high in chlormequat chloride treated plants. PGR's did not delay seed maturity, so that as seed harvest was delayed any PGR yield advantage tended to disappear. PGR treatments did not affect thousand seed weight or germination.

Chlormequat chloride applied at 1.5 kg a.i. ha^{-1} at the stem elongation stage increased secondary lateral branch production and hence the number of flower sites, while paclobutrazol applied at 1.0 kg a.i. ha^{-1} at the first visible bud stage increased flowers, seedheads and/or seeds per seedhead over that of control plants. However, dahlia plants did not appear to be capable of supporting the extra number of seeds through to maturation; cleaned seed yield was not always increased because light seed was cleaned out of the seed lot. For dahlia seed production it may be more effective to try and achieve increased inter-plant uniformity by growing at very high density, rather than trying to achieve this effect through chemical manipulation. This idea is briefly discussed.

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GENERAL INTRODUCTION

The production of high yields of high quality flower seeds requires considerable technical skill (Bodger, 1961). The basic differences between flower and field crops relates to the purpose of production. Most field crop production is concerned with seed or grain as the end product. Flower crop production, however, is often complicated by more than one end product, whether this be seed or the sale of inflorescences, leaves, bulbs, fruits or pods. In such cases growers may be more concerned with quality of parts of the plant other than seed (FAO, 1961; Salunkhe *et al.,* 1987). Flower seed production necessitates familiarity with methods and techniques often not well known by florists. A great deal of skill and knowledge is needed to carry crops through the final essential stages of flowering and seed development in order to produce high quality seeds and to maintain this quality through the harvesting and processing stages. Decision on correct or best harvest timing, for example, is complicated in many flower crops by the intense breeding effort which has been expended to develop cultivars with a long blooming period for floral and garden display (FAO, 1961). Also, many flower crops are prone to seed shattering, a process which may begin even before seed is mature.

Research into flower seed crop management has been negligible compared with the amount of research effort on field crops. In particular, areas such as weed control, plant spacing and seed processing have been, in many cases, totally neglected. This is perhaps not surprising since, for many flower species, the planted acreage and crop value may be quite inadequate to support the cost of the research which is needed. Nevertheless, profit motivation has tempted some private companies to focus on major crops such as petunias, impatiens, geraniums, begonias and marigold (Salunkhe *et al.*, 1987).

Dahlias are popular in many parts of the world. They are used as garden plants, for borders, background exhibitions, and as cut flowers, bedding and potted plants (James, 1963; Baumgart, 1970; Reilly, 1978; Salunkhe *et al.*, 1987) because of their remarkable diversity of form, colour and size (Runger and Cockshull, 1985).

However, only the taller growing, large-flowered cultivars are used for cut flower purposes by florists in Europe, Japan and Northern America (Boodley, 1981; Ball, 1985; Runger and Cockshull, 1985). The most profitable part of the dahlia business lies in the growing of dwarf cultivars for sale in the spring, either as potted plants or as bedding plants in packs (Boodley, 1981; Rowell, 1981; Ball, 1985). Dahlia is best and most easily grown from seed, and is usually sown as a mixture. The dwarf strains grow to a height of 25-60 cm and produce an abundance of brightly coloured flowers which range from 5.0-7.5 cm in diameter. Flowers are single, semi-double, or double (Ball, 1985). The Unwins strain is the most extensively grown bedding dahlia (Hammett, 1980). Figaro and Rigoletto have also approached 'most popular' status because of their dwarf habit (30-40 cm), and high percentage of double blooms (Ball, 1985).

Seed-grown dahlias lack uniformity of growth habit and are usually erratic bloomers (Still, 1988). This results in a wide range of seed maturity within a plant and thus hand picking is common in dahlia, as for many other flower crops, because they cannot efficiently be harvested by machine. However, although hand picking or cutting may result in the production of more seed, high labour costs and the need for speed dictate mechanical methods whenever possible (Bodger, 1961). This requirement becomes more obvious following the increased demand occurring as a result of the development of this industry into an international business (Kestr, 1990). Consequently, the need for dahlia seed crop research becomes more evident since production information is very limited. The present study was carried out to provide information on seed production and seed yield improvement of bedding dahlia through examination of some agronomic management practices, particularly chemical manipulation.

This study is divided into 7 chapters. Basic information on cultural practices and the management required for flower seed production, including dahlia, is reviewed in Chapter 1. The first experiment (Chapter 2) involves the effects of hand pinching at different node positions on the main stem on flower and seedhead production for seed yield improvement of dahlia cv. Unwins Dwarf Mixture under field grown conditions. Chapter 3 studies the effects of chemical manipulation by three plant growth regulators (paclobutrazol, daminozide and chlormequat chloride), and the best pinching treatment from the previous

experiment, on plant growth and development for dahlia seed production. In this chapter, two cultivars of bedding dahlia (cv. Unwins Dwarf Mixture, the most extensively-grown bedding dahlia, and cv. Figaro White, a dwarf early white flowered cultivar) were compared using the same treatments. These data are reported in two parts: the first part (Chapter 3A) for cv. Unwins Dwarf Mixture and the second part for cv. Figaro White. These two cultivars were chosen to compare the cultivar responses because of their difference in height (i.e. 60 and 30 cm) and flower colour (mixed and single) since high variation between plants was observed in the first experiment (Chapter 2). Paclobutrazol and chlormequat applied to cv. Unwins Dwarf Mixture showed possibilities for seed yield improvement and are further studied in more detail in Chapters 4, 5 and 6. Chapter 4 examines the effects of time of application of paclobutrazol and chlormequat on plant growth and development for seed yield improvement. Reproductive growth and development are examined in Chapter 5 which consists of two parts. The first part is an observation of the pattern of plant growth, flower bud formation, flower and seedhead production and seedhead maturity under ambient temperature in a glasshouse; the second part provides detail on seed development of individual seedheads under field conditions. In Chapter 6, the most promising plant growth regulator treatments from chapter 3A (paclobutrazol 1 kg a.i. ha^{-1} applied at visible flower-bud stage and chlormequat 1.5 kg a.i. ha^{-1} applied at stem-elongation stage) are further investigated to provide more information on the effects of harvesting timing on seed yield response. Finally, a general discussion and conclusion of all the experimental results and some recommendations for further study of dahlia seed production are presented in Chapter 7.

CHAPTER 1

LITERATURE REVIEW

1.1 General description of Dahlia

Dahlia is a perennial, herbaceous plant with a tuberous root system supporting stout, erect, branched stems bearing pinnate leaves in opposite pairs, and terminal, brightly coloured, capitate inflorescences (Runger and Cockskull, 1985). The aerial plant parts die each winter and in favourable climates are replaced by new growth from ground level each spring. In less favourable climates the dahlia is mainly treated as an annual (Hammett, 1980). The present day dahlias have arisen as a result of continuous crossing between several wild species and varieties (Salunkhe *et al.*, 1987). These wild species of *Dahlia* are natives of Mexico (Hay *et al.*, 1969; Hammett, 1980; Rowell, 1981; Salunkhe *et al.*, 1987) and were first introduced into Spain in 1789, before entering England at the end of eighteenth century and then spreading to other countries in the western hemisphere (Salunkhe *et al.*, 1987). The first dahlias to reach Europe from Mexico were single and semi-double types (Hammett, 1980). Originally, the flowers were single with a few broad ray florets (Rowell, 1981), and the colour range was restricted to white, red, pink, and purple (Bodman and Hughes, 1985). In modern dahlias, however, the colour range includes white, cream, yellow, orange, bronze, pink, red, lavender and purple as single colours, or combinations of two or more colours with a wide range of shape and growth habit (Rowell, 1981). Propagation is by seed, tuber, or by stem cutting from shoots or sprouted tubers (Runger and Cockshull, 1985; Salunkhe *et al.*, 1987).

'Dahlia' was named after Andreas Dahl (an eminent Swedish botanist living in Berlin, who had been a pupil of the great Linnaeus) by Antonio Jose Cavanilles, Director of the Royal Garden in Madrid (Emsweller *et al.*, 1937; Harrison, 1971; Hammett, 1980; Salunkhe *et al.*, 1987). It is a member of the compositae (Asteraceae) family. The alternative specific names *D. pinnata*, *D. variabilis*, or *D. hybrida* are frequently used in garden books due to some confusion over the correct scientific name for cultivated dahlia. Many American authors have

designated them as *D. pinnata* (Emsweller *et al*, 1937; Read *et al.*, 1972; Cathey, 1975; Haliburton, 1976) while others have used *D. variabilis* (Moser and Hess, 1968; Canham, 1969; Biran and Halevy, 1973). However, currently botanical opinion suggests that the modern double-flowered cultivars are hybrids of at least two species, presumably *D. pinnata* and possibly *D. coccinea* Cav., and that other species were also involved at some stage of their history (Sorensen, 1969; Barrett and De Hertogh, 1978a; Runger and Cockshull, 1985). According to Sorensen (1969) the modern cultivars have 64 chromosomes and are now generally regarded as tetraploids ($2n = 4x = 64$), though they have also been classed as octoploids ($2n = 8x = 64$). Crosses between single and double flowered types produce a continuous range of form, indicating that doubleness is determined by many genes. Flower colour, on the other hand, is determined by relatively few genes, but their interaction gives rise to many colours.

In New Zealand, dahlias are popular both for garden decoration and as a show flower. In the past, New Zealand growers have produced some outstanding dahlia cultivars which are still used around the world. In recent years, however, New Zealanders have been quick to import the very latest cultivars from overseas, a trend which reflects a lull in the production of local introductions (Hammett, 1980).

1.2 Floral and apical morphology

Each dahlia 'flower' is a capitate inflorescence consisting of a swollen receptacle carrying a few hundred florets, surrounded by involucral bracts, the outer layer of which reflexes during the later stages of flower bud development. As with other members of the Compositae such as chrysanthemum, the individual inflorescence is a raceme while the flowering shoot as a whole is a cyme, with the oldest inflorescence terminating in the growth of the main shoot (Runger and Cockshull, 1985). The florets are generally of two types, though intermediate types of the other variants do occur, and each floret arises in the axil of a receptacular bract (Runger and Cockshull, 1985). The outermost florets are called ray florets, are distinguished by being female or neuter, and the corolla is extended on one side to form a coloured tounge or ligule. The central disk florets are hermaphrodite and have a symmetrical corolla divided into five teeth (Bodman and Hughes, 1985;

Runger and Cockshull, 1985). The fruits are achenes (Runger and Cockshull, 1985).

Each flowering stem normally produces a central terminal bud and two ancillary lateral or 'wing' buds (Hammett, 1980). There also appears to be a basipetal gradient of increasing incompetence along the shoot axis, so that axillary buds near the shoot apex flower earlier and with fewer leaves than those near the base (Philipson, 1948; Barrett and De Hertogh, 1978a).

The inflorecences can be loosely classified as either 'single', in which an outer ring of coloured, showy florets surrounds a central disc of smaller, yellow florets, or 'double' in which the coloured florets predominate. When the term single-flowered is applied correctly it means that the flowers have just a single row of ray florets surrounding the central disc. In semi-double flowers more than one row of ray florets occurs, although the central disc remains visible. This type of flower is frequently seen in bedding dahlias of the Unwin type (Hammett, 1980).

In the dahlia inflorescence, the florets around the edge of the receptacle develop before those at the centre. In single flowers, pollen is shed first by the outermost florets of the disc. As the bloom ages, pollen is shed progressively by florets near the centre. In double flowers the same age sequence occurs; fully-developed ray florets at the edge of the receptacle form the back of the bloom as more florets develop progressively towards the centre. Blooms of different ages and at different stages of development may be observed on a single plant, irrespective of whether its blooms are double or single (Hammett, 1980).

The progress of flower initiation and development has been studied both in *D. pinnata* (Barrett and De Hertogh, 1978a) and *D. gracilis* Ortg. (Philipson, 1948) which is probably a synonym for *D. coccinea* (Sorensen, 1969). The vegetative apical meristem is small (up to 0.20 mm in diameter) and initiates leaf primordia in opposite and decussate pairs. It enlarges following floral induction, becomes domed (0.3 x 0.24 mm) and the decussate phyllotaxis is lost as it forms a whorl of up to eight outer, green involucral bracts which have no primordia in their axils and later become reflexed. The next organs to be formed, the membranous inner involucral bracts, also have no meristems in their axils

(Philipson, 1948). Finally, thin chaff-like bracts are formed with disk florets in their axils (Runger and Cockshull, 1985).

1.3 Species and cultivars

Garden dahlias are hybrids of very mixed parentage. Currently botanical opinion suggests that all garden dahlias have been derived from hybridization between *D. pinnata* and *D. coccinea* (Sorensen, 1969; Rowell, 1981). There are many sizes and shapes of dahlia which makes it almost impossible to characterize them; for example, marigold-like, allium-like or sunflower-like plants (Still, 1988). However, various classifications have been made by local groups in all parts of the world, mostly following the classification of the National Dahlia Society and the Royal Horticultural Society as follows: single, anemone-flowered, collarette, paeony-flowered, formal decorative, informal decorative, show, pompon, cactus, semi-cactus, and star (Hammett, 1980).

In spite of the complexities of the different flower shapes, dahlia plants may also be classified based on plant height into tall and dwarf types (Still, 1988). The tall dahlias are normally double-flowered types and grown for cut flower purposes (Ball, 1985). This type have to be propagated vegetatively because plants resulting from seeds of the double forms will produce a proportion of single and semi-double types in addition to double blooms (Hammett, 1980). The dwarf strains grow to a height of 25-60 cm and produce an abundance of brightly coloured flowers which range from 5-7.5 cm across. Flowers are single, semi-double, and double (Ball, 1985). However, as a general rule, only the single and semi-double types are accepted to 'breed true' from seed (Hammett, 1980). Although they may be raised either vegetatively or from seed, they are best and easiest grown from seed, and are usually sown as mixed colours (Ball, 1985) for bedding purposes in either boxes or in punnets and sold at garden centres (Hammett, 1980).

The two cultivars used in this study (Unwins Dwarf Mixture (Plate 1.1) and Figaro White (Plate 1.2)) are of the dwarf types and are normally grown as bedding plants.

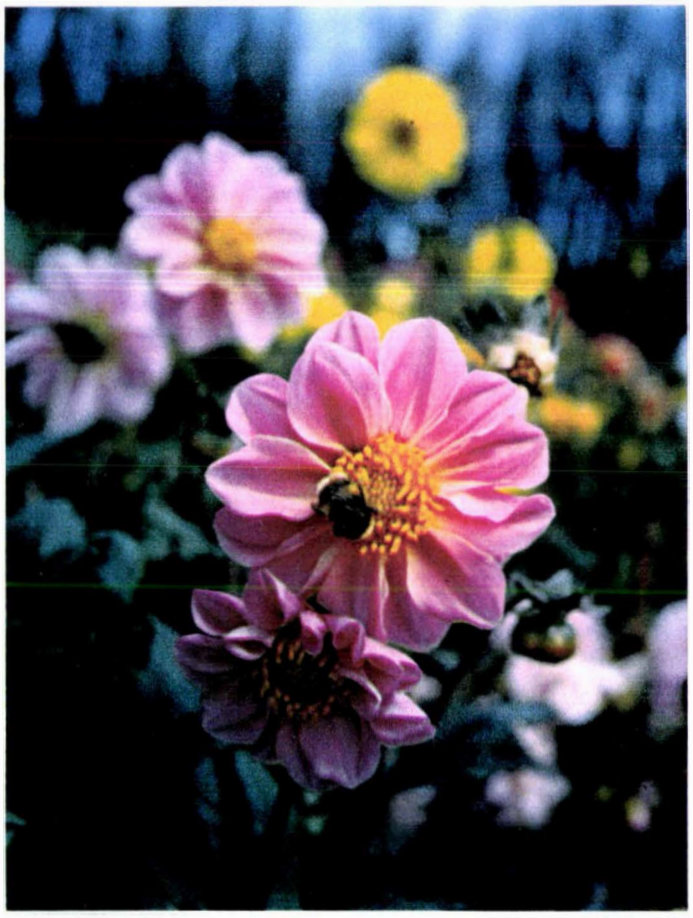

Plate 1.1 Dahlia 'Unwins Dwarf Mixture'.

Plate 1.2 Dahlia 'Figaro White'.

The Unwin strain was developed by the famous sweet pea grower, Charles Unwin of Cambridge, England. The most extensively grown bedding dahlias of all, the semi-double Unwins' Dwarf Hybrids and Unwins' Ideal Bedding, originated from crosses made between 'Coltness Gem' and a tall semi-double strain of dahlias known during the 1920s as Charm dahlias (Hammett, 1980). The cultivar Unwins Dwarf Mixture is the most extensively-grown bedding dahlia, 60 cm tall with semi-double mix coloured flowers.

The Figaro series is one of the newer and better selections with a compact habit (Still, 1988). This series was a result of the improvement of cv. Rigoletto. Both Figaro and Rigoletto have approached 'most popular' status because of their dwarf habit and uniformity; as well as the high percentage of double blooms. They stand 30-35 cm tall and are very early blooming (Ball, 1984). 'Figaro White' is the first separate colour in the Figaro series, and is 30 cm tall, uniform and early flowering (Kieft, 1992).

1.4 Photoperiod and temperature effects on flowering

Flowering in many plants is not determined solely by genetic constitution, but is controlled by environmental factors which interact with the genetic constitution in a specific manner (FAO, 1961; Zeevaart, 1962). For most crops, light and temperature are the primary factors controlling the change from vegetative to the reproductive stage, and it is only when this change has taken place that the secondary factors such as rainfall, wind, soil conditions and insects can exert their full influence (FAO, 1961).

Numerous observations have shown that genera, species, and varieties have developed photoperiodic responses which enable them to adjust the time of flowering and seed production to definite seasons characterized by certain length of day (FAO, 1961). However, during the vegetative period, temperature often has a greater influence than daylength in determining the time when crops flower. Moreover, unsuitable temperatures can prevent flowering, even if the daylength is favourable (FAO, 1961).

Dahlias are daylength sensitive (Mastalerz, 1985). Daylength has both a direct influence on flowering and an indirect one through its effects on vegetative

growth, dormancy, and tuber formation. Vegetative growth is promoted by day lengths of 12 h or more, and retarded by day lengths of 11 h or less (Moser and Hess, 1968). In daylengths of 12 h or less, shoot extension is inhibited, growth in weight of leaves and stems is greatly reduced (Konishi and Inaba, 1964; Konishi and Inaba, 1966b; Konishi and Inaba, 1966d), axillary buds become dormant and fail to sprout, and few side shoots are produced (Konishi and Inaba, 1967b). In addition, tuber formation is promoted by shortdays (SD), (Zimmerman and Hitchcock, 1929; Moser and Hess, 1968). The presence of tubers can also affect the dormancy of axillary buds (Konishi and Inaba, 1967b) and the speed with which they initiate flowers (Konishi and Inaba, 1966d) .

Flower primordia are formed in an early stage of development of the lateral bud (Konishi and Inaba, 1965) under photoperiods ranging from 8-16 hours (Konishi and Inaba, 1966a). Many dahlia cultivars initiate flowers in a daylength of 16 h but generally will do so earlier if the daylength is shortened. These are quantitative shortday (SD) plants for flower initiation (Konishi and Inaba, 1966b). Konishi and Inaba (1966a) also reported that the optimum daylength for flower initiation was 10 h and the optimum daylength for flower development was 13 h, although the critical daylength is 12 h as the flower bud does not develop normally in daylengths less than 12 h. Some cultivars such as Arthur and Summer Red are indifferent to daylength (Zimmerman and Hitchcock, 1929), while others such as Jersey's Beauty and Warner, have an obligate requirement for SD and fail to initiate flowers if the daylength is in excess of 16 h (Zimmerman and Hitchcock, 1929; Konishi and Inaba, 1966a; Mastalerz, 1976; Kumar *et al.*, 1978).

Zimmerman and Hitchcock (1929) also reported that daylength affects inflorescence differentiation; short day (SD) reduce the total number of florets formed and increase the proportion of disc florets. Furthermore, inflorescence differentiation is retarded in some cultivars at daylengths less than 12 h and in these cultivars a high proportion of flower buds that are formed fail to develop to anthesis in very SD (8 h) (Konishi and Inaba, 1964; Durso and De Hertogh, 1977; Konishi and Inaba, 1966a). Development to anthesis also tends to be delayed or even arrested at long daylength of 16 h or more (Zimmerman and Hitchcock, 1929; Konishi and Inaba, 1964; Konishi and Inaba, 1966a).

The total number of florets formed on each capitulum varies between cultivars, as does the proportion of ray to disc florets. Both attributes are also influenced by the environment; the total number of florets increases in LD (Konishi and Inaba, 1964), while the proportion of disc florets increases in SD (Konishi and Inaba, 1964; Durso and De Hertogh, 1977), which convert double inflorescences to single or 'daisy eyed' ones. This effect of daylength is exercised for only a short period during inflorescence formation; 10 SD followed by LD were sufficient to reduce floret number, principally by reducing the number of ray florets, while 15 SD were as effective as continual SD in the Japanese cv. Futarishizuka (Konishi and Inaba, 1966b). In other cvs. 25 SD were needed to reduce the number of ray florets and 14 SD had no effect (Konishi and Inaba, 1966c).

The outcome of all these influences is that the percentage of plants producing open flowers and the total production of flowers is often reduced in daylengths of 11 h or less, and the optimum daylength for flower production lies between 13 and 15 h for many cultivars (Konishi and Inaba, 1964; Konishi and Inaba, 1966a; Durso and De Hertogh, 1977). Shorter daylengths can be used to give earlier flowering, and their deleterious effects on growth and dormancy can be minimized if they are given to young plants for no more than 15 days in succession (Runger and Cockshull, 1985).

The illuminances used to give LD effects by means of daylength extensions have ranged from 20 lx with incandescent lamps (Konishi and Inaba, 1964) to between 1.6 and 2.2 klx using cool white tubular fluorescent lamps (Durso and De Hertogh, 1977). A central 4 h night break (0.65 to 1.08 klx, incandescent lamps) proved at least as inhibitory as a day-length of 16 h (Durso and De Hertogh, 1977), but 'dusk-to-dawn' lighting with incandescent lamps at an illuminance of 269 lx has been recommended to give maximum inhibition of flowering (Mastalerz, 1976).

In many seed-producing areas, temperature is a frequent serious stress; temperatures either too high or too low during maturation of a seed crop can inhibit seed development. High-temperatures (35/30 or 30/24 °C) cause damage to flowers of *Impatiens wallerana* (Lee *et al.*, 1990) or are lethal to pollen

(Herrero and Johnson, 1980; Zamir *et al.*, 1981; Smith-Huerta and Vasek, 1987), thus preventing seed set. Such results are readily seen and easily related to poor seed yields. Freezing injury as the crop matures often adversely affects seed quality. The extent of the freezing injury is a function of the freeze, minimum temperature, seed moisture content at the time of the freeze, physiological maturity of the seed, and the species and cultivar. Seed damage is generally slight if at the time of the freeze the seed is below 20% in moisture content (Harrington, 1972).

In dahlia, the effects of temperature on flowering have received little attention although Garner and Allard (1923) have reported that temperature and photoperiod are the two main climatic factors which control flowering.

Night temperatures between 10 and 26.7°C do not affect flower initiation, though flower development proceeds more slowly at the lower temperatures, giving rise to later flowering (Mastalerz, 1976). Flowering is further delayed at night temperatures of 5°C as compared with either 10 or 15°C (Konishi and Inaba, 1966c), and the date of anthesis of the first flower became later as both the day and night temperatures were lowered from 29°C day / 20°C night to 24°C day / 12°C night (Durso and De Hertogh, 1977). Durso and De Hertogh (1977) also reported that dahlia responds to increased temperature by producing shorter plants. The number of florets has also been reported to be affected by temperature. More florets are formed at 5°C than at 15°C night temperature, and fewer florets are formed under low-light conditions (Konishi and Inaba, 1966c).

1.5 Seed production practices

1.5.1 Climatic requirement

Each species of flower grown for seed has its own planting time, culture, problems of pollination, and harvesting technique, but there is one basic requirement for good seed production, which is a mild climate with little rain during the growing and harvesting seasons. Less favorable conditions result in uncertain and usually lower yields and germination percentages (Bodger, 1961). The growth and seed production of plants is strongly influenced not only by

genetic factors, but also by environmental factors such as light and temperature, rainfall, wind, soil conditions and insect activity (Ball, 1985).

The major determinant of successful seed production is climate. The most important factor is a long growing season free of late spring and early autumn frosts, adequate rainfall, warm temperatures and low humidity (Craig, 1976; Hawthorn and Pollard, 1954). In areas of such climatic conditions it is possible to sow many of the crops directly in the field and to mature a satisfactory crop the same season, thereby reducing the cost of production. Most flower seedsmen prefer a location relatively free of summer and autumn rain, yet having a sufficiently moist atmosphere to keep the shattering of the seed to a minimum (Hawthorn and Pollard, 1954).

Dahlia seeds are produced either in the open field or in the greenhouse; environmental control is a requisite during all stages of glasshouse production. However, the greatest amount of seed is produced outdoors. Included among these crops are most inbred or open-pollinated types, F2 strains and some F1 hybrids. Two methods may be used for the planting of seed crops; sowing the seed directly in the field or transplanting into the field (Craig, 1976). The Coltness or Unwin cultivars, which are grown for bedding plants, are the principal dahlias grown as seedlings (Potter, 1965).

1.5.2 Soil and fertility

Although dahlias can grow on a wide variety of soils, a rich, deep, well drained and well aerated loamy or sandy-loam soil is the most ideal for best growth. Soil pH should be around 6.5. The soil must be rich in humus, phosphorous and potassium (Hammett, 1980; Boodley, 1981; Rowell, 1981; Salunkhe *et al.*, 1987). As a general rule it is advisable to provide a plentiful supply of nutrients if high yields of seed are to be obtained (Hawthorn and Pollard, 1954). However, if soils are high in nitrogen, the plants will produce excessive growth and little bloom (Laurie, 1942; Fell, 1983). Blood or bonemeal (400 kg ha^{-1}) plus 1,000 kg ha^{-1} lime used to be a standard mixture for seed production of most flower species in New Zealand (FAO, 1961). However, the requirements will vary with the individual crop, as well as the soil and previous fertiliser practices (Hawthorn and Pollard, 1954).

The fertiliser need of dahlia plants for growth and flowering in pot was examined in cvs. Kolchelsee and Park Princess by Durso and De Hertogh (1977). They reported that fertiliser was essential and an application of one of several slow-release formulations of Osmocote (14-6.2-11.6, 18-4-10.8, 18-2.6-10, 18-2.6-10+14-6.2-11.6 and 18-4-10.8+18-2.6-10) at the rate of 5.7 kg m^3 planting medium or weekly application of 20N-8.8P-16.6K as a soluble fertiliser increased plant height, flower diameter, flower longevity and the total number of shoots and flowers per plant. The percentage of plants flowering increased from 0 to 100 percent for cv. Kolchelsee and from 73 to 100 percent for cv. Park Princess. Fertiliser also promoted earlier flowering of cv. Park Princess by about 14 days.

As dahlia requires constant feeding (Durso and De Hertogh, 1977), a mixed fertiliser of N-P-K (5-6-4.5) should be applied and tilled into the soil at the rate of 100-150 g m^{-2} two to three weeks before planting (Hammett, 1980; Bodman and Hughes, 1985). This is known as a base dressing. When the plants are just starting to produce flower buds more mixed fertiliser (i.e. NPK 13-10-13) at a rate of 15 g m^{-1} of row should be applied as a side dressing (Hammett, 1980; Boodley, 1981; Bodman and Hughes, 1985).

1.5.3 Sowing and planting

Dahlia from seed produces 30-90 cm high plants with flowers 2.5-7.5 cm across, blooming from early summer until ended by frost (Reilly, 1978). Seeds can be sown from spring to early summer (Bodman and Hughes, 1986). For the best results seed should be sown indoors (Reilly, 1978), covered with 10 mm of vermiculite, maintaining a temperature of 20-30 °C during germination (Reilly, 1978) and be kept well watered (Bodman and Hughes, 1985). Depending on the variety and temperature, germination takes 5 to 10 days and seedlings are ready for transplanting when 4 to 6 weeks old (Reilly, 1978; Bodman and Hughes, 1986), and flower within 16 weeks. Alternatively, seed may be direct sown where plants are to grow after all danger of frost has passed, at a plant spacing of 30-90 cm apart (Reilly, 1978).

1.5.4 Irrigation

Irrigation of flower crops is necessary in all seed-growing areas. The soil should be kept moist enough so that good growth can be obtained (Hawthorn and Pollard, 1954). Timing of irrigation is also critical for the production of high yields of quality seed (McCorkle and Reed, 1961). Over irrigation may result in excessive plant growth, thereby reducing the yield of seed, the same as for the production of some vegetable seed crops (Hawthorn and Pollard, 1954). In dahlias, however, checks in plant growth, flower size and production occur where dahlias are not given sufficient irrigation. Thus, two thorough irrigations per week are recommended for general practice and more in very hot weather or on very porous soils (Bodman and Hughes, 1985). However, during seed ripening, a common practice is to withold the water at the end of the season to encourage rapid uniform maturing of the seed crop (Bodger, 1961) and irrigation must be stopped as the seeds begin to mature (McCorkle and Reed, 1961).

1.5.5 Seed maturation and harvesting

After pollination and fertilization the seeds that are produced must reach a certain stage of maturity before they can be harvested. In some crops early maturing seed is not harvested. Harvesting is most efficient when the greatest amount of seed is mature at one time (Craig, 1976). Thomson (1979) suggested practical parameters commonly used to identify the best time of harvesting. These are first, when the number of seedheads are greater than at any time during the growing season, and second, the colour and consistency of the seeds.

Ample sunshine, little rainfall and the absence of strong winds have a decided advantage during the harvesting of seed of grass and legume crops, vegetable and root crops and many others. As a seed crop approaches maturity it becomes increasingly susceptible to shattering. Strong winds and heavy rainfall at or near harvest-time may cause large losses of seed, particularly in crops which have a tendency to shatter their seed readily. Such conditions may also complicate the harvesting of certain seed crops by lodging them. High wind and hail can also cause extensive damage to flowers and to seed setting. Apart from complicating pollination, excessive rainfall leads to disease and makes harvesting of many

crops extremely difficult. High rainfall also delays seed maturity and causes pregermination of seed in many crops (FAO, 1961).

Flower species are roughly divided into three groups according to the method of harvesting. Group 1: should be hands-picked, since seed shatters readily. Seeds are mature when the seed pods are fully developed and brown. Group 2: should be harvested by cutting the entire plants by hand and placing on canvas sheets to dry. Group 3: can be hand-cut or machine-cut and placed in rows for several days before threshing with a pick-up thresher (FAO, 1961).

Generally in field production harvesting is done mechanically by special machines designed for this purpose. Many crops are also hand picked because they cannot be harvested efficiently by machine. However, the major concern is to collect the greatest amount of seed at low cost (Craig, 1976). Although hand picking or cutting saves more seed, high labour cost and the need for speed dictate mechanical methods whenever possible (Bodger, 1961). However, seed harvest of most flowers involves hand cutting of the mature flower stalks and placing them on canvases to finish drying (McCorkle and Reed, 1961)

In dahlias, seedheads are harvested when they turn yellow, after which they are dried on canvas. Seed can be extracted by threshing or rolling. After cleaning, the seeds are stored in air-tight containers (Salunkhe *et al.*, 1987). In favourable climates it is best to allow seed pods to ripen on the plant. However, seeds contain viable embryos for an appreciable period before the seeds are dry, so that if a period of wet weather occurs the seed may well sprout prematurely while still in the seedhead, or may rot. Alternatively frosts may occur which are damaging to seed which has not dried. Where such situations are likely to occur, the seedheads can be cut once they appear to have stopped swelling, and placed in empty vases or jars in a glasshouse to dry. When ripe and dry the seeds have to be separated from the scale-like bracteole which arises from the receptacle. The separation of the seedheads can be done by hand followed by separating the seed by blowing the scales away from the seed in much the same way as winnowing wheat from the chaff (Hammett, 1980).

1.5.6 Pests and diseases

Like any other flowering plant, the dahlia is subject to attack by a range of insects, mites, nematodes, fungi, and bacteria (Hammett, 1980). The most common pests are spider mites, mealybug, thrips, leaf-eating caterpillars, broad mite, grasshoppers, flower-spoiling beetles, aphid, slugs and snails (Boodley, 1981; Bodman and Hughes, 1985; Selunkhe *et al.*, 1987).

Seedlings of dahlia normally grown from seed for bedding plants are susceptible to damping-off (*Rhizoctonia solani* and *Phythium spp.*) (Bodman and Hughes, 1985; Trolinger and Strider, 1985). The most common diseases that may become serious as the crop matures are powdery mildew, caused by the fungus *Erysiphe cichoracearum*, greymould (*Botrytis cinerea*), stem rot (*Rhizoctonia solani*, *Sclerotium rolfsii* and *Sclerotinia sclerotiorum*) and bacterial wilt caused by the bacterium *Pseudomonas solanacerum* (Bodman and Hughes, 1985). Late in the production cycle, dahlia flower are susceptible to Botrytis blight (*B. cinerea*). Dark grey or brown spots caused by *B. cinerea* appear on affected dahlia buds, leaves, and stems. Buds may be blasted or disorted and sporulation may be profuse on affected tissues (Trolinger and Strider, 1985).

1.5.7 Weed control

Weed control is always a great problem in flower seed production areas. Weeds can reduce seed yields; weed seed can mix with the seed lot during harvesting and become a part of the seed lot after threshing. Weeds must be controlled in the production of flower seeds, particularly during the early period of flower growth (McCorkle and Reed, 1961).

Since many of the flower plants are small and slow-growing, it is highly desirable to use land which is free of weeds (Hawthorn and Pollard, 1954); hand weeding and cultivation will then be kept to a minimum. Most fields need complete hand weeding three times or more a season; sometime this is combined with thinning in drilled crops (Bodger, 1961). Shallow cultivation is always recommended (Hawthorn and Pollard, 1954).

Chipping and pulling large weeds from around dahlias can result in injury to the stem and root systems, and often results in the entry of disease organism (Bodman and Hughes, 1985).

In the Netherlands, chemical weed control has been used successfully in many flower species, including dahlia. Vis (1980) reported sucessful spraying before emergence of the crop and before transplanting with Paraquat 20%,(20-30 ml/100 sq.m) for weed control including grasses and, Diquat 20%, (20-30 ml/100 sq.m) to control weeds except grasses.

In Australia, the inter-row area has been cleaned successfully by spraying with paraquat (Gramoxone) but extreme care is required to avoid injury to the dahlia plant. A comparatively new granular weedicide, Ronstar can be used to provide several months complete weed control if broadcast onto a weed free surface immediately after planting (Bodman and Hughes, 1985), however no detail on the rate of application of this chemical has been mentioned. Another herbicide, Fusilade (1.5-2.0 litre ha^{-1}) can be used to control grasses that have established themselves either between rows or within the row (Bodman and Hughes, 1985).

In the USA, weeds are controlled by physical and chemical methods. In general, the physical methods are the safest while the chemical methods are the least expensive (Kuhns and Haramaki, 1985). Hand weeding is a high cost method; it is not only expensive in terms of labour cost, but if weeds are allowed to grow out of control for a short period of time, the crop may be damaged during the pulling operation. Stems may be broken or roots severely damaged. Chemical methods used to control weeds are classified in several ways. The list of pre-emergence herbicides used successfuly for several bedding plants including dahlias includes: Bensulide (Betasan, Lescosan) at the rate of 11.2-13.5 kg a.i. ha^{-1} will control annual grasses and purslane for 3-4 months, but does not control broadleaved weeds; Chloramben (Ornamental weeder) at the rate of 4.5 kg a.i. ha^{-1} will control many grass and broad leaved weeds for 6-8 weeks; Chlorpropham (Chloro IPC) at the rate of 4.5-6.7 kg a.i. ha^{-1} controls a number of grass and broadleaved weeds; DCPA (Dacthal) at the rate of 10 kg a.i. ha^{-1} controls grasses and some broadleaved weeds; Diphenamid (Enide) 6.5-9.0 kg a.i. ha^{-1} in sprayable formulations, to control many grasses and broadleaved weeds as they germinate;

EPTC (Eptam) at the rate 5.6 kg a.i. ha^{-1} for control of quackgrass, bermudagrass, or mugwort; Oryzalin (Surflan), applied to established plants at the rate of 2.2-4.5 kg a.i. ha^{-1} provides excellent control of most annual grasses and some broadleaved weeds; Trifluralin (Treflan) at the rate of 1.1 kg a.i. ha^{-1} of the 4E formulation or 4.5 kg a.i. ha^{-1} of the 5G formulation is primarily a preplant treatment for the control of a wide range of annual grasses and broadleaved weeds (Kuhns and Haramaki, 1985).

CHAPTER 2

EFFECTS OF PINCHING ON FLOWERING AND SEED YIELD

2.1 INTRODUCTION

Increasing the number of flowers on a plant by hand pinching to increase the se number of lateral branches is a common floricultural practice (Williams and Bearce, 1964; Love, 1975; Ecke and Matkin, 1976). Nearly all species will flower profusely if pinched back in early growth (FAO, 1961). Wainwright and Irwin (1987) showed that the later the stage of plant growth at pinching, the greater the reduction in spike length and delay in flowering of antirrhinum. Pinching also encourages the development of axillary shoots, and the more even distribution of assimilates between several growing points rather than just one, which results in greater flower synchrony (Ecke and Matkin, 1976; Larson, 1980). With many cut-flower crops, larger terminal inflorescences can be produced by removing all the competing axillary flower buds by 'disbudding', and more flower buds can be produced if the apical bud of the main shoot is removed at an early stage by 'pinching' to encourage branching (James, 1963; Runger and Cockshull, 1985; Salunkhe *et al.*, 1987). The removal of the main growing point stimulates the development of axillary buds down the stem; these grow into lateral branches, thus causing the plant to bush out (Hammett, 1980). It also increases main stem diameter, thus making the main stem solid (Rowell, 1981). Pinching position is also important. Barrett and De Hertogh (1978c) using tuberous-rooted dahlias cv. Park Princess and cv. Miramar showed that pinching at node 4 produced about twice as many flowers per plant and least delay in flowering compared to unpinched plants, while pinching at node 2 resulted in the greatest delay and fewest flowers.

This study was undertaken to investigate the effects of pinching at different nodes on the flowering pattern, relative flower production and seed yield of dahlia cv. Unwins Dwarf Mixture grown under field conditions.

2.2 MATERIALS AND METHODS

2.2.1 Site and land preparation

The field experiment was conducted during the months of October 1987-May 1988 at the Seed Technology Centre Research area, Massey University, Palmerston North, New Zealand (40° 21' S). Weather data during this time are presented in Appendix 2.1. The site was a Tokomaru silt loam soil, which is moderately leached and moderately acid, and classified as a yellow-grey earth (Typic fragiaquaf). It is formed on fairly thick deposits of loess of fine sandy loam texture. Drainage is impeded during wet seasons which results in the common occurrence of pale coloured horizons bearing iron/ manganese concretions lying between the top and subsoil (Cowie, 1978). A soil analysis from samples taken in October 1987 is given in Appendix 2.2.

The land used in this study was ploughed on 16 October 1987 and harrowed two weeks later. Treflan (Trifluralin, 400 g litre^{-1}) was applied by spraying with a knapsack sprayer at a rate of 3 litres ha^{-1} on 7 December 1987, and then incorporated into the soil. A broad spectrum granular insecticide, Thimet 20 G (phorate, 200 g kg^{-1} pellet) was scattered by hand at the rate of 8.0 kg ha^{-1} to control aphids, mites and root lesion nematodes on 13 December 1987. The field was harrowed again prior to planting. A compound fertilizer 18-20-0 (150 kg ha^{-1}), sulphate of potash (500 kg ha^{-1}) and calcium ammonium nitrate (150 kg ha^{-1}) were hand broadcast onto the plots at planting. Snail and slug bait, Mesurol (Methiocarb, 20 g kg^{-1} bait), was also broadcast immediately after transplanting at about 100 baits m^{-2}.

2.2.2 Planting procedure and crop management

Forty-seven-day old seedlings of dahlia cv. Unwins Dwarf Mixture were purchased from a local nursery and hand transplanted to the field on 14 December 1987 at a square spacing of 50 cm (plant density of 4 plants m^{-2}). At transplanting the seedlings were about 20-25 cm high with 6-7 leaf pairs. The terminal flower buds were visible and about 1-2 lateral shoots had formed on the main stem.

Irrigation was applied by using an overhead sprinkler system (garden sprinkler) which delivered 6,000 litre water ha^{-1} h^{-1}. During the first two weeks after transplanting, 15 minutes of watering was given every evening to ensure good establishment. Watering was continued every five to seven days until peak flowering and then discontinued.

To foster the growth and development of the plants, a foliar fertiliser 12-8-16 (Nylex New Zealand Ltd, Auckland) was applied at a rate of 35 kg ha^{-1} at 10, 20 and 30 days after transplanting via a fertiliser dispenser attached to a soft spray wand. In addition, a nitrogenous fertiliser (urea at 25 kg ha^{-1}) was also applied as a side dressing by hand broadcasting between the rows of the plants 14 days after transplanting.

During plant establishment, disease and pest control was achieved by spraying the broad spectrum fungicides, Orthocide 80 W (Captan 800g ha^{-1}) at 2.4 kg a.i. ha^{-1} or Benlate (benomyl) at 0.25 kg a.i. ha^{-1} or Bravo 500 F (Chlorothalonil) at 1.5 kg a.i. ha^{-1} and the insecticides, Attack (pirimiphos-methyl, 475 g $litre^{-1}$ plus permethrin 25 g $litre^{-1}$) at 0.5 kg a.i. ha^{-1} or Lannate (methomyl, 200 g $litre^{-1}$) at 0.25 kg a.i. ha^{-1} or Mavrik Aquaflow (fluvalinate, 240 g $litre^{-1}$) at 0.1 kg a.i. ha^{-1} every two weeks. These fungicides or insecticides were used in rotation to prevent the build up of disease or pest resistance.

Plots were hand weeded as required to control weed invasion throughout the experiment.

2.2.3 Treatment and experimental design

The pinching treatments were done by hand removal of the shoot tip just above the designated node on the main stem one week after transplanting. There were 4 treatments as follows:

Unpinched (control).
Pinched above node 3.
Pinched above node 4.
Pinched above node 5.

The experiment utilised a completely randomized design with three replicates per treatment. Plot size was 3x3 m and there were 12 plots altogether. Treatment mean comparisons were performed using Least Significant Difference (LSD) with 5 % probability.

2.2.4 Data collected

2.2.4.1 Flowering pattern

To establish the pattern of flowering, four plants per plot were selected at random one week after transplanting and identified by means of a numbered cane placed beside each plant. Twice a week newly opened flower heads were tagged and the date written on each tag (Plate 2.1).

The number of days to first flowering, number of days to peak flowering, and the total number of flowers per plant were also recorded. These parameters were defined as:

Days to first flowering	- days from transplanting until the first open flower appeared.
Days to peak flowering (PF)	- days from transplanting until the greatest number of open flowers were recorded.
Total flower numbers	- total number of flowers at all development stages (including seed heads) counted one week after peak flowering.

Plate 2.1 Experimental plots (A) and tagged plant (B).

2.2.4.2 Plant height

Plant height was measured from ground level to the highest point of the plant at peak flowering and seed harvest.

2.2.4.3 Seed yield

All plants from each plot (excluding border rows) were hand harvested by cutting at ground level on 3 May 1988 (140 days after transplanting) to avoid the danger of frost damage. Ground frosts had occurred continuously from 25 April 1988 and an air frost occurred on 2 May 1988. Seedheads were separated from the plants immediately and dried for 7 days using the 'Mini Kiwi Dryer' developed by Massey University's Seed Technology Centre (Anonymous, 1989). The drying temperature varied between 28-30 °C with an airflow of 34 m^3 sec^{-1}. One week after drying, the seed was removed and cleaned to obtain 'harvested seed yield' and 'actual cleaned seed yield'. Harvested seed yield was obtained by hand removal of all seeds from hand harvested heads. The subsequent seed sample was cleaned by removing inert matter in a 'Vertical Airblast' seed blower (Burrows Model No. 1836-4) at an air flow setting of 85 m min^{-1}. All seed (including immature, mature and empty seed) was retained. Actual cleaned seed yield was obtained by hand removal of all seeds from hand harvested heads. The subsequent seed sample was cleaned on an air screen cleaner (Clipper Seed Cleaner) using a 2 mm oblong screen and an aspiration setting of 42 cfm. All inert matter, empty seeds and immature seeds were removed resulting in a pure seed content in all samples of over 99%. After final cleaning, the seed moisture content varied from 8-9 %. Seed yield per plant for each treatment was adjusted to 0 % moisture content for presentation of actual cleaned seed yield following air oven test for moisture content using the ISTA low temperature method (103°C, 17 hours, whole seed) (ISTA, 1985). In the absence of any specified 'commercial' or 'trading' seed moisture content for dahlia seed, yields were corrected to 0% moisture (dry weight), rather than using an arbitrary seed moisture content of, say 10%. This method was also use in subsequent experiments.

Seed yield components were determined from four sample plants per plot. The number of seedheads was a mean of total seedhead numbers per plant. Seed numbers per head were counted from 20 seedheads taken at random from the seedheads of each plant. Thousand seed weight was ten times the mean dry weight of eight replicates of 100 seeds.

2.3 RESULTS

2.3.1 Flowering pattern.

The number of flowers produced at each observation time differed among treatments only before 54 days after transplanting (DAP), mostly due to a delay in flowering induced by the pinching treatments (Figure 2.1). Flowering pattern after 54 DAP was similar among all treatments, with two peaks being recorded between 65-68 DAP, and 87-93 DAP. This extended period of flowering over a period of more than two months resulted in seedheads of various ages, as can be seen from the appearance of different colours and shapes of the seedheads (i.e. green, yellow-brown, brown and shattered) as well as flowers and flower buds being present at harvest (Plate 2.2).

2.3.2 Number of flowers per plant.

There were no significant differences between treatments in the total number of flowers per plant counted at the first and second peaks of flowering (Table 2.1). However, pinched plants, especially those pinched above node 4 and 5 had 10-15 % more flowers per plant at the second flowering peak.

2.3.3 Days to first flowering.

The number of days from transplanting to first flowering was delayed ($P<0.05$) by the pinching treatments, the delay being from 7-15 days depending on which node was pinched (Table 2.2). The first flowers from unpinched plants were observed at 30 DAP followed by plants pinched above node 5, 4 and 3 at 37, 42 and 45 days respectively.

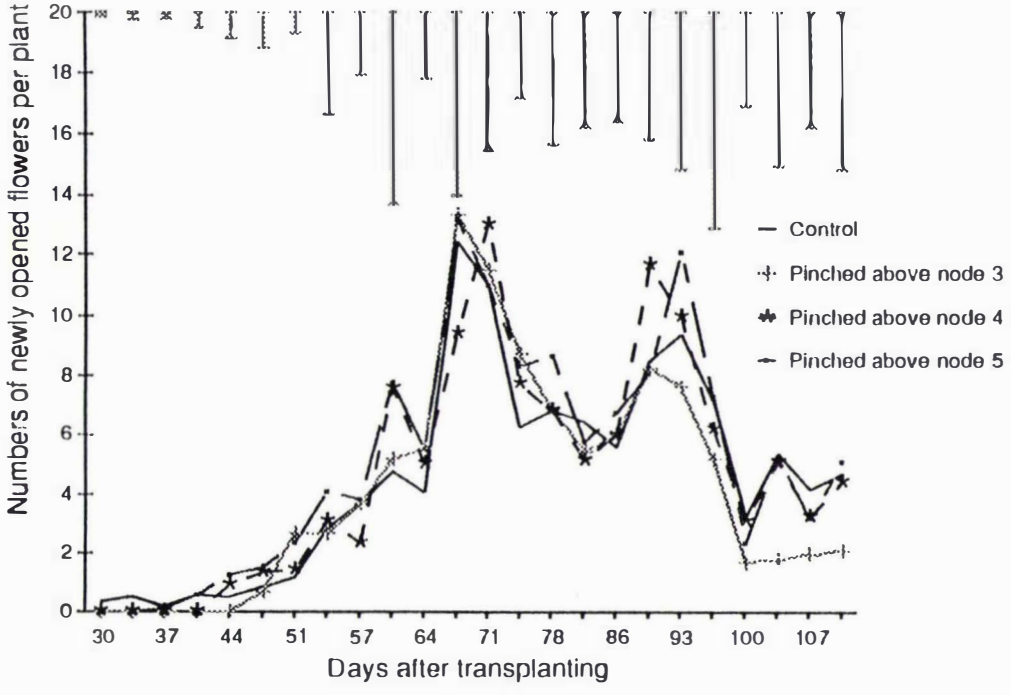

Figure 2.1 Flowering pattern of dahlia cv. Unwins Dwarf Mixture.

Plate 2.2 Flower buds, flowers and seed heads at different development stages present on an individual plant just prior to harvest.

2.3.4 Days to peak flowering.

The number of days taken to reach the first and second peak flowering did not differ among treatments (Table 2.2). However, although there were no significant differences in number of days from transplanting to peak flowering, when the number of days from first flowering to peak flowering were counted, the data showed highly significant differences among the treatments (Table 2.3). Plants pinched above node 3 reached the first and second peak flowering more quickly than plants pinched above nodes 4 and 5, while unpinched plants took longer than other treatments.

2.3.5 Plant height and morphological structure

All pinching treatments significantly increased plant height at first peak flowering (Table 2.4), but at seed harvest only plants pinched above node 3 and 4 were significantly taller than the control.

Plant morphological structure changes following pinching above node 4 are presented in Plate 2.3. Pinched plants had a more uniform lateral branch growth compared to the control. At each node both lateral buds were initiated simultaneously and lateral branches grew at wider angles from the main stem compared with the control, resulting in a more upright plant shape with flower heads produced at a similar level on the top of the plant. In unpinched plants, alternate lateral branches grew simultaneously and lower nodes often produced only one branch.

2.3.6 Seed yield and yield components

Although there were no significant differences in any components of seed yield between pinching treatments and the control (Table 2.5), pinching above node 4 significantly increased harvested seed yield per plant (LSD $P<0.05$) by 40 % (Table 2.6). However, the 32 % increase in cleaned seed yield following pinching above node 4 was not significantly different from the control. A higher percentage cleaning loss was recorded in treatments that produced high harvested seed yields (Table 2.6).

Table 2.1 Effects of pinching on number of flowers per plant.

Treatment	Number of flowers	
	PF1	PF2
Unpinched control	47.6	82.4
Pinched above node 3	51.5	88.9
Pinched above node 4	50.8	90.5
Pinched above node 5	49.6	94.7
LSD (P<0.05)	12.3	12.4
Significance	NS	NS
% CV.	13.2	7.3

PF1 = First peak flowering

PF2 = Second peak flowering

Table 2.2 Effects of pinching on time to first and peak flowering.

Treatment	Number of days from transplanting to		
	FF	PF1	PF2
Unpinched control	29.9	64.7	89.0
Pinched above node 3	45.3	65.0	86.0
Pinched above node 4	41.8	68.0	85.7
Pinched above node 5	37.1	65.0	89.3
LSD (P<0.05)	3.2	14.3	13.7
Significance	***	NS	NS
% CV.	1.9	6.7	5.4

FF = first flowering

PF1 = first peak flowering

PF2 = second peak flowering

Table 2.3 Effects of pinching on days from first flowering to first and second peak flowerings.

Treatment	Number of days from first flowering to	
	PF1	PF2
Unpinched control	35.3	59
Pinched above node 3	21.0	42
Pinched above node 4	28.0	46
Pinched above node 5	28.3	52
LSD (P<0.05)	6.1	8.3
Significance	**	**
% CV.	11.6	8.8

PF1 = first peak flowering
PF2 = second peak flowering

Table 2.4 Effects of pinching on plant height.

Treatment	Plant height (cm)	
	First peak flowering	Harvest
Unpinched control	66.7	76.0
Pinched above node 3	76.7	80.7
Pinched above node 4	74.0	81.3
Pinched above node 5	72.3	79.7
LSD (P<0.05)	4.8	4.4
Significance	**	*
%CV.	3.6	2.9

Plate 2.3 Plant structure of control plant (left) and plant pinched above node 4 (right).

Table 2.5 Effects of pinching on seed yield components.

Treatment	Seedheads per plant	Seeds per seedhead	TSW (g)
Unpinched control	117.2	24.9	6.585
Pinched above node 3	118.1	20.1	7.141
Pinched above node 4	134.1	29.9	6.792
Pinched above node 5	128.0	29.3	6.569
LSD (P<0.05)	57.29	7.90	0.70
Significance	NS	*	NS
% CV.	24.5	16.1	5.5

Table 2.6 Effects of pinching on harvested and cleaned seed yield, and percentage cleaning loss.

Treatment	Seed yield (g/plant) harvested	cleaned	% cleaning loss
Unpinched control	18.81	11.83	37.1
Pinched above node 3	16.77	11.09	33.9
Pinched above node 4	26.42	15.61	40.9
Pinched above node 5	24.58	13.37	45.6
LSD (P<0.05)	7.57	7.94	
Significance	*	NS	
% CV.	18.6	32.5	

2.4 DISCUSSION

2.4.1 Effects of pinching on flowering pattern

All treatments produced similar flowering patterns i.e. an extended period of flowering over a period of more than 2 months from mid January to March 1988, with two peak flowerings between 65-68 DAP and 87-93 DAP. This resulted in seed of various maturities at harvest. This problem is similar to that reported by Gray (1987) in carrot (*Daucus carota*) where the inflorescence is highly branched, flowering prolonged and seeds mature at different times. Two peaks of flowering have also been reported in leaf lettuce (*Lactuca sativa*) (Sukprakarn, 1985) which, like dahlia, belongs to the compositae family. This feature makes judging the harvest time particularly difficult if once-over or machine harvesting is desired. Any management or treatment that can reduce this long flowering period would obviously be beneficial.

2.4.2 Effects of pinching on number of flowers

Pinching is a common practice for flower production, particularly for potted plants or plants for display. Pinched plants will flower more profusely due to the better uniformity of lateral branch growth simultaneous flower appearance and increased flower numbers (Williams and Bearce, 1964; Love, 1975; Ecke and Matkin, 1976). However, the number of flowers is normally counted shortly after flowering, or at the plant display or selling period. For example as reported by Barrett and De Hertogh (1978c) in dahlia cv. Park Princess, pinching at node 3 or 4 resulted in about twice as many flowers per plant (from 2.4 to 4.4 and 5.5) compared to unpinched plants. In their experiment, the number of flowers were counted at 7 days after opening of the first flower. In the present experiment, early flowering results were the same as for flower production (i.e. pinching resulted in more simultaneous flowering, see 2.4.3), but when flower numbers were counted later at first and second peak flowering (5-8 weeks after first flowering), pinching did not significantly increase flower numbers at either of the flowering peaks (Table 2.1). This suggests that while pinching is effective in

terms of delaying the onset of flowering and therefore reducing flowering duration of dahlia crops it does not alter flowering intensity at peak flowering. While pinching treatments can be used as a method of increasing the number of flowers produced at an early stage for potted plants or cut-flower production purposes, this practice is unlikely to be beneficial for increasing the total number of flowers for seed production.

2.4.3 Effects of pinching on days to flowering

The number of days from transplanting to first flowering was significantly delayed by the pinching treatments. This confirms results from a study on dahlia cvs. Park Princess and Miramar by Barrett and De Hertogh (1978a) who showed that when pinched, over 80% of the lateral branches were reproductive at 12 days later than the unpinched control. A delay in flowering following pinching has also been reported in geranium (*Pelargonium x hortorum* Bailey) (White, 1970), chrysanthemum (*Chrysanthemum spp.*) (Laurie *et al.*, 1979; Kofranek, 1981), antirrhinum (*Antirrhinum majus*) (Wainwright and Irwin, 1987), verbena (*Verbena venosa*) (Norremark, 1986), impatiens (*Impatiens hybrids*) (Starman, 1991) and China aster (*Callistephus chinensis*) (Phetpradap, 1992).

The position of the pinch also affected the time of flowering, in that the lower the node of the pinch, the greater the delay. This result is supported by Philipson (1948) who found in *Dahlia gracilis* that when the plant enters the reproductive phase all active apices on the plant are committed to capitulum production, not simultaneously, but in basipetal sequence down the secondary branches, and in similar sequences down the tertiary branches. Differences in days to flowering between the pinching position on cvs. Park Princess and Miramar were also reported by Barrett and De Hertogh (1978c); on most pinched plants, the first flower to open was on a lateral arising from the most distal node. Pinching at node 3 or 4 resulted in the least delay, while pinching at node 2 resulted in the greatest delay.

Although pinching delayed first flowering, it promoted a more intense and even time of onset of flowering as lateral flower production was more simultaneous; thus all treatments reached peak flowering at the same time (Table 2.2) and had a

similar number of flowers (Table 2.1). Wainwright and Irwin (1987) have also reported that, in antirrhinum, pinching caused axillary shoot development which resulted in a more even distribution of assimilates between several growing points rather than just one. This effect of promoting simultaneous flowering would be considered to be an advantage for high quality seed production.

2.4.4 Effects of pinching on plant height and morphological structure

Pinching increased plant height of dahlia cv. Unwins Dwarf Mixture. This increase was due to the greater elongation of lateral branches. Increases in plant height after pinching because of elongation of the lateral branches have also been reported in cv. Park Princess by Barrett and De Hertogh (1978c). In contrast, pinching has been reported to reduce plant height of marigold (*Tagetes erecta*) cvs. African Giant Orange, African Giant Yellow and French Dwarf Red (Bhati and Chitkara, 1987); verbena (*Verbena venosa*) (Norremark, 1986) and antirrhinum (*Antirrhinum majus*) (Wainwright and Irwin, 1987). These contrasting results may be due to differences in species responses, management or plant measurements; for example Wainwright and Irwin (1987) reported that in antirrhinum, pinching caused a reduction in plant height due to a greater reduction in flower spike length.

The better uniformity of lateral branch growth (Plate 2.3) as an effect of the pinching in the present study agreed well with the report by Barrett and De Hertogh (1978c). This uniformity is likely to lead to a shorter time from first to peak flowering and hence a higher uniformity in maturation of seedheads would be expected. Moreover, this treatment may also provide improved ease for harvesting, as flower heads or seedheads were produced at a similar level.

2.4.5 Effects of pinching on seed yield and yield components

Although the results for seed yield components did not show significant differences in the number of seedheads per plant or thousand seed weight (Table 2.5), pinching above node 4 increased the number of seedheads per plant by 15 % and the number of seeds per seedhead by 20 %. These greater numbers were high enough to result in a significant increase in harvested seed yield (40 %). Cleaned

seed yield following pinching above node 4 was also increased by 32 % but this difference was not significant, possibly because the data coefficient of variation was high. A greater amount of immature seed lost during cleaning may be another possible reason. The average of 1091 more seeds per plant following pinching above node 4 may also have lead to greater assimilate competition, and therefore some delay in seed maturity. As the final harvest had to be done on 3 May 1988 due to the dangers of frost damage, it is possible that the pinched plants (above node 4) still had a high number of immature seeds and that these seeds were removed during the cleaning process. It is possible that if frosts had not been a threat, cleaned seed yield would have been significantly increased.

2.5 CONCLUSION

As reported by Still (1988), seed-grown dahlias are usually erratic bloomers due to the lack of a uniform growth habit, and this indeterminate flowering may cause a wide range of seed maturity within a plant. Results in this study showed that pinching did not increase the total number of flowers per plant or shorten the total flowering period. Pinching did shorten the days from first to peak flowering due to more uniform lateral branch growth, which subsequently resulted in more simultaneous flowering and higher harvested seed yields, particularly in plants pinched above node 4. However, the 32 % increase in cleaned seed yield did not significantly differ from the control, presumably because of relatively high variation between plant (CV.= 32.5 %) and also the possibility that a greater amount of immature seed was lost during cleaning. It is possible that if frosts had not been a threat, cleaned seed yield would have been significantly increased. Further work to study any treatment which could reduce the spread of flowering and improve seed yield and quality (such as plant growth regulators), is obviously required.

CHAPTER 3

EFFECT OF HAND PINCHING AND PLANT GROWTH REGULATOR MANIPULATION OF PLANT GROWTH AND DEVELOPMENT ON SEED PRODUCTION

3.1 INTRODUCTION

Hand-pinching results (Chapter 2) suggested a possibility for improving seed yield in dahlia (cv. Unwins Dwarf Mixture) by pinching at node 4. Pinching shortened the days from first to peak flowering and subsequently produced a more simultaneous initial flowering and higher harvested seed yield. Pinched plants had a better uniformity of lateral branch growth and seedhead maturation at harvest. However, despite these changes in plant morphology, plants still had a wide range of flowering periods, similar to the unpinched plants. This prolonged flowering resulted in seeds maturing at different times, as the plants still contained flower buds, flowers and seedheads of various maturities at harvest. This feature made judging the best harvest time difficult, a situation which promted more critical studies on seed development and harvest timing later in the study (Chapters 5 and 6 respectively). Furthermore, hand pinching may be difficult in practical situations, especially for large scale seed production in the field.

An indeterminate flowering habit, where the plant flowers over a long period, has also been reported as a major obstacle for seed production of birdsfoot trefoil (*Lotus corniculatus* L.) (McGraw and Beuselink, 1983). Li (1989) reported that in this species flowering can continue for up to three months with two or three flowering peaks, resulting in flower buds, blooming flowers, immature pods, mature pods and pods ready to shatter all present on the plant at the same time. This long period of flowering resulted from a continuous shoot succession and the capability of shoots to switch to reproductive growth as soon as conditions were suitable for flower induction (Li and Hill, 1988; Li, 1989). Seed yield improvement has been successfully achieved following the use of plant growth regulating chemicals in *Lotus* species, for example in *Lotus corniculatus* and *L.*

uliginosus following paclobutrazol application (Clifford and Hare, 1987; Hampton *et al.*, 1989b; Li, 1989), and in *L. uliginosus* following cycocel application (Tabora, 1991). The plant growth regulator daminozide has also increased yields in *Trifolium pratense* - red clover (White *et al.*, 1987; Christie and Choo, 1990).

3.1.1 Plant growth regulators

Chlormequat (Cycocel, CCC) is perhaps the most extensively used plant growth retardant in agriculture. One of its primary uses is to control lodging of grain crops (Kust, 1986). It is also used extensively to control shoot growth in many floricultural crops. The compound is quite effective in controlling shoot elongation when applied to the foliage. Chlormequat can also be applied as a soil drench. It is not particularly persistent and may need to be applied more than once if cropping time is long. Persistence in the soil is also usually not very great (Davis and Andersen, 1989).

Daminozide (Alar, B-Nine, SADH) is a hydrazine derivative which is an effective plant growth retardant. Its major use in agriculture is to regulate fruiting and post-harvest quality of tree fruits. Daminozide is generally quite effective in controlling shoot elongation of most dicots and is often used in bedding plants. Its persistence is not great and re-application may sometimes be necessary. Daminozide is usually administered as a foliar spray (Davis and Andersen, 1989).

Paclobutrazol (PP333, Cultar) primarily acts by inhibiting the biosynthesis of gibberellins (Davis and Andersen, 1989) and has been shown to shift assimilate partitioning from leaves to roots (Globerson, *et al.*, 1989). It can also increase the carbohydrate, soluble protein and mineral levels in leaf tissue (Wang, *et al.*, 1986). The translocation of paclobutrazol from the root is primarily through the xylem (Sterrett, 1985).

The chemical structure of paclobutrazol was released in September 1981 (Froggatt *et al.*, 1982). First reports indicated that it was highly effective in restricting extension growth of amenity grasses (Shearing and Batch, 1980, 1982). When compared to other growth retardants, paclobutrazol is highly active in small

dosages. Paclobutrazol is also quite persistent in checking growth, particularly when soil-applied. Because of its persistence, paclobutrazol usually needs to be applied only once. This offers potential for reducing labour costs for the grower (Davis and Andersen, 1989).

3.1.2 Plant growth regulators in floriculture

The discovery and development of growth-regulating chemicals with a broad spectrum of activity is of considerable interest for floriculture use because such compounds can improve the capability to manipulate and control growth and cropping. In ornamental horticulture, for example, the availability of a method for controlling plant height and form will largely determine whether certain species can be grown as pot plants (Menhenett, 1984). In bedding plants chemical growth regulators are commonly applied to produce more compact plants and extend marketability (Mastalerz and Holcomb, 1985). For new floriculture crops growth regulators may also be useful in altering plant shape, size, and form when these are naturally too large for standard container culture (Davis and Anderson, 1989).

Regulation of the growth of chrysanthemum, poinsettia, and bedding plants by the application of growth regulators is widely practiced commercially (Semeniuk and Taylor, 1970). Growth regulators are also used to suppress vegetative growth and to promote flower initiation in many plants such as *Rhododrendron* (azalea) (Stuart, 1961, 1962; MacDowell and Larson, 1966), *Pelargonium X hortorum* Bailey (White, 1970; Armitage *et al.*, 1984), *Camellia X Williamsii* (Wilkinson and Richards, 1988), and *Rhododendron* (Wilkinson and Richards, 1991).

In commercial production, daminozide has been widely used for height control of bedding plants and other greenhouse crops, such as *Impatiens holstii* cv. Dwarf Bright Orange, *Petunias hybrida, Salvia splendens* cv. Red Pillar, *Tagetes erecta* (Marigold) cv. Double Eagle, *Verbena hybrida* cv. Sparkle (Cathey, 1976), and *Zinnia elegans* (Sachs and Hackett, 1972, Cathey, 1976; Armitage *et al.*, 1981).

In azalea, daminozide induced the formation of more multiple flower buds and promoted very uniform flowering compared with other compounds (Stuart, 1964).

Similar studies on azalea flower bud initiation were also reported by McDowell and Larson (1969). They found that flower bud initiation occurred more readily on plants of cv. Red Wing when plants were treated with chlormequat or daminozide applied as foliar sprays. McConnel and Struckmeyer (1970) studied the response of marigold (*Tagetes erecta*) cv. Sovereign to daminozide in two different daylength treatments. They showed that plants responded to daminozide application similarly for both photoperiods although there was more vegetative growth with increased height and dry weight of tops and longer internodes in long days compared to short days. The major responses of marigold following daminozide application were shorter internodes, delay in flowering and altered leaf shape.

Chlormequat (CCC) has been used on geranium (*Pelargonium hortorum* Bailey). Semeniuk and Taylor (1970) reported that growth regulation by the application of CCC could be practised commercially. CCC suppressed vegetative growth, shortened internodes, produced stockier plants, and increased the number of basal shoots, resulting in a greater number of flowers. Schekel and Blau (1987) also found that CCC stimulated early flowering and thereby reduced production time. They also stated that the early flowering caused by the retardant occurred as a result of accelerated floral initiation, possibly due to antagonism of the retardant to gibberellic acid (GA) synthesis.

Paclobutrazol (PP333) has been shown to be an anti-gibberellin. Drenches of 2.5 to 7.5 µg ai/plant to Sprinter Scarlet geranium seedlings reduced flowering time by as much as 20 days. Application timing was critical with no effect observed when applications were made after 6 or more leaves had expanded on the seedlings. Exogenous applications of GA reversed the effects of paclobutrazol on treated seedlings.

Paclobutrazol is already available for commercial use, and has received clearance for use as a growth regulator on selected floricultural crops in the USA and some European countries (Davis and Andersen, 1989).

Paclobutrazol has been effective in retarding growth of numerous flowering potted plants (McDaniel, 1986; Davis *et al.*, 1988), foliage plants (Hickman,

1986), and annual bedding plants (Barrett and Nell, 1986), such as *Chrysanthemum morifolium* (Barrett, 1982; Barrett and Bartuska, 1982; McDaniel, 1985), *Camellia X Williamsii* (Wilkinson and Richards, 1988), *Euphorbia pulcherrima* Willd. (poinsettia) (Keever and Cox, 1989), and rhododendron (Wilkinson and Richards, 1991).

Some plants such as *Epicia cupreata* (Stamp and Henny, 1986) *Hydrangea macrophylla* (Bailey *et al.*, 1986), and *Bouvardia humboldtii* (Wilkinson and Richards, 1987) respond to paclobutrazol treatment with increased and/or earlier flowering. Paclobutrazol also promotes early flowering of *Fuchsia X hybrida* cv. La Campanella (Davis and Andersen, 1989).

Shaw and Hayslett (1991) worked on the effect of paclobutrazol and uniconizole on marigold (Inca Series) and ageratum (*Ageratum mexicanum* cv. Adriatic Hybrid). They reported that single applications of 40 and 80 ppm of uniconizole significantly reduced ageratum height as compared to the control. Height retardation was effectively achieved in ageratum with 30, 60, and 120 ppm of paclobutrazol applied as a foliar spray. Marigold height was also reduced by single applications of either paclobutrazol or uniconizole. The higher drench rates resulted in excessive height reduction with both chemicals. Single spray applications of 10, 20, and 40 ppm of uniconizole and 15, 60 and 120 ppm of paclobutrazol were effective in controlling height in marigolds.

3.1.3 Plant growth regulators in seed production

Information on flower seed production has been comparatively limited compared to other crops, and, until recently, only a few reports on the use of PGR's in flower seed production had been published. There were none for dahlia seed production. However the use of PGR's to improve seed yield and yield components has been reported in many crops with various degrees of success, depending on chemical application (kinds, rate, method etc.), plant growth or size, and species or cultivars (Menhennett, 1980; Goulston and Shearing, 1985; Larson, 1985). For example in field bean (*Vicia faba* L.), Attiya *et al.*, (1983) reported that plants sprayed with paclobutrazol (1.0 kg a.i. ha^{-1}) at the 6 leaf stage and at the commencement of flowering were shorter and were less susceptible to

lodging. Paclobutrazol changed growth habit, and yield components and grain yield were increased significantly. The increased yield was associated with significant increases in pods per plant and seeds per unit area. They further concluded that paclobutrazol increased harvest index and may increase pod retention on plants.

In oilseed rape (*Brassica napus*), it has been suggested that growth regulators could benefit yields by reducing pod abortion, seed shedding or lodging (Wooley, 1982) or by increasing apical dominance of the terminal raceme, which has a greater harvest index than the side branches (Daniels *et al.*, 1984). Altering branching and crop height could influence penetration of light into the canopy, giving better utilisation of available light (Dawkins and Almond, 1984). Child (1984) pointed out that reduced crop height could enable easier spraying and harvesting and that growth regulators which induced abscission of late-opening flowers could give more uniform ripening, leading to less pod shatter and reduced seed losses at harvest.

A PGR application in oilseed rape during the winter may influence subsequent crop development by altering apical development and reproductive hierarchy, thus modifying the components of seed yield (Almond and Dawkins, 1985).

Sustained retardance of growth, which produces a lower, more compact canopy in a field crop may result in increased pod number, thereby providing the basis for possible yield increase. Significant yield increases in oilseed rape cv. Jet Neuf of 20-30% after treatment with 'triazole' (UK140 and Bas 111000W) and daminozide have been reported by Child *et al.*, (1985).

The effect of paclobutrazol on flowering, stem elongation and seed production in three vegetables crops was investigated by Globerson *et al.*, (1989). They reported that spraying onions (*Allium cepa*) with 1000 ppm when 3-5% of the onion stalks were visible in the field reduced the length of the seed stalk by 20-30 %. Later sprays led in many cases to development of onion set instead of flowers. Spraying cucumber (*Cucumis sativus*) with 500-1000 ppm at the 4-6 leaf stage reduced the plant size without affecting the number of fruits or seeds per plant. Spraying carrot (*Daucus carota*) plants before seed stalk appearance

reduced the flower stalk from 90-100 cm to 30-40 cm. Paclobutrazol application did not affect thousand seed weight or seed germination in these three species (Globerson *et al.*, 1989).

3.1.4 Plant growth regulators in dahlia

Plant growth regulator research on growth and development of dahlia has concentrated on tubers or cuttings. Biran and Halevy (1973 b,c) demonstrated that a 16 hour dip of cuttings in 125 ppm indolebutyric acid and either 20 ppm N-6 benzyladenine or 0.75-3.0 ppm abscissic acid would enhance the rooting of cuttings. They also found that reproductive or growing shoots suppressed rooting (Biran and Halevy, 1973a), and that rooting inhibitors are apparently formed in the roots and transported to the shoot (Biran and Halevy, 1973c).

Although the basic mechanism for controlling tuberisation of dahlia is under photoperiodic control (Zimmerman and Hitchcock, 1929), this phenomenon can also be influenced by exogenous plant growth substances (De Hertogh *et al.*, 1976). Moser and Hess (1968) reported that daminozide would promote tuberisation under an 18 hour photoperiod and that GA_3 suppressed tuber enlargement of either daminozide treated plants or plants grown under an 8 hour photoperiod. Read *et al.* (1972) confirmed the effect of daminozide and demonstrated that chlormequat would also promote tuberisation. Biran *et al.* (1972) also reported daminozide and GA3 effects and showed that abscissic acid and ethephon would promote tuberization. However, these studies concentrated only on the relationship of growth substances to tuberization.

Rounkova (1989) investigated the effect of ethylene producing substances and paclobutrazol on some ornamental plants i.e. chrysanthemum, phlox, and dahlia. All inhibitors were applied by spraying the leaves and stems of the plants two weeks after transplanting into the field (height 20-25 cm). Growth inhibition was observed for all above-ground parts of the plants, especially stems, and the effect was retained through the next year. In Rounkova's experiment Paclobutrazol reduced stem height by about 50 %. Paclobutrazol also delayed flowering for 3-5 days and a shorter period of inflorescence production was also observed. He also (Rounkova, 1989) concluded that paclobutrazol was able to produce dwarf dahlia plants with normal inflorescences.

This study primarily aimed to investigate the effects of three plant growth regulators (paclobutrazol, daminozide and chlormequat chloride) on seed production of dahlia under field conditions. Two experiments are reported in this study. Both experiments had the same treatments but differed in the cultivar used. The first was Unwins Dwarf Mixture (Chapter 3A) which is the same cultivar as used in Chapter 2 and the second was Figaro White (Chapter 3B). Figaro White was chosen because it is a single colour in an attempt to reduce the high variation among plants of different flower colours present in Unwins Dwarf Mixture and used in the previous experiment (Chapter 2). Although there is a suggestion that dwarf cultivars such as Figaro White may not respond to pinching or chemical treatment with plant growth regulators the choice of this cultivar was determined by the fact that it was the only single colour cultivar for which seed was available commercially.

Although hand pinching did not significantly improve seed yield overall (Chapter 2) the 'best' treatment (pinching above node 4) was included in this subsequent trial for comparative purposes.

The objective of this study was to determine whether hand pinching and/or growth regulators would change the morphological structure, flowering pattern and seedhead production of the plants and thus increase seed yield in two cultivars of dahlia, Unwins Dwarf Mixture and Figaro White.

PART A. cv. Unwins Dwarf Mixture

3A.1 MATERIALS AND METHODS

3A.1.1 Experimental site

The experiment was conducted at the same site and adjacent to the area used in the previous year (Chapter 2). Soil preparation procedures and general management, unless otherwise stated, were the same as described in Chapter 2. Weather data during this experiment are presented in Appendix 3.1.

3A.1.2 Plant materials and establishment

Seeds of dahlia cv. Unwins Dwarf Mixture were dusted with thiram [1 g product (80% wettable powder)/100 g seed] and direct field sown by hand on 21 December 1988. Approximately four seeds per hole were sown at a square spacing of 30 cm, at a depth of about 2 cm. Water was applied for one hour immediately after sowing using a garden sprinkler which delivered 6,000 litres ha^{-1} h^{-1}. During the first two weeks after sowing, irrigation was applied for 30 minutes every 3 days with the same sprinkler. This continued subsequently every five to seven days, except during wet periods until peak flowering when irrigation was discontinued. Plants were thinned to one per hole 14 days after seedling emergence. Missing plants were replaced by transplanting seedlings of the same age from surplus seedlings growing near the experimental plot. Hand weeding was employed throughout the experiment.

Ammophos (12-10-10-8) fertilizer at the rate of 100 kg ha^{-1} was applied as a side dressing by scattering onto the soil surface 40 days after sowing (30 January 1989). In addition, foliar spray fertilizer 'Happy Garden' 12-8-16 (Nylex New Zealand Ltd, Auckland) was also applied at 20 and 35 days after sowing via a fertilizer dispensor attached to a soft spray wand at the rate of 35 kg ha^{-1}.

Snail and slug pellets, Mesurol (Methiocarb, 20g kg^{-1} bait) were broadcast at about 100 pellets m^{-2} one week after sowing. Disease and pest control was

achieved by spraying broad spectrum fungicides, Orthocide 80 W (captan, 800 g kg^{-1}) 1.2 kg a.i. ha^{-1} or Benlate (benomyl, 0.25 kg a.i. ha^{-1}) or Bravo 500 F (chlorothalonil, 150 ml a.i. ha^{-1}) and the insecticides Attack (pirimiphos-methyl, 475 g $litre^{-1}$ plus permathrin 25 g $litres^{-1}$) 0.5 kg a.i. ha^{-1} or Lannate (methomyl, 200 g $litre^{-1}$) at 0.25 kg a.i. ha^{-1} or Mavrik Aquaflow (fluvalinate, 240 g $litres^{-1}$) 0.1 kg a.i. ha^{-1} every two weeks starting from two weeks after seed emergence. These fungicides or insecticides were used alternately to prevent disease or pest resistance.

3A.1.3 Treatment and experimental design

Hand pinching and three plant growth retardants, chlormequat chloride (CCC), daminozide (Alar) and paclobutrazol (PP333) were the treatments used.

Pinching was done by hand removal of the apical shoot tip above node 4 (between node 4 and 5) when the plants had 6-7 pairs of true leaves (21 February 1989).

A single application of the three plant growth regulators were applied via a 5 litre pressure sprayer in one litre of water per plot. Twenty hours after PGR application, water was applied for 30 minutes via sprinkler irrigation which delivered 6,000 litres ha^{-1} h^{-1}. Each growth regulator was applied at two rates:

1.5 or 3.0 kg a.i. ha^{-1} for chlormequat,
2.0 or 4.0 kg a.i. ha^{-1} for daminozide, and
0.5 or 1.0 kg a.i. ha^{-1} for paclobutrazol.

Each chemical application rate was made at two stages of plant growth:

Stage 1 : at first visible terminal bud stage or when the plants had 4-5 nodes and were approximately 15-20 cm in height (48 days after sowing) (8 February 1989);

Stage 2 : at stem elongation or when the plants had 6-7 nodes, branches were beginning to extend and plants were approximately 25-30 cm in height (62 days after sowing) (21 February 1989).

Stage of plant growth at hand pinching and PGR application are shown in Plate 3A.1.

There were therefore 14 treatments as follows:

Control: untreated
Pinching above node 4
Paclobutrazol 0.5 kg a.i. ha^{-1} stage 1
Paclobutrazol 1.0 kg a.i. ha^{-1} stage 1
Daminozide 2.0 kg a.i. ha^{-1} stage 1
Daminozide 4.0 kg a.i. ha^{-1} stage 1
Chlormequat chloride 1.5 kg a.i. ha^{-1} stage 1
Chlormequat chloride 3.0 kg a.i. ha^{-1} stage 1
Paclobutrazol 0.5 kg a.i. ha^{-1} stage 2
Paclobutrazol 1.0 kg a.i. ha^{-1} stage 2
Daminozide 2.0 kg a.i. ha^{-1} stage 2
Daminozide 4.0 kg a.i. ha^{-1} stage 2
Chlormequat chloride 1.5 kg a.i. ha^{-1} stage 2
Chlormequat chloride 3.0 kg a.i. ha^{-1} stage 2

Treatments were assigned in a randomized complete block design with 3 replicates. The plot size was 1.5 X 2 m with a distance of 2 m between blocks. There were 30 plants per plot or 11 plants m^{-2}. Data were analysed by analysis of variance and treatment mean comparisons were performed using Least Significant Differences.

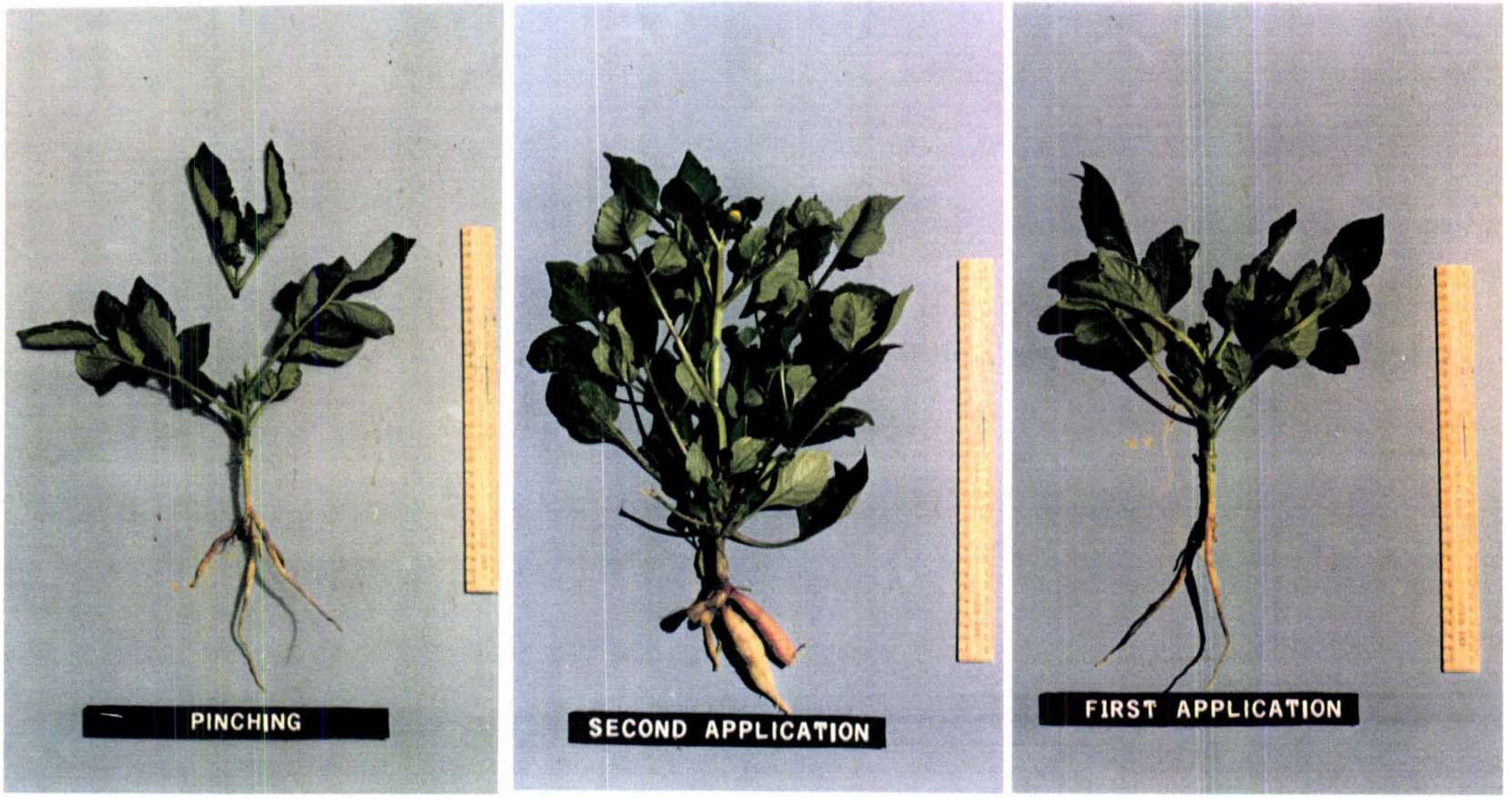

Plate 3A.1 Stage of plant growth at hand pinching and PGR application.

3A.1.4 Data collection

3A.1.4.1 Definitions

The following definitions have been adopted in this study:

Days to first flowering	- number of days from sowing to the time when 50% of the plants in each plot had the first flower open.
Days to peak flowering	- number of days from sowing to the time when maximum open flowers from four sample plants taken at random from each plot were counted.
Plant height	- measured from ground level to the highest point of the plant.
Main stem length	- measured from ground level to the base of the open terminal flower on the main stem.
Lateral branches	- axillary branches on the main stem with at least one visible flower bud.
Lateral branch length	- measured from the base of the lateral branch to the base of the open terminal flower of each branch.
Flower stalk length	- measured from the last node to the base of the open terminal flower on the lateral branches.
Number of flowers	- all flower heads from the time that the outer ray florets started to open until they were fully opened.
Number of seedheads	- flower heads from which all petals had dropped were counted as a seedhead; the number included mature and immature seedheads at harvest.

Number of seeds per seedhead - the number of developed seeds per seedhead counted from 20 seedheads of each plant from four sample plants per plot taken at random.

Thousand seed weight - the mean dry weight of eight replicates of 100 seeds.

All plant growth measurements (plant height, main stem, lateral branch length, and the number of lateral branches) and seed yield components were made at harvest. Only the number of flower heads were counted at peak flowering.

3A.1.4.2 Seed yield and yield components

All plants from each plot (excluding border rows) were hand harvested by cutting the whole plant at ground level on 9 May 1989 (139 days after sowing). Seedheads were separated from the plants, dried, threshed, weighed and cleaned using the same method as described earlier in Chapter 2. Seed yield components were determined from four randomly chosen sample plants per plot.

For germination and viability testing four lots of 50 seeds per plot were thiram dusted [1 g (80 % wettable powder) per 100 g seeds], prechilled at 5 °C for 5 days then germinated using the between paper roll method at 20/30 °C (ISTA, 1985). Seedlings were counted after 7 and 14 days with the final count at 21 days. Germination percentage was calculated from the normal seedlings. Seeds which showed evidence of life (normal and abnormal seedlings and fresh ungerminated seeds) were counted as viable seeds.

3A.2 RESULTS

3A.2.1 Plant growth and development

3A.2.1.1 Plant height and main stem length

Pinched plants had a significantly shorter main stem length than the untreated control and all PGR treatments, but because lateral branches originating from all positions were significantly longer than the control, the net effect was no significant difference in plant height at harvest (Table 3A.1).

Growth retardation effects on all PGR treated plants were first seen 2-3 weeks after application. Of these three PGR's, paclobutrazol provided the most uniform plants and its effects lasted for longer than those of daminozide and chlormequat (Plate 3A.2). However by seed harvest, only the main stem length of plants treated with paclobutrazol at 1.0 kg ha^{-1} and daminozide at 4.0 kg ha^{-1} applied at the first visible flower bud stage were significantly decreased. There were no significant differences in plant height between PGR treatments and the control, and lateral branch lengths of all treatments were not significantly changed (Table 3A.1). However, treatments with chlormequat showed a promoting trend after plant growth recovered while paclobutrazol and daminozide tended to show retarding effects.

3A.2.1.2 Lateral branch number

Pinching reduced the number of lateral branches (from 12.7 to 8.0) but PGR treatments did not significantly change the number of lateral branches (Table 3A.2).

Table 3A.1 Effect of hand pinching and growth regulator application on main stem length, lateral branch length from different positions on the plant, and plant height at harvest (cv. Unwins Dwarf Mixture).

Treatment	Main stem length (cm)	Branch length			Plant height (cm)
		Base (cm)	Middle (cm)	Top (cm)	
Control	32.0	57.3	51.3	33.9	64.3
Pinching	5.1	72.0	71.6	66.9	74.3
Paclobutrazol 0.5 kg ai (1)	32.3	57.0	49.1	36.4	60.3
Paclobutrazol 1.0 kg ai (1)	26.0	56.2	46.6	29.9	56.7
Daminozide 2.0 kg ai (1)	26.7	54.0	45.6	30.7	57.3
Daminozide 4.0 kg ai (1)	25.3	52.2	45.5	30.5	56.3
Chlormequat 1.5 kg ai (1)	37.0	65.8	51.1	38.9	70.3
Chlormequat 3.0 kg ai (1)	31.0	59.8	52.0	36.9	63.3
Paclobutrazol 0.5 kg ai (2)	31.3	58.4	48.6	29.0	61.0
Paclobutrazol 1.0 kg ai (2)	28.0	52.0	44.1	26.0	57.3
Daminozide 2.0 kg ai (2)	31.0	61.6	54.6	36.9	64.0
Daminozide 4.0 kg ai (2)	30.0	54.3	42.3	33.3	59.3
Chlormequat 1.5 kg ai (2)	31.3	69.8	56.9	41.0	71.0
Chlormequat 3.0 kg ai (2)	28.3	64.7	55.3	37.8	68.0
LSD (P<0.05)	5.6	13.5	11.7	9.4	13.7
Significance	***	*	**	***	*
% CV	11.9	13.5	13.7	15.4	12.9

(1) = Applied at visible bud stage

(2) = Applied at stem elongation stage

Plate 3A.2 Experimental plots (A), plants prior to first flowering (B) and plants at peak flowering (C).

1 = Control 2 = Pinching

3 = Paclobutrazol 1 kg a.i. ha^{-1} applied at visible terminal bud stage

4 = Daminozide 4 kg a.i. ha^{-1} applied at visible terminal bud stage

5 = Chlormequat 3 kg a.i. ha^{-1} applied at stem elongation stage

3A.2.1.3 Flower number

No significant differences in number of flowers per plant among pinching or PGR treatments and the control were recorded at peak flowering (Table 3A.2). Two treatments (paclobutrazol at 0.5 kg a.i. ha^{-1} at first-visible-bud stage and chlormequat at 1.5 kg a.i. ha^{-1} at stem elongation) had 10-12 more flowers per plant (+30 % and 37 % respectively), but high variation produced non-significant results.

3A.2.1.4 Flower stalk length

The lengths at harvest of terminal flower stalks from lateral branches which originated from the base, middle and top positions on the main stem are presented in Table 3A.3. No significant differences in flower stalk length among the control, pinching and PGR treatments were recorded from basal lateral branches. On middle lateral branches, flower stalks of pinched plants were significantly longer than all other treatments except for the control and plants treated with daminozide 2.0 kg a.i. ha^{-1} at the stem-elongation stage. Pinching significantly increased flower stalk length of top lateral branches, but PGR's did not.

3A.2.1.5 Days to first flowering and peak flowering

Pinching significantly delayed first flowering by 13 days (Table 3A.4). PGR treatments also delayed first flowering by 1-4 days (Table 3A.4), but these delays were significant only for daminozide (4.0 kg a.i. ha^{-1}) and chlormequat (3.0 kg a.i. ha^{-1}) when applied at first-visible-bud stage, and paclobutrazol (1.0 kg a.i. ha^{-1}) and daminozide (both rates) at stem elongation.

No effects of pinching and PGR treatments on the number of days to peak flowering were recorded (Table 3A.4). All treatments took 98-102 days to reach peak flowering, the same time as the control. Paclobutrazol, particularly at 1.0 kg a.i. ha^{-1} was observed to produce plants which had a higher uniformity in seedhead production than other treatments (Plate 3A.3).

Table 3A.2 Effect of hand pinching and growth regulator application on number of lateral branches at harvest and number of flowers at peak flowering.

Treatment	Lateral branches per plant	Flowers per plant
Control	12.7	34.7
Pinching	8.0	35.0
Paclobutrazol 0.5 kg ai (1)	13.2	45.4
Paclobutrazol 1.0 kg ai (1)	11.3	26.2
Daminozide 2.0 kg ai (1)	11.6	22.5
Daminozide 4.0 kg ai (1)	10.9	34.0
Chlormequat 1.5 kg ai (1)	12.0	33.7
Chlormequat 3.0 kg ai (1)	12.1	31.2
Paclobutrazol 0.5 kg ai (2)	13.1	35.1
Paclobutrazol 1.0 kg ai (2)	11.4	24.2
Daminozide 2.0 kg ai (2)	10.9	24.0
Daminozide 4.0 kg ai (2)	11.1	29.6
Chlormequat 1.5 kg ai (2)	14.1	47.5
Chlormequat 3.0 kg ai (2)	13.2	37.7
LSD (P<0.05)	2.8	16.1
Significance	*	*
% CV	14.2	29.1

(1) = Applied at visible bud stage

(2) = Applied at stem elongation stage

Table 3A.3 Effect of hand pinching and growth regulator application on flower stalk length from different positions of the plant at harvest.

Treatment	Flower stalk length (cm)		
	Base	Middle	Top
Control	14.7	13.9	13.3
Pinching	14.0	18.0	18.1
Paclobutrazol 0.5 kg ai (1)	14.9	11.8	13.9
Paclobutrazol 1.0 kg ai (1)	11.1	12.0	14.1
Daminozide 2.0 kg ai (1)	11.3	10.9	12.9
Daminozide 4.0 kg ai (1)	13.8	10.7	12.1
Chlormequat 1.5 kg ai (1)	16.0	12.2	11.9
Chlormequat 3.0 kg ai (1)	14.2	10.3	11.7
Paclobutrazol 0.5 kg ai (2)	13.3	11.8	12.0
Paclobutrazol 1.0 kg ai (2)	11.1	9.7	9.9
Daminozide 2.0 kg ai (2)	17.7	16.2	12.1
Daminozide 4.0 kg ai (2)	13.6	13.4	12.2
Chlormequat 1.5 kg ai (2)	17.0	12.6	17.5
Chlormequat 3.0 kg ai (2)	15.1	9.9	13.9
LSD (P<0.05)	5.0	4.4	4.5
Significance	*	*	*
% CV	21.1	21.2	20.4

(1) = Applied at visible bud stage

(2) = Applied at stem elongation stage

Table 3A.4 Effect of mechanical pinching and growth regulator application on number of days to first and peak flowering.

Treatment	Number of days from sowing to	
	First flowering	Peak flowering
Control	67.3	99.0
Pinching	80.7	102.3
Paclobutrazol 0.5 kg ai (1)	69.7	98.3
Paclobutrazol 1.0 kg ai (1)	69.0	97.7
Daminozide 2.0 kg ai (1)	70.0	98.7
Daminozide 4.0 kg ai (1)	70.3	100.3
Chlormequat 1.5 kg ai (1)	68.7	100.3
Chlormequat 3.0 kg ai (1)	70.3	102.0
Paclobutrazol 0.5 kg ai (2)	69.0	100.3
Paclobutrazol 1.0 kg ai (2)	70.7	99.0
Daminozide 2.0 kg ai (2)	70.3	102.0
Daminozide 4.0 kg ai (2)	71.7	102.0
Chlormequat 1.5 kg ai (2)	69.3	99.7
Chlormequat 3.0 kg ai (2)	69.0	98.7
LSD (P<0.05)	2.8	4.2
Significance	***	*
% CV	2.4	2.5

(1) = Applied at visible bud stage

(2) = Applied at stem elongation stage

3A.2.2 Seed yield and yield components

Paclobutrazol at 1.0 kg a.i. ha^{-1} at first visible bud and chlormequat at 1.5 kg a.i. ha^{-1} at stem elongation significantly increased cleaned seed yield per plant by 72 % and 66 % respectively (Table 3A.5). The harvested seed yields did not significantly differ from the control. Various seed losses were recorded among treatments (Table 3A.5) due to different amounts of immature seeds.

The number of seeds per seedhead was significantly increased only by paclobutrazol at 1.0 kg a.i. ha^{-1} at first visible bud stage. No significant differences in seedhead number were recorded, although two treatments, paclobutrazol at 0.5 kg a.i. ha^{-1} at first visible bud stage and chlormequat at 1.5 kg a.i. ha^{-1} at stem elongation had 8 and 16 more seedheads per plant (+21 % and +42 %, respectively) compared to the control. Again, however, high variation between plants produced non-significant results. No significant differences were recorded for TSW (Table 3A.6).

3A.2.3 Germination and seed viability

Pinching and PGR treatments had no effect on the percentage germination and viability of the seeds (Table 3A.7). Between 87-95 % of the seeds were viable and germination ranged from 83-94 %.

Plate 3A.3 Control, hand pinched and PGR treated plots at three weeks before seed harvest.

Table 3A.5 Effect of hand pinching and growth regulator application on harvested seed yield, cleaned seed yield and percentage cleaning loss.

Treatment	Seed yield (g/plant) harvested	cleaned	% cleaning loss
Control	8.95	4.99	44.2
Pinching	9.21	6.28	31.8
Paclobutrazol 0.5 kg ai (1)	10.94	6.02	45.0
Paclobutrazol 1.0 kg ai (1)	9.70	8.62	11.1
Daminozide 2.0 kg ai (1)	6.27	6.06	3.3
Daminozide 4.0 kg ai (1)	7.87	5.66	28.1
Chlormequat 1.5 kg ai (1)	9.71	5.54	42.9
Chlormequat 3.0 kg ai (1)	8.41	5.70	32.2
Paclobutrazol 0.5 kg ai (2)	8.09	6.58	18.7
Paclobutrazol 1.0 kg ai (2)	7.78	7.67	1.4
Daminozide 2.0 kg ai (2)	6.62	5.46	17.5
Daminozide 4.0 kg ai (2)	7.86	5.09	35.2
Chlormequat 1.5 kg ai (2)	11.51	8.29	28.0
Chlormequat 3.0 kg ai (2)	10.26	5.72	44.2
LSD (P<0.05)	3.91	2.96	
Significance	*	*	
% CV	26.5	28.2	

(1) = Applied at visible bud stage

(2) = Applied at stem elongation stage

Table 3A.6 Effect of hand pinching and growth regulator application on number of seed heads per plant, seeds per seed head and seed weight.

Treatment	Seed heads per plant	Seeds per seed head	TSW (g)
Control	37.6	36.0	6.74
Pinching	40.3	34.6	6.50
Paclobutrazol 0.5 kg ai (1)	45.6	38.3	6.50
Paclobutrazol 1.0 kg ai (1)	31.3	46.4	6.78
Daminozide 2.0 kg ai (1)	30.0	32.2	6.57
Daminozide 4.0 kg ai (1)	33.7	34.3	6.92
Chlormequat 1.5 kg ai (1)	40.0	39.6	6.18
Chlormequat 3.0 kg ai (1)	39.3	35.3	6.14
Paclobutrazol 0.5 kg ai (2)	33.7	36.9	6.48
Paclobutrazol 1.0 kg ai (2)	30.7	37.1	6.85
Daminozide 2.0 kg ai (2)	28.7	35.4	6.57
Daminozide 4.0 kg ai (2)	32.7	34.3	7.04
Chlormequat 1.5 kg ai (2)	53.3	32.2	6.76
Chlormequat 3.0 kg ai (2)	39.0	39.9	6.61
LSD (P<0.05)	16.6	8.54	0.91
Significance	*	*	NS
% CV	26.8	13.9	8.2

(1) = Applied at visible bud stage

(2) = Applied at stem elongation stage

Table 3A.7 Effect of hand pinching and growth regulator application on germination and percent viability.

Treatment	Germination (%)	Viability (%)
Control	88.5	89.5
Pinching	89.5	91.2
Paclobutrazol 0.5 kg ai (1)	83.3	89.0
Paclobutrazol 1.0 kg ai (1)	88.7	91.3
Daminozide 2.0 kg ai (1)	88.0	89.3
Daminozide 4.0 kg ai (1)	85.7	87.7
Chlormequat 1.5 kg ai (1)	87.5	90.8
Chlormequat 3.0 kg ai (1)	91.0	92.5
Paclobutrazol 0.5 kg ai (2)	92.5	93.8
Paclobutrazol 1.0 kg ai (2)	88.2	91.3
Daminozide 2.0 kg ai (2)	93.7	94.0
Daminozide 4.0 kg ai (2)	93.2	94.7
Chlormequat 1.5 kg ai (2)	89.5	91.3
Chlormequat 3.0 kg ai (2)	88.3	91.3
LSD (P<0.05)	8.9	7.4
Significance	NS	NS
% CV	5.9	4.9

(1) = Applied at visible bud stage

(2) = Applied at stem elongation stage

3A.3 DISCUSSION

This trial was not sown until 21 December (compared with the use of 47 day old seedlings transplanted into the field on 14 December in the previous trial, Chapter 2). Plant spacing was at 30 cm square planting compared with 50 cm in the previous trial (Chapter 2). This confounds comparison between results in Chapters 2 and 3 but was considered to be appropriate in the present study in an attempt to reduce the length of the vegetative period in the hope this would shorten the duration of flowering. Reduced plant spacing (30 cm, 111,111 plants ha^{-1} in this trial compared with 50 cm, 40,000 plants ha^{-1} in Chapter 2) was also designed to allow comparison of results between the two cultivars, and particularly to not disadvantage Figaro White, a dwarf cultivar which is recommended to be planted at a spacing of 25-30 cm. The spacing of 30 cm was slightly lower than that recommended for Unwins Dwarf Mixture (40-60 cm) which resulted in yields of cleaned seed per plant of 4.99 g in this cultivar compared with 11.83 g/plant in Chapter 2 at 50 cm spacing.

3A.3.1 Effects on plant growth and development

3A.3.1.1 Pinching

Although pinching reduced main stem length, lateral branch length from all positions of the plant, including flower stalk length at the top lateral branch, was significantly increased by pinching. The reduction of main stem length was due to the plant top removal. This removal of the apical point presumably encouraged the movement of assimilates to lateral branch growth, resulting in a greater elongation of lateral branches. Increases in lateral branch length from pinched plants conforms well with the results in Chapter 2 and the report of Barrett and De Hertogh (1978c) who found a greater elongation of lateral branches after pinching. However, results for plant height in the present experiment did not agree well with the previous experiment. All pinching treatments in Chapter 2 significantly increased plant height but although pinched plants in this experiment were 10 cm higher, this was not significant, probably due to a high variation among treatments and between replicates.

3A.3.1.2 Plant growth regulators

Paclobutrazol

Plants treated with paclobutrazol were observed to have more compact growth and a darker green leaf colour. This effect lasted for only 2-3 weeks. At seed harvest, however, only plants treated with paclobutrazol at 1.0 kg a.i. ha^{-1} at the first-visible-flower-bud stage had significantly shorter main stems compared to the control. This shorter main stem was presumably due to the gibberellin biosynthesis inhibition effect of paclobutrazol (Hedden *et al.*, 1983; Goulston and Shearing, 1985; Davis *et al.*, 1988) which results in a shortened internode length (Rounkova, 1989). A reduction in internode length following paclobutrazol application has been reported in other plants (Wample and Culver, 1983; Wood, 1984; Hampton, 1985; LeCain *et al.*, 1986; Lever, 1986; Li and Hill, 1989; Tolentino, 1990; Tabora, 1991). However, the length of lateral branches and flower stalks from all positions of the main stem did not change. This result conflicts with the report of Rounkova (1989) who found that paclobutrazol caused a reduction of all above-ground parts of the plant, especially stems and flower stalks, which were considerably shorter than the control. Davis *et al.* (1988) suggested that the effects of paclobutrazol application to the plants depended upon many factors, including method of application (e.g., foliar spray, stem injection or soil/root), transpiration rate, degree of vascular binding, amount reaching the leaves versus the growing points, the level of endogeneous gibberellins at time of treatment, and time of treatment (season of the year as well as developmental stage of the plant). Timing of application of the compound in relation to crop physiological stage and environmental stress may also have a major influence on the type of effect seen (Lever, 1986). There is a great dependence for the effect of paclobutrazol on the cultivar used, as observed in other plants e.g. in bedding tulips (Menhenett and Hanks, 1982), *Chrysanthemum morifolium* (Barrett and Bartuska, 1982), and *Lotus corniculatus* (Supanjani, 1991). It is possible that the different results between this and Rounkova's experiments may be due to a different rate and method of application and different plant sources used in the experiment. Rounkova (1989) applied paclobutrazol (50 ppm) by spraying onto the leaves and stems of rooted cuttings for three weeks in succession, while in this experiment paclobutrazol was applied only once to plants grown from seeds.

Paclobutrazol has been successfully used to increase the number of lateral branches in other plants, for example in *Lotus uliginosus* (Tabora, 1991), or increase tiller numbers, for example in *Lolium perenne* (Hampton and Hebblethwaite, 1985a). However paclobutrazol did not increase the number of lateral branches of dahlia. Similar results were also found in 'Meiwa' Kumquat (*Fortunella clasifolia* Swingle) (Iwahori and Tominaga, 1986), Geraldton wax flower (*Chamelaucium uncinatum* Schauer)(Lamont, 1986), *Holcus lanatus* L.- Yorkshire fog (Tolentino, 1989), and *Lotus corniculatus* L. (Supanjani, 1991).

Daminozide

The early retarding effects of daminozide on plant growth and development were similar to paclobutrazol. At seed harvest daminozide at 4.0 kg a.i. ha^{-1} applied at first-visible-flower-bud stage significantly reduced main stem length. Lateral branches and flower stalk lengths did not significantly differ from the control. De Hertogh *et al.* (1976) also reported that daminozide had no effect in retarding plant height of dahlia cv. Early Bird. A failure to retard internode length has also been reported in *Begonia X cheimantha* (Heide, 1969), *Celosia agentea*, *Coleus blumei* and *Antirrhinum majus* (Heins *et al.*, 1979), and *Trifolium pratense* (Niemelainen, 1987). Conflicting results following the use of daminozide have been published, which suggests that this plant growth regulator may be species and/or cultivar specific (Kust, 1986; Davis and Andersen, 1989).

Chlormequat

Plants treated with chlormequat did not have reduced main stem, lateral branch or flower stalk length, or number of lateral branches at seed harvest. These results are similar to those of De Hertogh *et al.* (1976) who found that chlormequat had no effect in retarding plant height of dahlia cv. Early Bird. Similar results were also found in *Chrysanthemum X morifolium* (Cathey and Stuart, 1961), *Cleome spinosa* and *Petunia X hybrida* (Cathey, 1964), *Philodendron oxycardium*, *Epipremnum aureum* and *Syngonium podophyllum* (Poole, 1970).

Cathey (1964) reported that plants that form resting organs such as bulbs, rhizomes, and corms are unresponsive to even massive applications of chlormequat. In contrast, in wheat even low levels of chlormequat in solution culture or as a soil treatment increased both vegetative growth and dry matter accumulation.

3A.3.2 Effects on flowering

3A.3.2.1 Pinching

Results in this experiment confirmed the finding in Chapter 2; i.e. that pinching promoted simultaneous flowering, as time from first to peak flowering was shortened (first flowering was delayed by 13 days but peak flowering was reached at the same time). There was no difference in flower numbers, although pinched plants had significantly fewer lateral branches than the control.

3A.3.2.1 Plant growth regulators

Flowering was also delayed by some PGR applications, but the delay was not as obvious as for the pinching treatment (3-4 days compared to 13 days). Delay in flowering after paclobutrazol application to dahlia has also been reported by Rounkova (1989), and in other flower species such as marigold (McConnell and Struckmeyer, 1970), and chrysanthemum (McDaniel, 1983; Menhenett, 1984; Zalewski, 1989). In contrast, daminozide has been reported not to influence the flowering of some floricultural crops (Bhattacharjee *et al.*, 1976; De Hertogh *et al.*, 1976; Read *et al.*, 1972; Larson, 1985).

In this experiment, flower number did not significantly change and the delay in flowering was usually with the higher PGR rates. Paclobutrazol generally has no influence on flower numbers or floral initiation in some herbaceous species (McDaniel, 1983; Menhenett, 1984; Gianfagna and Wulster, 1986a), but at relatively high rates of application, paclobutrazol can significantly delay anthesis (McDaniel, 1983; Menhenett, 1984).

Shortening the flowering period by using PGR's was one of the general aims in this study, as a shorter flowering period should lead to more even maturity of the crop which in turn could be expected to ease the problems of harvesting, reduce seed shedding and other sources of seed loss (Ward *et al.*, 1985). None of the PGR treatments in this experiment provided this advantage, and although most of the higher rates did shorten the initial flowering duration, this effect was not enough to reduce the total flowering duration. Thus a high variation in seed maturation was still present and a high percentage of seed loss still occurred in many of the treatments.

3A.3.3 Effects on seed yield and yield components

3A.3.3.1 Pinching

Pinching did not significantly increase seed yield or any of its components, which was similar to the previous year's results. In percentage terms the harvested and cleaned seed yield were greater in the pinching treatment (by 22 and 26%) but these increases were lower than in the previous experiment (40 and 32%, Chapter 2). This may have been due to an interaction with the effects of plant density (see Chapter 7).

3A.3.3.2 Plant growth regulators

The results from this experiment showed that only plants treated with paclobutrazol at 1.0 kg a.i. ha^{-1} at the first visible bud stage and chlormequat at 1.5 kg a.i ha^{-1} at the stem elongation stage produced a significantly increased seed yield per plant (72% and 66%, respectively).

The increase in seed yield from plants treated with paclobutrazol was associated with a significant increase in number of seeds per seedhead (29 %). This result is similar to observations in other plants e.g. *Lolium perenne* (Hampton and Hebblethwaite (1985a), *Lotus uliginosus* (Clifford and Hare, 1987; Hampton *et al.*, 1989a), *Bromus willdenowii* (Hampton *et al.*, 1989a) and *Holcus lanatus* (Tolentino, 1989). Seed yield increases from this treatment were also due to a

lower percentage of seed loss (11.1 % compared to 44.2 % for the control) as a result of better uniformity of seedhead development and hence a greater number of mature seedheads at harvest (Plate 3A.2).

The reason for the seed yield increase following application of chlormequat is unclear as there were no significant differences in the number of lateral branches, number of flowers per plant or any other seed yield components. Despite this, the seed yield increase following chlormequat application at 1.5 kg a.i. ha^{-1} at stem elongation was best explained by the increase in the number of flower heads and seedheads rather than by any change in seed number. Chlormequat treated plants had 13 more flowers and more seedheads per plant than the control, and although not significant, the result suggests that this treatment might be worth re-examining in a further study. Chlormequat has been reported to enhance flower production and reduce the incidence of flower abortion in gladiolus and rose (Halevy, 1985), to improve the development and uniformity of tomato fruits (Bergman, 1966), reduce the competitive action of sinks in wheat, and improve synchrony of ear and grain formation (Jung, 1984). Increased seed yield following chlormequat application has also been found in peppers (Cathey, 1964), oat (*Avena sativa*) and wheat (*Triticum aestivum*) (Kust, 1986), perennial ryegrass (*Lolium perenne*) (Hampton, 1986), *Bromus willdonowii* (Hampton *et al.*, 1989a), and *Lotus uliginosus* (Tabora, 1991). However the higher number of seedheads following chlormequat application may have caused a delay in seedhead development, as a greater number of immature seedheads were observed at harvest (Plate 3A.2).

The application of daminozide had no benefit for seed production of this dahlia cultivar. Seed yield and yield components were not affected by daminozide application. This result is similar to that for *Brassica napa* (Child *et al.*, 1985) and *Lotus corniculatus* (White *et al.*, 1987; Supanjani, 1991). They found that daminozide application under diverse combinations of conditions, including crop age, location, genotypes and cultivar, planting design, application schedule and treatment time, did not change seed yield. Despite this, daminozide has been successfully used to increase seed yield in red clover seed crops (Jakesova and Svetlik, 1987; Christie and Choo, 1990).

Variation in the percentage of seed loss between harvested and cleaned seed yield suggested variation in seed maturity among treatments (Table 3A.5) and indicated a requirement for more accurate harvest timing for each treatment. Two treatments (paclobutrazol 1.0 kg a.i. ha^{-1} applied at first visible flower bud and chlormequat 1.5 kg a.i. ha^{-1} at stem elongation) which produced a significantly increased seed yield per plant were chosen for a further study for correct harvesting time (Chapter 6).

3A.4 CONCLUSION

Hand pinching was confirmed as being of little value as a management strategy for seed production of field grown dahlia cv. Unwins Dwarf Mixture. Although pinching enhanced an initial simultaneous flowering, it reduced the number of lateral branches and flower heads, and all other yield components did not differ from the control. Pinching also requires more labour and may be not practical for large scale production.

All chemicals showed plant growth retarding effects shortly after application but the effects were not persistent. However seed yield was increased following the application of paclobutrazol (1.0 kg a.i. ha^{-1}) at visible-terminal-flower bud stage and chlormequat (1.5 kg a.i ha^{-1}) at the stem elongation stage. Seed yield increase following paclobutrazol was due to a significant increase in seed numbers per seedhead and greater maturation uniformity, but the reason for the effect of chlormequat is still not clear. As both paclobutrazol and chlormequat showed possibilities for increasing seed yield, these two plant growth regulators were selected for further study.

PART B. cv. Figaro White

3B.1 MATERIALS AND METHODS

3B.1.1 Experimental site

The experimental site was adjacent to the area used for cv. Unwins Dwarf Mixture (Chapter 3A). Soil preparation procedures and general management, unless otherwise stated, were the same as has been described previously in Chapter 2 and Chapter 3A.

3B.1.2 Plant materials and establishment

Seeds of dahlia cv. Figaro White were sown on 19 October 1988 at four seeds per cell into root trainers (45 mm x 30 mm x 80 mm deep) filled with Smith's soil (a sterile mixture of peat, pumice and sand containing balanced proportions of fertiliser and slow release trace elements plus terrazol soil fungicide, Smith Soil Industries Limited, Auckland, New Zealand) and raised in a glasshouse (30/20±5 °C) at the Plant Growth Unit, Plant Science Department, Massey University. The plants were thinned to one per cell one week after seedling emergence. Seedlings were hand transplanted into the field at a square spacing of 30 cm on 21 November 1988 (33 days after sowing).

Water was applied for one hour immediately after transplanting by using a garden sprinkler which delivered 6,000 litres ha^{-1}. Watering (30 minutes per irrigation time) was continued every three days during the first two weeks and every five to seven days (except during wet periods) until peak flowering, and then discontinued. Other crop husbandry such as fertilizer use, weed and disease and pest control was as previously described for the cv. Unwins Dwarf Mixture experiment (Chapter 3A).

3B.1.3 Treatment and experimental design

Details of the treatments and experimental design were the same as already described for cv. Unwins Dwarf Mixture except that hand pinching was done on 14 December 1988 (23 days after transplanting), and plant growth regulators were applied on 4 December 1988 for stage 1 and 20 December 1988 for stage 2 (13 and 29 days after transplanting, respectively). The plot size was 2 x 4 metres with 78 plants per plot.

3B.1.4 Data collection

3B.1.4.1 Definitions

The definitions used were the same as in cv. Unwins Dwarf Mixture except that secondary lateral branches and empty seedhead were added:

Secondary lateral branch - branch arising from the lateral branches.

Empty seedheads - seedheads in which fertilization was not successful or which contained no seed.

3B.1.4.2 Growth measurements

Plant growth data were measured from four sample plants taken at random from each plot at peak flowering and at seed harvest.

To obtain peak flowering date, four plants per plot were selected at random and identified by means of a numbered cane placed beside each plant. Once a week newly opened flowers were recorded and the day the greatest number of open flowers were counted was defined as the peak flowering date.

At peak flowering plant height, main stem length, number of lateral branches, number of secondary lateral branches, and flowers were recorded. The lateral branches of each plant were divided into three parts (base, middle and top) according to the position of the branch which developed from the main stem. The length of lateral branches and the length of the terminal flower stalk from each of the lateral branches were also recorded. After measuring, each plant was separated into main stem, branch, leaf, flower stalk and flower. Each fraction was then dried in an oven to a constant weight at 80°C for 3 days.

At seed harvest plant height, main stem length, number of lateral branches, lateral branch length and flower stalk length (base, middle and top) were recorded.

3B.1.4.3 Seed yield and yield components.

Seed harvest was timed to concide with the date on which 80% or more seedheads had turned brown. This occurred 43-51 days after peak flowering (13 March 1989). Although this is later than the optimum time of harvest in individual seedhead development studies determined later (Chapter 5), the use of such a harvesting criterion in a field situation is consistent between trials (Chapters 2, 3 and 4). It should be noted, however, that some early heads (approximately 10% of the population) had begun to show visual signs of shattering at this time.

Seed yield from 3.6 m^2 / plot (excluding border rows) was obtained by hand cutting all plants at ground level on 13 March 1989 (113 days after transplanting). Seedheads were separated from the plants and dried, threshed and cleaned using the same method as described earlier for cv. Unwins Dwarf Mixture (Chapter 2).

Determination of other yield components, as well as germination and viability methods were also the same as for the cv.Unwins Dwarf Mixture experiment (Chapter 3A).

3B.2 RESULTS

3B.2.1 Plant growth and development

3B.2.1.1 Plant height

At peak flowering, all treatments except pinching and chlormequat applied at stem elongation had significantly reduced plant height (Table 3B.1), but by harvest differences were no longer significant, except for daminozide at 4.0 kg a.i. ha^{-1} applied at stem elongation which was significantly shorter than the control.

3B.2.1.2 Main stem length

The main stem of pinched plants was shorter than the control at both peak flowering and harvest. Main stems of plants treated with paclobutrazol (1.0 kg a.i. ha^{-1}) at both stages and daminozide (4.0 kg a.i.ha^{-1}) at first visible bud stage were shorter than the control only at peak flowering (Table 3B.1).

3B.2.1.3 Branch length

At peak flowering, both rates of paclobutrazol and daminozide applied at first visible bud, and daminozide (4.0 kg a.i. ha^{-1}) applied at stem elongation had significantly reduced lateral branch length at the base of the plant. For plants treated with paclobutrazol 1.0 kg a.i. ha^{-1}, daminozide both rates, chlormequat 3.0 kg a.i. ha^{-1} at visible bud and daminozide 4.0 kg a.i. ha^{-1} at stem elongation stage, the top lateral branch lengths were shorter than the control, but there were no differences in middle lateral branch length (Table 3B.2).

At harvest, there were no significant differences between PGR treatments and the control for lateral branch length at the base and top of the plant (Table 3B.2). For the middle lateral branches, plants treated with daminozide at 2.0 kg a.i. ha^{-1} at first visible flower bud and at 4.0 kg a.i. ha^{-1} at stem elongation were significantly shorter than the control.

Table 3B.1 Effect of hand pinching and growth regulator application on plant height and main stem length at peak flowering (PF) and seed harvest (H).

Treatment	Plant height (cm)		Main stem length (cm)	
	PF	H	PF	H
Control	28.2	37.0	7.9	9.1
Pinching	25.9	32.7	4.5	4.8
Paclobutrazol 0.5 kg ai (1)	18.0	34.0	6.5	7.6
Paclobutrazol 1.0 kg ai (1)	18.8	33.5	5.6	6.5
Daminozide 2.0 kg ai (1)	18.9	32.6	6.3	7.5
Daminozide 4.0 kg ai (1)	19.6	32.4	4.7	7.4
Chlormequat 1.5 kg ai (1)	21.8	34.1	7.1	7.4
Chlormequat 3.0 kg ai (1)	20.7	36.3	6.7	10.2
Paclobutrazol 0.5 kg ai (2)	21.9	33.6	6.2	8.7
Paclobutrazol 1.0 kg ai (2)	22.6	32.6	5.8	8.2
Daminozide 2.0 kg ai (2)	21.7	33.5	6.6	9.4
Daminozide 4.0 kg ai (2)	19.5	31.9	6.7	7.5
Chlormequat 1.5 kg ai (2)	24.2	38.5	7.5	8.2
Chlormequat 3.0 kg ai (2)	26.4	37.3	7.4	8.9
LSD (P<0.05)	5.5	5.0	2.0	2.8
Significance	*	*	*	*
%CV	14.8	8.6	18.5	20.7

(1) = Applied at visible bud stage

(2) = Applied at stem elongation stage

Table 3B.2 Effect of hand pinching and growth regulator application on lateral branch length from different positions on the plant at peak flowering and seed harvest.

Treatment	Peak flowering			Harvest		
	Base	Middle	Top	Base	Middle	Top
Control	16.4	11.7	11.0	34.7	33.0	25.3
Pinching	17.2	8.9	9.5	31.8	29.9	27.1
Paclobutrazol 0.5 kg ai (1)	9.7	9.5	6.8	33.6	30.8	24.5
Paclobutrazol 1.0 kg ai (1)	9.8	10.0	4.8	32.0	30.0	25.8
Daminozide 2.0 kg ai (1)	9.1	11.2	6.3	31.2	27.8	21.8
Daminozide 4.0 kg ai (1)	11.0	8.5	5.5	31.5	29.5	24.7
Chlormequat 1.5 kg ai (1)	12.1	10.6	8.0	32.0	29.7	24.5
Chlormequat 3.0 kg ai (1)	11.7	9.5	6.4	35.9	32.4	26.0
Paclobutrazol 0.5 kg ai (2)	14.1	9.5	7.4	32.1	29.8	23.3
Paclobutrazol 1.0 kg ai (2)	11.8	10.7	10.4	32.0	30.7	26.4
Daminozide 2.0 kg ai (2)	12.5	10.2	8.9	32.4	30.4	25.8
Daminozide 4.0 kg ai (2)	10.0	9.4	5.5	30.8	26.3	22.0
Chlormequat 1.5 kg ai (2)	13.1	12.4	7.8	36.2	32.5	26.1
Chlormequat 3.0 kg ai (2)	17.1	11.9	8.4	35.9	32.3	24.8
LSD (P<0.05)	4.8	4.0	4.3	4.9	5.1	5.3
Significance	*	NS	*	*	**	NS
% CV	23.0	23.0	17.1	9.0	10.0	12.7

(1) = Applied at visible bud stage

(2) = Applied at stem elongation stage

3B.2.1.4 Branch number

The number of lateral branches was recorded at peak flowering and at harvest. The number of secondary lateral branches was recorded only at peak flowering.

There was no effect of PGRs and pinching on the number of lateral branches at both peak flowering and at final harvest, or in the number of secondary lateral branches at peak flowering (Table 3B.3).

3B.2.1.5 Flower stalk length

The length of flower stalks from the base, middle and top of lateral branches at peak flowering and harvest are presented in Table 3B.4.

At peak flowering, all PGR treatments except daminozide 2.0 kg a.i. ha^{-1} applied at first visible bud, paclobutrazol 1.0 kg a.i. ha^{-1}, daminozide 4.0 kg a.i. ha^{-1} and chlormequat 1.5 kg a.i. ha^{-1} applied at stem elongation reduced flower stalk length of the base lateral branch. All PGR's applied at first visible bud except for chlormequat 3.0 kg a.i. ha^{-1} reduced flower stalk length of the middle and top lateral branches. However, all PGR treatments applied at stem elongation with the exception of daminozide 4.0 kg a.i. ha^{-1} did not reduce flower stalk length of the middle and top lateral branches. Pinching reduced flower stalk length at the base but not the middle and top lateral branches.

At seed harvest, no differences in flower stalk length were recorded for the base lateral branches. However, for plants treated with paclobutrazol (both rates) and daminozide 4.0 kg a.i. ha^{-1} at first visible bud, the middle flower stalk lengths were shorter than the control and pinching treatments (Table 3B.4). Plants treated with chlormequat 3.0 kg a.i. ha^{-1} at both stages and daminozide 4.0 kg a.i. ha^{-1} at stem elongation also had a reduced flower stalk length of the top lateral branch compared with the control.

Table 3B.3 Effect of hand pinching and growth regulator application on number of lateral and secondary lateral branches.

Treatment	Lateral branches		Secondary lateral branches
	Peak flowering	Harvest	Peak flowering
Control	8.8	8.6	32.9
Pinching	8.0	8.0	33.8
Paclobutrazol 0.5 kg ai (1)	9.2	7.7	29.2
Paclobutrazol 1.0 kg ai (1)	9.9	8.2	30.5
Daminozide 2.0 kg ai (1)	10.2	9.3	37.4
Daminozide 4.0 kg ai (1)	7.9	8.6	26.7
Chlormequat 1.5 kg ai (1)	10.3	10.5	34.4
Chlormequat 3.0 kg ai (1)	9.8	8.2	32.0
Paclobutrazol 0.5 kg ai (2)	8.2	7.7	32.7
Paclobutrazol 1.0 kg ai (2)	10.9	8.5	38.1
Daminozide 2.0 kg ai (2)	8.7	8.9	34.7
Daminozide 4.0 kg ai (2)	9.3	9.5	28.7
Chlormequat 1.5 kg ai (2)	11.3	9.7	41.4
Chlormequat 3.0 kg ai (2)	9.8	9.8	32.8
LSD (P<0.05)	3.3	2.3	11.3
Significance	*	*	*
% CV	20.9	15.8	20.3

(1) = applied at visible bud stage

(2) = applied at stem elongation stage

Table 3B.4 Effect of hand pinching and growth regulator application on flower stalk length from different positions on the plant at peak flowering and harvest.

Treatment	Peak flowering			Harvest		
	Base	Middle	Top	Base	Middle	Top
Control	11.8	12.2	11.4	10.8	11.4	11.3
Pinching	8.7	11.7	10.8	11.0	11.3	10.3
Paclobutrazol 0.5 kg ai (1)	8.6	7.8	7.1	9.2	9.3	9.0
Paclobutrazol 1.0 kg ai (1)	9.1	7.1	8.5	9.5	8.8	9.9
Daminozide 2.0 kg ai (1)	9.7	8.4	8.8	10.0	10.1	9.6
Daminozide 4.0 kg ai (1)	8.5	8.2	7.1	10.1	9.0	9.9
Chlormequat 1.5 kg ai (1)	9.1	9.3	9.0	8.5	9.8	9.5
Chlormequat 3.0 kg ai (1)	9.0	10.7	10.4	8.6	10.7	8.4
Paclobutrazol 0.5 kg ai (2)	7.8	10.1	9.8	11.0	8.8	9.9
Paclobutrazol 1.0 kg ai (2)	10.7	11.0	9.5	10.8	10.0	10.9
Daminozide 2.0 kg ai (2)	9.2	10.1	8.8	9.1	10.5	10.2
Daminozide 4.0 kg ai (2)	9.5	8.6	7.9	9.9	10.3	8.8
Chlormequat 1.5 kg ai (2)	11.0	10.0	10.2	8.5	9.6	9.4
Chlormequat 3.0 kg ai (2)	9.3	10.0	7.8	9.4	10.7	8.6
LSD (P<0.05)	2.3	2.9	2.2	2.7	1.9	2.4
Significance	*	*	*	NS	*	*
% CV	14.3	17.8	14.5	16.8	11.4	14.6

(1) = Applied at visible bud stage

(2) = Applied at stem elongation stage

3B.2.1.6 Days to first flowering and peak flowering

Pinching delayed first flowering by 16 days, and PGR treatments also delayed first flowering by 3 to 7 days (Table 3B.5). However these delays were significant only for paclobutrazol (1.0 kg a.i. ha^{-1}) and daminozide (2.0 kg a.i. ha^{-1}) when applied at first visible bud stage, and paclobutrazol (0.5 kg a.i. ha^{-1}) and chlormequat (1.5 kg a.i. ha^{-1}) at stem elongation.

All treatments delayed peak flowering. The delays induced by PGR treatments were only 1-3 days, but that for pinching was 7 days (Table 3B.5).

3B.2.1.7 Number of flowers per plant

At peak flowering, pinching had produced 16.4 more flower heads than the control but the difference was not significant. None of the PGR treatments significantly changed flower number (Table 3B.5).

3B.2.2 Plant dry weight

Pinching reduced main stem dry weight (Table 3B.6), but total dry weight and dry weight of other plant parts did not differ from the control. Paclobutrazol applied at first visible bud and daminozide applied at both times significantly reduced total plant dry weight through reducing branch, leaf, main stem, flower stalk and flower dry weights. Paclobutrazol applied at stem elongation did not significantly affect plant dry weight.

Chlormequat at the first-visible-bud-stage showed a rate response, as 1.5 kg a.i. ha^{-1} did not reduce plant dry weight, but 3.0 kg a.i. ha^{-1} did through branch, main stem, flower stalk and flower dry weight reductions. At stem elongation chlormequat did not alter plant dry weight (Table 3B.6).

Table 3B.5 Effect of hand pinching and growth regulator application on number of days to first flowering, peak flowering and number of flowers at peak flowering.

Treatment	Days from transplanting to first flowering	Days from transplanting to peak flowering	Flower numbers
Control	31.0	62.0	56.5
Pinching	47.0	69.6	72.9
Paclobutrazol 0.5 kg ai (1)	34.3	64.7	44.4
Paclobutrazol 1.0 kg ai (1)	37.3	63.8	41.9
Daminozide 2.0 kg ai (1)	38.6	64.5	47.9
Daminozide 4.0 kg ai (1)	34.3	63.5	46.0
Chlormequat 1.5 kg ai (1)	34.6	64.2	47.6
Chlormequat 3.0 kg ai (1)	33.6	65.4	56.6
Paclobutrazol 0.5 kg ai (2)	35.6	64.1	57.9
Paclobutrazol 1.0 kg ai (2)	35.0	64.6	65.7
Daminozide 2.0 kg ai (2)	35.0	63.8	47.0
Daminozide 4.0 kg ai (2)	34.4	64.5	46.9
Chlormequat 1.5 kg ai (2)	36.0	64.2	63.4
Chlormequat 3.0 kg ai (2)	34.3	64.0	44.9
LSD (P<0.05)	4.2	1.3	18.9
Significance	***	***	*
% CV	3.6	0.8	21.3

(1) = Applied at visible bud stage

(2) = Applied at stem elongation stage

Table 3B.6 Effect of hand pinching and growth regulator application on plant dry weight at peak flowering.

Treatment	Dry weight (g)					
	Branch	Leaf	Main stem	Flower stalk	Flower	Total
Control	8.35	13.76	1.09	2.97	13.54	39.73
Pinching	10.00	15.10	0.75	2.89	14.09	42.86
Paclobutrazol 0.5 kg ai (1)	4.02	8.68	0.63	1.61	8.65	23.61
Paclobutrazol 1.0 kg ai (1)	3.79	8.86	0.64	1.53	7.93	22.77
Daminozide 2.0 kg ai (1)	4.76	10.45	0.72	2.08	9.07	27.09
Daminozide 4.0 kg ai (1)	3.82	7.55	0.52	1.16	8.30	21.82
Chlormequat 1.5 kg ai (1)	6.74	12.58	0.84	2.49	12.13	34.80
Chlormequat 3.0 kg ai (1)	5.29	11.02	0.73	1.74	8.95	27.76
Paclobutrazol 0.5 kg ai (2)	7.11	12.16	0.77	2.22	12.02	34.26
Paclobutrazol 1.0 kg ai (2)	7.23	13.12	0.85	2.96	12.89	37.08
Daminozide 2.0 kg ai (2)	5.28	10.05	0.72	1.80	10.07	27.93
Daminozide 4.0 kg ai (2)	5.12	10.37	0.78	1.96	10.11	28.37
Chlormequat 1.5 kg ai (2)	7.43	13.59	1.16	2.49	12.50	37.19
Chlormequat 3.0 kg ai (2)	6.22	11.97	0.88	2.26	9.80	31.15
LSD (P<0.05)	2.72	3.58	0.30	0.96	3.28	9.93
Significance	**	**	*	*	**	**
% CV	26.7	18.8	22.5	26.3	18.2	19.0

(1) = Applied at visible bud stage

(2) = Applied at stem elongation stage

3B.2.3 Seed yield and yield components

Harvested seed yield was increased 21-39 % by some of the PGR treatments. Paclobutrazol 1.0 kg a.i. ha^{-1} applied at stem elongation, daminozide 4.0 kg a.i. ha^{-1} at visible flower bud and daminozide 2.0 kg a.i. ha^{-1} at stem elongation increased yields (21, 28 and 39 %, respectively (Table 3B.7). However, due to high variation, no significant differences between PGR treatments and the control for either harvested or cleaned seed yield per plant were recorded in this study. Percentage seed cleaning losses were recorded among treatments. These ranged from 30-60 % due presumably to differing amounts of immature seeds (Table 3B. 7).

As shown in Table 3B.8, the number of empty seedheads was reduced by pinching and some PGR treatments. Daminozide 4.0 kg a.i. ha^{-1} applied at first visible flower bud, paclobutrazol 0.5 kg a.i. ha^{-1}, daminozide at both rates, and chlormequat 1.5 kg a.i. ha^{-1} at stem elongation all reduced the number of empty seedheads per plant. However, total seedhead numbers per plant at seed harvest for all treatments except daminozide 4.0 kg a.i. ha^{-1} applied at stem elongation did not differ from the control (Table 3B.8).

No significant differences in the number of seeds per seedhead and thousand seed weight between pinching, PGR treatments and the control were recorded. However the number of seeds per seedhead from plants treated with daminozide 4.0 kg a.i. ha^{-1} at first visible flower bud and 2.0 kg a.i. ha^{-1} at stem elongation stage was increased about 59 % compared with the control (Table 3B.9).

Germination and viability were not affected by pinching or PGR treatments. Germination ranged from 70-80 % and viability from 76-83 % (Table 3B.10).

Table 3B.7 Effect of hand pinching and growth regulator application on harvested and cleaned seed yield per plant, and percentage cleaning loss.

Treatment	Seed yield (g/plant) harvested	cleaned	% cleaning loss
Control	3.90	1.75	55.1
Pinching	2.70	1.52	43.7
Paclobutrazol 0.5 kg ai (1)	3.90	1.91	51.1
Paclobutrazol 1.0 kg ai (1)	2.50	1.37	45.0
Daminozide 2.0 kg ai (1)	2.90	1.61	44.5
Daminozide 4.0 kg ai (1)	4.98	2.33	53.2
Chlormequat 1.5 kg ai (1)	4.00	1.92	52.0
Chlormequat 3.0 kg ai (1)	4.10	1.88	54.1
Paclobutrazol 0.5 kg ai (2)	3.70	1.92	48.1
Paclobutrazol 1.0 kg ai (2)	4.74	2.36	49.8
Daminozide 2.0 kg ai (2)	5.41	2.15	60.2
Daminozide 4.0 kg ai (2)	2.40	1.33	44.6
Chlormequat 1.5 kg ai (2)	2.30	1.60	30.4
Chlormequat 3.0 kg ai (2)	3.68	1.74	51.7
LSD (P<0.05)	2.60	1.29	
Significance	*	*	
% CV	42.4	42.3	

(1) = Applied at visible bud stage

(2) = Applied at stem elongation stage

Table 3B.8 Effect of hand pinching and growth regulator application on number of empty seedheads and number of seedheads at harvest.

Treatment	Empty seedheads per plant	Seedheads per plant
Control	28.8	99.9
Pinching	17.6	81.0
Paclobutrazol 0.5 kg ai (1)	18.1	86.2
Paclobutrazol 1.0 kg ai (1)	21.5	85.8
Daminozide 2.0 kg ai (1)	20.4	83.2
Daminozide 4.0 kg ai (1)	17.3	82.0
Chlormequat 1.5 kg ai (1)	21.9	96.5
Chlormequat 3.0 kg ai (1)	22.9	83.6
Paclobutrazol 0.5 kg ai (2)	15.7	80.4
Paclobutrazol 1.0 kg ai (2)	23.4	98.9
Daminozide 2.0 kg ai (2)	13.4	91.0
Daminozide 4.0 kg ai (2)	16.8	67.3
Chlormequat 1.5 kg ai (2)	15.4	81.2
Chlormequat 3.0 kg ai (2)	27.8	100.1
	10.9	21.6
Significance	*	*
% CV	32.0	14.8

(1) = Applied at visible bud stage

(2) = Applied at stem elongation stage

Table 3B.9 Effect of hand pinching and growth regulator application on number of seeds per seedhead and seed dry weight.

Treatment	Number of seeds per seed head	TSW (g)
Control	6.4	6.00
Pinching	6.3	5.61
Paclobutrazol 0.5 kg ai (1)	7.5	5.89
Paclobutrazol 1.0 kg ai (1)	5.3	5.56
Daminozide 2.0 kg ai (1)	6.3	5.57
Daminozide 4.0 kg ai (1)	10.2	5.98
Chlormequat 1.5 kg ai (1)	7.1	5.88
Chlormequat 3.0 kg ai (1)	7.4	6.36
Paclobutrazol 0.5 kg ai (2)	8.2	5.80
Paclobutrazol 1.0 kg ai (2)	8.4	5.79
Daminozide 2.0 kg ai (2)	10.2	5.64
Daminozide 4.0 kg ai (2)	5.6	6.24
Chlormequat 1.5 kg ai (2)	5.3	5.34
Chlormequat 3.0 kg ai (2)	6.1	5.68
LSD (P<0.05)	4.2	0.77
Significance	*	*
% CV	34.9	7.9

(1) = Applied at visible bud stage

(2) = Applied at stem elongation stage

Table 3B.10 Effect of hand pinching and growth regulator application on germination and percent viability.

Treatment	Germination (%)	Viability (%)
Control	79.5	82.2
Pinching	78.8	82.7
Paclobutrazol 0.5 kg ai (1)	77.8	79.0
Paclobutrazol 1.0 kg ai (1)	74.5	78.5
Daminozide 2.0 kg ai (1)	69.8	75.7
Daminozide 4.0 kg ai (1)	75.7	78.7
Chlormequat 1.5 kg ai (1)	70.8	77.2
Chlormequat 3.0 kg ai (1)	70.0	77.8
Paclobutrazol 0.5 kg ai (2)	75.3	79.0
Paclobutrazol 1.0 kg ai (2)	75.7	79.8
Daminozide 2.0 kg ai (2)	74.8	80.5
Daminozide 4.0 kg ai (2)	70.5	78.3
Chlormequat 1.5 kg ai (2)	77.2	80.7
Chlormequat 3.0 kg ai (2)	80.0	81.7
LSD (P<0.05)	9.6	6.6
Significance	*	*
% CV	7.6	5.0

(1) = Applied at visible bud stage

(2) = Applied at stem elongation stage

3B.3 DISCUSSION

3B.3.1 Effects on plant growth and development

Although pinching had no effect on plant height at peak flowering, all of the PGR treatments (except for the late application of chlormequat at stem elongation) reduced plant height at peak flowering. However, none of these effects persisted until harvest, with the exception of daminozide 4.0 kg a.i. ha^{-1} applied at stem elongation.

A similar effect occurred in terms of main stem length, except that pinching significantly decreased main stem length both at peak flowering and at harvest. The effect of PGRs, however, was similar to the effect on plant height, with all treatments except paclobutrazol 1.0 kg a.i. ha^{-1} and chlormequat applied at stem elongation having a depressing effect on main stem length at peak flowering. However, by harvest, pinching was the only treatment in which this effect persisted.

This illustrates the transient effect of PGRs in this study. This effect of PGRs is supported by Pobudkiewicz and Goldsberry (1989) who found that chlormequat retarded plant height of dwarf carnation (*Dianthus caryophyllus*) cv. Snowmass but retardation was evident only for a short time. Transient effects of paclobutrazol have also been reported in China aster (*Callistephus chinensis*) (Phetpradap, 1992) and in indoor plant species (Davis *et al*, 1985). Cartwright and Zamani (1991) also reported that the growth retarding effect of chlormequat was only transient in barley (*Hordeum vulgare*).

The relatively short term effect of pinching and PGRs was, however, less pronounced in terms of lateral branch length (Table 3B.2). The influence of paclobutrazol and daminozide, particularly when these chemicals were applied at the first-visible-bud-stage, was to decrease lateral branch length at the base and top of the plants at peak flowering. Again, however, most of these differences had disappeared at harvest. Although the effects of daminozide at the base and top lateral branches had disappeared by harvest, some reduction in lateral branch

length in the middle of the main stem were, for the first time, apparent. It is interesting that, again, the effects of paclobutrazol (a PGR reported in the literature to be highly persistent in some other species) did not continue until harvest.

The lack of effect of hand pinching and PGR's on lateral and secondary lateral branch numbers was surprising (Table 3B.3) since the literature suggests that some PGRs, and particularly paclobutrazol, have their main effect in increasing flower numbers by increasing lateral and secondary branches e.g. in *Lotus uliginosus* (Tabora, 1991). The lack of such a response at peak flowering or harvest (for lateral branches) or at peak flowering (for secondary lateral branches) again suggests a short term, transient and dilution effect of these PGRs in dahlia. The physical removal of apical dominance by pinching (above node 4) also showed a similar effect. This was also unexpected, since pinching has been shown in the literature to be effective in stimulating lateral branch numbers in dahlia (Barrett and De Hertogh, 1978a, 1978b) and in some other plant species (William and Bearce, 1964; Thomas, 1972; Love, 1975; Ecke and Matkin, 1976; Wainright and Irwins, 1987; Starman, 1991) but not in field bean (*Vicia faba*) (Bochaniarz and Pleskacz, 1987).

The failure of PGR's and pinching to stimulate the number of lateral or secondary lateral branches in this experiment can possibly be explained by a cultivar difference, as previously reported in pot-grown tulips (Menhennett and Hanks, 1982/83) and chrysanthemum (Menhennett, 1984). Dahlia cv. Figaro White is a dwarf-type bedding plant and it is possible that because of this dwarf habit, and relatively uniform and very early blooming, apical dominance effects appear only for a short while and pinching may not be required to stimulate the number of lateral or secondary lateral branches for increasing flower numbers. Mellon and Goldsmith (1985) have suggested that pinching may not be necessary for increasing flower numbers in dwarf types of dahlia. A similar suggestion has also been made for other flowering plant species (Ball, 1985). A reduced response of dwarf cultivars to PGR, particularly chlormequat, has also been reported in barley (*Hordeum vulgare*) by Cartwright and Zamani (1991).

3B.3.2 Effects on flowering

Pinching in particular, but also paclobutrazol 1.0 kg a.i. ha^{-1} and daminozide 2.0 kg a.i. ha^{-1} applied at first visible bud and paclobutrazol 0.5 kg a.i. ha^{-1} and chlormequat 1.5 kg a.i. ha^{-1} applied at stem elongation significantly delayed the onset of flowering by up to 16 days. These differences were generally less obvious by peak flowering. Delays of 1-3 days compared with the control were common at this stage. A delay in flowering following PGR application of this species has also been reported in cv. Unwins Dwarf Mixture (Chapter 3A) and the reports by Bhattacharjee *et al.* (1976), De Hertogh *et al.* (1976), Read *et al.* (1972) and Rounkova (1989), and in other flower species such as cleome (*Cleome spinosa* Jacq.) (Cathey and Stuart , 1961), marigold (*Tagetes erecta*) (McConnell and Struckmeyer, 1970), and *Chrysanthemum* (McDaniel, 1983; Menhenett, 1984; Zalewska, 1989). However, there was a difference in the number of days to peak flowering between this cultivar and cv. Unwins Dwarf Mixture (Chapter 3A) in that PGR delayed peak flowering in cv. Figaro White but not in cv. Unwins Dwarf Mixture (Chapter 3A). As has been discussed in the previous Chapter (3A) PGR application to delay the start of flowering significantly, and therefore reduce the flowering duration in crops allowing greater seed harvest recovery, does not have any great potential for reducing the time of onset and total flowering duration in dahlia cv. Figaro White.

All PGR treatments did not significantly increase flower numbers at peak flowering. This was not surprising considering the inability of any of the treatments to increase lateral branch numbers and therefore to increase sites for flower formation.

In chapter 2, two flowering peaks occurred. This made the determination of best harvest timing difficult. In subsequent field trials, however, (Chapter 3-6) only one peak flowering was recorded. This is presumeably a reflextion of the wider plant spacing (50 cm) used in chapter 2 allowing two flowering peaks compared with the single peak flowering which occurred in other field trials which were sown at a 30 cm spacing.

3B.3.3 Effect on plant dry weight

A reduction in dry weight has been reported earlier by many workers. Moser and Hess (1968) and Read *et al.* (1972) found that daminozide slightly reduced top growth of dahlias. A reduction in the dry weight of marigold (McConnell and Struckmeyer, 1970) and apple (Halfacre *et al.*, 1968) has also been reported as an effect of daminozide. Cathey and Stuart (1961) reported that chrysanthemum and petunia treated with growth retarding substances including chlormequat chloride weighed less than untreated plants, and the reduction in weight was primarily a result of reduction in stem length. They further reported that over-treatment frequently inhibited leaf expansion as well as stem elongation and thus resulted in reduced weight of all parts of the plant. Similar effects of paclobutrazol in reducing plant dry weight have also been found in other plant species (Barrett and Batuska, 1982; Jaggard, 1982; De Jong and Doyle, 1984; Sankhla *et al.*, 1985; Steffens *et al.*, 1985; Wample *et al.*, 1987; Davis *et al.*, 1988; Gilbertz, 1988; 1992).

In the present experiment, the effect of paclobutrazol was most obvious when the chemical was applied early (first visible bud stage). Total plant dry weight was reduced from all measured components, possibly due to the inhibition of gibberellin biosynthesis which is known as a promotor of cell elongation and cell enlargement (Davis *et al.*, 1988) with the result that the growth of the main stem, axillary buds and shoots is inhibited and thus plant dry weight is reduced. The effect of daminozide was more long term, causing a reduction in the dry weight of most plant parts irrespective of time of application. The effect of chlormequat was evident only at the early application and then only at the high rate. This suggests the chemical is more effective at the high rate but that its ability to alter plant dry matter is stage-of-growth dependent, since its effect on reproductive growth was seen following application at the first visible flower bud stage only.

3B.3.4 Effects on seed yield and yield components.

The suggestion was that daminozide 4.0 kg a.i. ha^{-1} applied at first visible bud, daminozide 2.0 kg a.i. ha^{-1} or paclobutrazol 1.0 kg a.i. ha^{-1} at stem elongation

increased both harvested (by 1.08, 1.51 and 0.80 g/plant respectively) and cleaned seed yield (by 0.58, 0.40 and 0.61 g/plant respectively). However, because variability of plants within plots and between plots and hand harvesting of seeds from small plots can lead to large coefficients of variation (CV), the results were not significantly different. Very high CV's following hand harvesting from small plots in Puna chicory (*Cichorium intybus*), which belongs to the same family (Asteraceae), has also been reported by Hare and Rolston (1987).

Although none of the treatments increased seedhead numbers, there was, in this cultivar, a major problem of low seed setting and sterile seed head production. In the control treatment about 28 % of seedheads did not form seed. This percentage was also relatively consistent (19-29 %) among treatments. This suggests that cv. Figaro White may have an inherent problem in this regard, since flower head sterility was generally not a problem in cv. Unwins Dwarf Mixture (an open pollinated cultivar).

As explained earlier, the purpose of choosing a single coloured flowering cultivar such as Figaro White was to attempt to reduce the obvious flowering variation previously observed in the mixed colour cultivar (Unwins Dwarf Mixture). However it became obvious that the dwarf cultivar Figaro White did not respond to the treatments imposed to any great extent. Perhaps one explanation may be that the cultivar has been improved for flower quality and flowering duration as a single colour display (Kieft, 1988). In the selection programme it is possible that seed production capacity had been reduced, possibly as a result of floret sterility or high ovule or seed abortion. It should be noted that control plants of Figaro White had many more flowers per plant than control plants of Unwins Dwarf Mixture at peak flowering (56.5 vs 34.7). Despite this, low seed yields were obtained in Figaro White (1.75 g vs 4.99 g/plant for Unwins Dwarf Mixture). A cleaning loss (by weight) of 55.1 % compared with a 44.2 % loss in Unwins Dwarf Mixture supports the suggestion that many seedheads of Figaro White failed to set and develop ripe seed. This may be due to the breeding history of Figaro White which has been developed more for pot plant use where prolific flower display is important. Unwins Dwarf Mixture, on the other hand, is more widely used as a bedding plant where lengthy flowering may be considered to be more of an advantage. In addition the white flower colour of Figaro White was observed to be far less attractive to bee pollinators than the other coloured (i.e.

red, yellow, pink, orange and purple) blooms of cv. Unwins Dwarf Mixture (see Chapter 5). White flowered variants have also been recorded as having failed to set seed in *Clarkia cylindrica* (Lewis, 1953) and in *Pseudomuscari azureum* (Garbari, 1972). All of these reasons may individually or in combination have contributed to the lower seed yields and greater numbers of empty seedheads in cv. Figaro White. The great reduction in seed numbers per seedhead in Figaro White (5-10 seeds seedhead^{-1}, Table 3B.9) compared with cv. Unwins Dwarf Mixture (32-46 seeds seedhead^{-1}, Table 3A.6) supports this view. Although, again, pinching and PGR application did not significantly improve either the number of seeds per seedhead or TSW (Table 3B.9) in cv. Figaro White the effect of the 'shy' seeding capacity of this cultivar was not compensated for by increases in thousand seed weight (5.81 g). This can be compared with a thousand seed weight in cv. Unwins Dwarf Mixture of 6.62 g.

The results in Table 3B.10 confirm the general result obtained in many other studies with a wide range of plant species (Clifford and Hare, 1987; Globerson *et al.*, 1989; Li and Hill, 1989) that PGRs such as paclobutrazol, daminozide and chlormequat do not have any deleterious effect on either seed germination (% normal seedlings) or total seed viability.

3B.4 CONCLUSION

The results in this chapter have highlighted another aspect of the use of PGRs in affecting plant morphology and seed yield. Although PGRs such as paclobutrazol, daminozide and chlormequat have been shown to alter plant structure (Read and Fieldhouse, 1970; Gray and Thomas, 1982; Frost and Kretchman, 1987; Gray, 1987; Deyton *et al.*, 1991), flowering intensity and ultimately seed yield in a number of different species (Hampton and Hebblethwaite, 1985a; Hebblethwaite, 1985; Daniels and Scarisbrick, 1986; Halmer, 1987) the present comparison has strongly suggested that intraspecific response differences may also be important. In the tall (70 cm) multicoloured bloom cultivar Unwins Dwarf Mixture, seed yield was significantly increased by earlier application (visible-terminal-flower-bud stage) of paclobutrazol 1.0 kg a.i. ha^{-1} and later application (stem-elongation stage) of chlormequat 1.5 kg. However in the dwarf cultivar Figaro White (30-35 cm) these treatments were ineffective.

CHAPTER 4

EFFECTS OF TIME OF APPLICATION OF PACLOBUTRAZOL AND CHLORMEQUAT ON PLANT GROWTH AND DEVELOPMENT OF DAHLIA (CV. UNWINS DWARF MIXTURE)

4.1 INTRODUCTION

Results from the previous year's experiments (Chapter 3) suggested that both paclobutrazol and chlormequat had some possibility for improving seed production in Unwins Dwarf dahlia. However dahlia plants responded to these two chemicals in different ways depending on application rates and times. Seed yield increases were obtained following the earlier application of the high paclobutrazol rate (1.0 kg a.i. ha^{-1} at visible terminal bud stage) and by the late application of the low chlormequat rate (1.5 kg a.i. ha^{-1} at stem elongation stage). Seed yield increase following paclobutrazol application was due to a significant increase in seed numbers per seedhead, while chlormequat tended to increase flower numbers per plant.

Both time (i.e. growth stage) and rate are important for growth regulator application (Seeley, 1979; Goulston and Shearing, 1985; Kust, 1986; Davis and Andersen, 1989). Greater retardation effects have been reported following earlier retardant treatment (prior to flower initiation compared with after flower initiation) in geranium (*Pelargonium* X *hortorum*) (Armitage, 1986). Tall chrysanthemum cultivars (*Chrysanthemum* X *morifolium*) also showed very little response to paclobutrazol application (McDaniel, 1983) and an early application was considered desirable (Goulston and Shearing, 1985). Lever (1986) explained that there is normally a delay between the time a growth retardant is applied to the plant and the exhibition of growth retardation. Larter (1967) also demonstrated that stem shortening can be achieved if sufficient retardant is maintained in barley during stem elongation. This suggested a hypothesis that for dahlia cv. Unwins Dwarf Mixture, paclobutrazol should be applied early enough to ensure the chemical is already available to maintain suppression of gibberellin biosynthesis, and allow earlier assimilate movement to the lateral buds to promote flowering, support seeds and increase seed yield.

An experiment was therefore designed to test this hypothesis. Treatments were selected based on seed yield results from the previous experiment. Thus only the high rate of paclobutrazol (1.0 kg a.i. ha^{-1}) was chosen to determine its effects at the relatively earlier application times (vegetative growth stage).

For chlormequat, this vegetative stage was not included as the previous results showed that later application (at stem elongation) was more effective at increased seed yield. However, a reinvestigation of the other previous treatments was considered desirable to provide more detailed information on the effects of different rates and times of application on seed yield, as the reason for the increase was still not clear.

Therefore the objective of this experiment was to determine the effects of time and rate of application of these two growth regulators on vegetative and reproductive growth and development, seed yield and yield components of dahlia cv. Unwins Dwarf Mixture.

4.2 MATERIALS AND METHODS

4.2.1 Experimental site

The experiment was conducted on a Tokomaru silt loam soil at the Seed Technology Centre, Massey University, Palmerston North. This was the same site and adjacent to the area used in previous experiments (Chapters 2 and 3). The field was ploughed in mid October 1989 and harrowed two weeks later. A compound fertiliser 18-20-0 (150 kg ha^{-1}) was broadcast by hand and soil incorporated by rotary cultivator on 30 October 1989. A basal fertilizer (sulphate of potash (50 kg ha^{-1}) and calcium ammonium nitrate (150 kg ha^{-1})) was also applied at planting. Weather data at Palmerston North during the months of the trial are presented in Appendix 4.1.

4.2.2 Plant material and establishment

Seeds of dahlia cv. Unwins Dwarf Mixture were dusted with thiram [1 g of product (80 % wettable powder) per 100 g seed] and direct field sown by hand on 1 November 1989. Approximately four seeds per hole were sown at a depth of about 2 cm in a square plant spacing of 30 x 30 cm. Thinning to one plant per hole was made 14 days after sowing. Missing plants were replaced by transplanting seedlings of the same age from surplus seedlings planted near the experimental area.

A broad spectrum granular insecticide, Thimet 20 G (Phorate, 200 g kg^{-1}) was applied by hand at a rate of 8 kg a.i. ha^{-1} to control chewing insects. Snail and slug bait, Mesurol (Methiocarb, 20 g kg^{-1} bait) was also broadcast at about 100 baits m^{-2}. This was followed by an overhead sprinkler irrigation immediately after sowing. Watering was continued for 30 minutes at each irrigation time every 3 days during the first two weeks and every five to seven days as necessary until peak flowering and then discontinued. Irrigation was applied using an overhead sprinkler system which delivered 6,000 litres ha^{-1} h^{-1}.

Foliar fertiliser, "Happy Garden" 12-8-16 (Nylex New Zealand Ltd, Auckland) was applied at 20 and 30 days after sowing via a fertiliser dispenser attached to a soft spray wand at the rate of 1 pellet (35 g) per ten square metres. Ammophos (12-10-10-8) fertiliser at the rate of 100 kg ha^{-1} was also applied 30 days after sowing. Crop protection was achieved by alternate use of the same products and rates as described in chapter 3. Benlate (benomyl, 0.25 kg a.i. ha^{-1}) and Bravo 500 F (chlorothalonil, 150 ml a.i. ha^{-1}) were also used in this programme.

4.2.3 Treatments and experimental design

Paclobutrazol at 1.0 kg a.i. ha^{-1} and chlormequat at 1.5 and 3.0 kg a.i. ha^{-1} were applied at the following plant growth stages:

Stage 1: - vegetative stage or when the plants had 2-3 pairs of true leaves (30 days after sowing) (paclobutrazol only);

Stage 2: - first terminal bud visible (45 days after sowing); and

Stage 3: - during stem elongation (60 days after sowing).

There were therefore 8 treatments as follows:

Control
Paclobutrazol 1.0 kg ai ha^{-1} (stage 1)
Paclobutrazol 1.0 kg ai ha^{-1} (stage 2)
Paclobutrazol 1.0 kg ai ha^{-1} (stage 3)
Chlormequat 1.5 kg ai ha^{-1} (stage 2)
Chlormequat 3.0 kg ai ha^{-1} (stage 2)
Chlormequat 1.5 kg ai ha^{-1} (stage 3)
Chlormequat 3.0 kg ai ha^{-1} (stage 3)

Growth regulators were applied using a 5 litre pressure sprayer in one litre of water per plot. Twenty four hours after PGR application, water was applied for 30 minutes via a sprinkler system which delivered 6,000 litres ha^{-1} h^{-1}.

Treatments were assigned in a randomized complete block design with 3 replicates. The plot size was 3x3 metres and as the seeds were sown at a square spacing of 30 cm, there were therefore 100 plants per plot or 111,111 plants ha^{-1}. Treatment mean comparisons are presented using Least Significant Differences.

4.2.4 Data collection

Unless otherwise stated, definitions and methods for plant measurement used in this experiment were the same as previously described (Chapter 3).

Green seedheads - flower heads which developed into seedheads but were still green in colour at harvest.

Brown seedheads - seedheads in which the colour had changed from green to yellow brown, brown and brown with the seedhead open.

4.2.4.1 Plant measurements

Three plants were sampled at random from each plot for growth analysis at first flowering (15 January 1990), peak flowering (10 February 1990), and seed harvest (22 March 1990). At each sampling, plants were cut at ground level before plant height, main stem length, number of nodes on the main stem, and the numbers of lateral branches, secondary lateral branches, flower heads and seedheads were recorded. The lateral branches of each plant were then divided into three parts (base, middle and top) depending on the position of the branch that developed from the main stem. The length of lateral branches and terminal flower stalks from the main stem of each lateral branch were also recorded. At final harvest, seedheads were separated from each lateral branch position into two groups (green and brown seedheads) and the numbers of these seedheads was recorded. After measuring, each plant was separated into main stem, leaves, branches, flowers and seedheads. Each fraction was oven dried at 80 °C to a constant weight (72 hours) before dry weight was recorded.

4.2.4.2 Seed yield and yield components

Seed yield from each plot excluding border rows (5.76 m^{-2}) was obtained by hand-cutting individual plants at ground level on 22 March 1990 (142 days after sowing) when most of the seedheads on the plants had turned brown and some of the seedheads had started to open. From each plant seedheads were separated, dried, threshed and cleaned using the same methods as described in Chapter 3. After cleaning, the seed moisture content varied from 7 to 10 %. Seed weight values were corrected to 0 % moisture content to get actual seed yield per plant.

Seed yield components were determined from three randomly chosen sample plants per plot at the final harvest. Numbers of seeds per seedhead were counted after seeds were hand threshed and cleaned by passing through a 'Vertical Airblast' seed blower (Burrows Model No. 1836-4) with the air flow set at 85 m min^{-1}. Five grams of seed were counted and used to calculate the number of seeds per seedhead by multiplying seed weight per plant and dividing by the number of seedheads per plant. Thousand seed dry weight was ten times the mean dry weight of eight replicates of 100 seeds. Plant dry weight was obtained using the air oven method, at 80°C to constant dry weight (3 days). Germination and viability tests were done 30 days after final harvest using the same methods as described previously (Chapter 3).

4.3 RESULTS

4.3.1. Plant growth and development

4.3.1.1 Plant height

Paclobutrazol at all application times significantly reduced plant height at peak flowering and harvest (Table 4.1, Plate 4.1). At first flowering, however, only plants treated with paclobutrazol at the vegetative stage were significantly shorter than the control. No significant differences in plant height between the control and chlormequat treatments were recorded at any of the observation times (Table 4.1, Plate 4.1) .

4.3.1.2 Main stem length

There were no significant differences between PGR treatments and the control for main stem length at first flowering (Table 4.2). At peak flowering, paclobutrazol applied at the vegetative and visible terminal bud stages significantly reduced main stem length, but by harvest only plants treated with paclobutrazol applied at the vegetative stage had main stems significantly shorter than the control. No significant differences between the control and any chlormequat treatments were recorded (Table 4.2).

Table 4.1 Effect of PGRs on plant height (cm).

Treatment	First flowering	Peak flowering	Final harvest
Control	50.5	77.2	78.8
Paclobutrazol (1)	43.1	64.8	64.7
Paclobutrazol (2)	48.3	67.1	70.0
Paclobutrazol (3)	45.2	66.8	66.8
Chlormequat 1.5 kg ai (2)	47.2	74.6	74.7
Chlormequat 3.0 kg ai (2)	52.6	74.8	75.3
Chlormequat 1.5 kg ai (3)	46.5	76.4	77.3
Chlormequat 3.0 kg ai (3)	53.6	75.0	75.1
LSD (P<0.05)	6.6	6.0	5.9
Significance	*	**	**
% CV	7.8	4.8	4.7

Table 4.2 Effect of PGRs on main stem length (cm).

Treatment	First flowering	Peak flowering	Final harvest
Control	23.2	33.8	33.7
Paclobutrazol (1)	22.7	22.4	23.0
Paclobutrazol (2)	27.8	26.4	29.0
Paclobutrazol (3)	25.6	29.7	30.0
Chlormequat 1.5 kg ai (2)	22.9	33.0	32.9
Chlormequat 3.0 kg ai (2)	29.4	29.2	29.8
Chlormequat 1.5 kg ai (3)	29.4	31.5	32.2
Chlormequat 3.0 kg ai (3)	31.3	31.2	32.7
LSD (P<0.05)	8.4	6.4	6.9
Significance	*	*	*
% CV	18.4	12.3	12.9

Plate 4.1 Plant structure at peak flowering.

1 Control

2 Paclobutrazol 1.0 kg a.i. ha^{-1} (vegetative stage)

3 Paclobutrazol 1.0 kg a.i. ha^{-1} (first visible flower bud stage)

4 Paclobutrazol 1.0 kg a.i. ha^{-1} (stem elongation stage)

5 Chlormequat 1.5 kg a.i. ha^{-1} (first visible flower bud stage)

6 Chlormequat 3.0 kg a.i. ha^{-1} (first visible flower bud stage)

7 Chlormequat 1.5 kg a.i. ha^{-1} (stem elongation stage)

8 Chlormequat 1.5 kg a.i. ha^{-1} (stem elongation stage)

4.3.1.3 Branch length

Lateral branch lengths at first flowering, peak flowering and harvest are presented in Tables 4.3-4.5. At first flowering, only plants treated with paclobutrazol at the vegetative stage had significantly shorter middle lateral branches (Table 4.3). However, paclobutrazol applied at all stages of growth reduced the base and middle lateral branches lengths at peak flowering (Table 4.4) and seed harvest (Table 4.5). No significant length differences between the control and paclobutrazol treated plants were observed for the top lateral branches at either peak flowering or harvest. Chlormequat did not alter lateral branch length at any observation time.

Table 4.3 Effect of PGR's on lateral branch length from different positions on the plant at first flowering.

Treatment	Lateral branch length (cm)		
	Base	Middle	Top
Control	37.7	36.8	31.7
Paclobutrazol (1)	31.5	30.3	28.7
Paclobutrazol (2)	35.6	33.6	27.2
Paclobutrazol (3)	34.2	33.1	30.7
Chlormequat 1.5 kg ai (2)	34.0	31.8	31.5
Chlormequat 3.0 kg ai (2)	41.0	39.2	33.9
Chlormequat 1.5 kg ai (3)	33.6	36.4	29.2
Chlormequat 3.0 kg ai (3)	38.1	37.8	35.9
LSD (P<0.05)	9.1	5.5	8.7
Significance	*	*	NS
% CV	14.7	9.1	15.7

Table 4.4 Effect of PGR's on lateral branch length from different positions on the plant at peak flowering.

Treatment	Lateral branch length (cm)		
	Base	Middle	Top
Control	71.4	69.9	52.9
Paclobutrazol (1)	59.9	56.4	47.7
Paclobutrazol (2)	61.3	55.7	49.3
Paclobutrazol (3)	62.4	58.5	48.7
Chlormequat 1.5 kg ai (2)	68.9	63.4	55.8
Chlormequat 3.0 kg ai (2)	68.8	63.8	53.8
Chlormequat 1.5 kg ai (3)	71.3	67.2	54.7
Chlormequat 3.0 kg ai (3)	67.1	65.4	53.2
LSD (P<0.05)	8.1	6.7	5.7
Significance	*	**	*
% CV	6.9	6.2	6.3

Table 4.5 Effect of PGR's on lateral branch length from different positions on the main stem at final harvest.

Treatment	Lateral branch length (cm)		
	Base	Middle	Top
Control	74.8	69.3	52.7
Paclobutrazol (1)	59.1	56.5	47.1
Paclobutrazol (2)	64.7	58.7	49.2
Paclobutrazol (3)	62.5	58.3	50.1
Chlormequat 1.5 kg ai (2)	69.4	67.2	55.7
Chlormequat 3.0 kg ai (2)	72.3	67.2	55.9
Chlormequat 1.5 kg ai (3)	71.1	69.0	54.2
Chlormequat 3.0 kg ai (3)	67.8	65.2	53.5
LSD (P<0.05)	8.8	7.0	6.1
Significance	*	**	*
% CV	7.5	6.2	6.7

4.3.1.4 Flower stalk length

The length of the flower stalk on the main stem was recorded at first flowering, peak flowering and harvest (Table 4.6). Plants treated with paclobutrazol at the vegetative stage and chlormequat 1.5 kg a.i. ha^{-1} at stem elongation were shorter than the control at first flowering. However, no significant differences between the control and PGR treatments were recorded at peak flowering or at harvest (Table 4.6).

The lengths of terminal flower stalks from the base, middle and top lateral branches were recorded only at harvest. None of the differences between PGR's and the control were significant (Table 4.7).

Table 4.6 Effect of PGR's on flower stalk length from the main stem.

Treatment	Flower stalk length (cm)		
	First flowering	Peak flowering	Final harvest
Control	22.6	22.0	22.6
Paclobutrazol (1)	15.4	18.6	20.1
Paclobutrazol (2)	17.5	17.6	17.7
Paclobutrazol (3)	17.8	17.9	18.6
Chlormequat 1.5 kg ai (2)	20.9	16.8	21.3
Chlormequat 3.0 kg ai (2)	20.5	22.6	24.1
Chlormequat 1.5 kg ai (3)	16.2	22.4	23.5
Chlormequat 3.0 kg ai (3)	18.0	19.2	19.9
LSD (P<0.05)	5.4	5.8	5.8
Significance	*	*	*
% CV	16.6	16.8	15.9

Table 4.7 Effect of PGR's on flower stalk length from different positions on the plant at harvest.

Treatment	Flower stalk length (cm)		
	Base	Middle	Top
Control	16.3	12.4	15.2
Paclobutrazol (1)	13.5	10.4	11.7
Paclobutrazol (2)	15.6	14.1	14.5
Paclobutrazol (3)	14.8	13.5	16.9
Chlormequat 1.5 kg ai (2)	16.0	15.1	15.3
Chlormequat 3.0 kg ai (2)	15.3	13.4	15.5
Chlormequat 1.5 kg ai (3)	12.7	14.1	14.3
Chlormequat 3.0 kg ai (3)	16.5	13.3	14.0
LSD (P<0.05)	3.9	2.9	4.4
Significance	NS	*	*
% CV	14.7	12.5	17.1

4.3.1.5 Lateral branches, secondary lateral branches and node number

There were no significant differences between the control and PGR treatments in terms of the number of nodes (Table 4.8) or the number of lateral branches (Table 4.9). A greater number of secondary lateral branches were counted at both peak flowering and harvest for all PGR treatments, but the increases were not significant except for chlormequat 1.5 kg a.i. ha^{-1} applied at stem elongation where the number of secondary branches was significantly greater than the control (Table 4.10).

Table 4.8 Effect of PGR's on number of nodes on the main stem.

Treatment	First flowering	Peak flowering	Final harvest
Control	7.0	7.7	7.7
Paclobutrazol (1)	7.0	7.3	8.0
Paclobutrazol (2)	7.0	7.7	8.3
Paclobutrazol (3)	7.0	7.7	7.3
Chlormequat 1.5 kg ai (2)	7.0	7.7	7.7
Chlormequat 3.0 kg ai (2)	7.0	7.0	8.0
Chlormequat 1.5 kg ai (3)	7.0	8.0	7.3
Chlormequat 3.0 kg ai (3)	7.3	7.3	7.7
LSD (P<0.05)	0.3	0.8	0.9
Significance	NS	NS	NS
% CV	2.9	6.1	6.7

Table 4.9 Effect of PGR's on number of lateral branches per plant.

Treatment	First flowering	Peak flowering	Final harvest
Control	11.7	13.0	13.0
Paclobutrazol (1)	11.7	12.0	12.7
Paclobutrazol (2)	12.0	12.3	13.3
Paclobutrazol (3)	12.0	13.0	13.0
Chlormequat 1.5 kg ai (2)	12.3	12.3	12.3
Chlormequat 3.0 kg ai (2)	12.7	12.0	12.7
Chlormequat 1.5 kg ai (3)	11.7	13.0	13.0
Chlormequat 3.0 kg ai (3)	11.7	13.0	13.3
LSD (P<0.05)	1.5	1.4	1.6
Significance	NS	NS	NS
% CV	7.2	6.4	7.1

Table 4.10 Effect of PGR's on number of secondary lateral branches per plant.

Treatment	First flowering	Peak flowering	Final harvest
Control	16.3	17.3	17.7
Paclobutrazol (1)	14.0	20.3	21.0
Paclobutrazol (2)	11.3	20.3	20.7
Paclobutrazol (3)	15.3	20.3	20.0
Chlormequat 1.5 kg ai (2)	13.0	19.7	19.7
Chlormequat 3.0 kg ai (2)	16.7	21.3	23.7
Chlormequat 1.5 kg ai (3)	13.0	17.7	25.0
Chlormequat 3.0 kg ai (3)	11.7	19.7	20.0
LSD (P<0.05)	9.2	6.0	6.9
Significance	NS	NS	*
% CV	39.2	17.4	18.9

4.3.2 Plant dry weight

No significant differences in plant dry weight were recorded from any parts of the plant at first flowering with the exception of plants treated with chlormequat at 3.0 kg a.i. ha^{-1} at stem elongation, for which flower dry weight was significantly greater than the control (Table 4.11).

At peak flowering, only chlormequat 1.5 kg a.i. ha^{-1} applied at stem elongation significantly increased leaf dry weight (Table 4.12). However no significant differences between PGR's and the control were recorded for main stem, branch, flower or total plant dry weight.

At harvest, paclobutrazol applied at the vegetative stage reduced main stem dry weight. However, leaf, branch, flower and total dry weight for this and all other treatments did not differ significantly from the control (Table 4.13).

Table 4.11 Effect of PGR's on plant dry weight at first flowering.

Treatment	Dry weight (gm)				
	Main stem	Leaf	Branch	Flower	Total
Control	2.69	13.47	8.0	3.43	27.57
Paclobutrazol (1)	2.41	10.17	6.22	3.43	22.10
Paclobutrazol (2)	3.23	11.15	7.10	3.30	24.90
Paclobutrazol (3)	2.93	10.78	7.18	4.34	25.23
Chlormequat 1.5 kg ai (2)	2.57	12.60	7.31	3.11	25.59
Chlormequat 3.0 kg ai (2)	3.43	12.62	8.77	4.08	28.91
Chlormequat 1.5 kg ai (3)	2.79	11.50	7.49	4.09	25.87
Chlormequat 3.0 kg ai (3)	3.46	12.05	8.46	5.37	29.35
LSD (P<0.05)	1.09	4.97	3.30	1.92	8.98
Significance	NS	NS	NS	*	NS
% CV	21.3	24.1	24.9	28.2	19.6

Table 4.12 Effect of PGR's on plant dry weight at peak flowering.

Treatment	Dry weight (g)				
	Main stem	Leaf	Branch	Flower	Total
Control	4.95	15.59	25.33	15.04	60.90
Paclobutrazol (1)	3.71	14.07	22.39	19.76	59.93
Paclobutrazol (2)	4.12	17.29	24.06	16.99	62.45
Paclobutrazol (3)	3.99	14.33	23.60	16.84	58.75
Chlormequat 1.5 kg ai (2)	5.34	15.40	26.46	17.10	64.29
Chlormequat 3.0 kg ai (2)	4.42	14.30	22.68	15.79	57.19
Chlormequat 1.5 kg ai (3)	5.42	19.60	27.66	17.97	70.65
Chlormequat 3.0 kg ai (3)	4.59	15.09	26.07	17.61	63.36
LSD (P<0.05)	1.26	3.23	6.77	5.2	13.7
Significance	*	*	NS	NS	NS
% CV	15.7	11.7	15.6	17.3	12.6

Table 4.13 Effect of PGR's on plant dry weight at final harvest.

Treatment	Dry weight (g)				
	Main stem	Leaf	Branch	Flower	Total
Control	5.16	15.62	30.48	18.98	70.24
Paclobutrazol (1)	3.69	14.13	22.48	24.89	65.17
Paclobutrazol (2)	4.11	18.37	29.85	25.72	78.05
Paclobutrazol (3)	4.12	14.39	23.81	20.58	62.90
Chlormequat 1.5 kg ai (2)	5.35	15.89	31.93	24.94	78.12
Chlormequat 3.0 kg ai (2)	4.50	18.17	38.20	25.27	86.14
Chlormequat 1.5 kg ai (3)	5.72	19.94	36.78	27.60	90.04
Chlormequat 3.0 kg ai (3)	4.65	15.13	29.92	24.96	74.66
LSD (P<0.05)	1.40	4.88	8.87	8.88	20.56
Significance	*	*	*	NS	*
% CV	17.2	16.9	16.6	21.0	15.5

4.3.3 Number of days to first and peak flowering

Plants treated with paclobutrazol at stem elongation and chlormequat 1.5 kg a.i. ha^{-1} at first visible flower bud reached first flowering two days earlier than the control. However, no significant differences between the control and PGR treatments were recorded for the number of days to peak flowering (Table 4.14).

Table 4.14 Effect of PGR's on number of days from sowing to first and peak flowering.

Treatment	First flowering	Peak flowering
Control	75	100
Paclobutrazol (1)	75	100
Paclobutrazol (2)	76	101
Paclobutrazol (3)	73	98
Chlormequat 1.5 kg ai (2)	73	100
Chlormequat 3.0 kg ai (2)	75	99
Chlormequat 1.5 kg ai (3)	73	100
Chlormequat 3.0 kg ai (3)	73	100
LSD (P<0.05)	2.1	2.6
Significance	*	*
% CV	1.6	1.6

4.3.4 Seed yield and yield components

There were no significant differences in total flower production per plant at peak flowering (Table 4.15) but at seed harvest paclobutrazol applied at first terminal bud significantly increased the total number of flowers compared with the control (Table 4.15). The total number of seedheads per plant at harvest was significantly increased in plants treated with paclobutrazol at visible flower bud and chlormequat 1.5 kg a.i. ha^{-1} at stem elongation (Table 4.16). The total number of seedheads from plants treated with paclobutrazol at the visible bud stage was increased because the plants had more brown seedheads on the base, middle and top lateral branches (Table 4.18), while plants treated with chlormequat 1.5 kg a.i. ha^{-1} at stem elongation had a greater number of green seedheads on the middle lateral branches (Table 4.17) and more brown seedheads on the top lateral branches (Table 4.18). Plants treated with chlormequat 1.5 kg a.i. ha^{-1} at the first visible bud stage also had an increased number of brown seedheads on the top lateral branches (Table 4.18).

No significant differences between PGRs and the control for the number of seeds per seedhead, thousand seed dry weight (Table 4.16), percentage germination and viability (Table 4.19) were recorded.

Paclobutrazol applied at visible bud formation and both applications of chlormequat 1.5 kg a.i. ha^{-1} significantly increased harvested seed yield (Table 4.20). However, greater percentages of seed cleaning losses were recorded following all PGR treatments due to immature seeds. Cleaned seed yield was affected by differential seed cleaning losses, particularly in treatments with late chlormequat application (at stem elongation) (Table 4.20). Only paclobutrazol (applied at visible terminal bud) significantly increased cleaned seed yield, despite the fact that one third of the harvested seed yield was lost during cleaning (Table 4.20).

Table 4.15 Effect of PGR's on total flowers produced per plant at peak flowering and seed harvest.

Treatment	Flower number	
	Peak flowering	Harvest
Control	37.8	48.0
Paclobutrazol (1)	42.4	52.3
Paclobutrazol (2)	44.4	67.3
Paclobutrazol (3)	40.3	49.3
Chlormequat 1.5 kg ai (2)	39.3	57.3
Chlormequat 3.0 kg ai (2)	36.1	57.7
Chlormequat 1.5 kg ai (3)	41.1	62.3
Chlormequat 3.0 kg ai (3)	38.9	54.3
LSD (P<0.05)	12.7	15.3
Significance	NS	*
% CV	18.1	15.6

Table 4.16 Effect of PGR's on seed yield components.

Treatment	Seedheads per plant	Seeds per seedhead	TSW (g)
Control	42.0	35.7	6.0
Paclobutrazol (1)	45.0	36.7	6.1
Paclobutrazol (2)	62.1	42.3	6.1
Paclobutrazol (3)	45.7	38.3	6.0
Chlormequat 1.5 kg ai (2)	51.7	41.3	6.2
Chlormequat 3.0 kg ai (2)	50.3	40.3	6.0
Chlormequat 1.5 kg ai (3)	55.5	44.3	5.7
Chlormequat 3.0 kg ai (3)	45.8	35.0	6.0
LSD (P<0.05)	11.4	10.1	0.42
Significance	*	NS	*
% CV	13.6	14.7	3.9

Table 4.17 Effect of PGR's on number of harvested green seedheads from different lateral branch positions.

Treatment	Number of green seedheads		
	Base	Middle	Top
Control	4.1	2.3	2.7
Paclobutrazol (1)	3.5	2.7	2.1
Paclobutrazol (2)	5.0	3.4	2.6
Paclobutrazol (3)	4.3	2.8	1.6
Chlormequat 1.5 kg ai (2)	4.0	2.7	2.8
Chlormequat 3.0 kg ai (2)	4.7	3.2	4.0
Chlormequat 1.5 kg ai (3)	4.2	4.9	3.0
Chlormequat 3.0 kg ai (3)	2.4	2.2	2.0
LSD (P<0.05)	2.2	1.8	2.3
Significance	*	*	*
% CV	30.9	34.9	50.7

Table 4.18 Effect of PGR's on number of harvested brown seedheads from different lateral branch positions.

Treatment	Number of brown seedheads		
	Base	Middle	Top
Control	10.9	9.3	12.7
Paclobutrazol (1)	11.3	11.1	14.2
Paclobutrazol (2)	17.6	15.8	17.8
Paclobutrazol (3)	12.7	10.7	13.7
Chlormequat 1.5 kg ai (2)	11.8	12.3	18.1
Chlormequat 3.0 kg ai (2)	13.2	11.1	14.0
Chlormequat 1.5 kg ai (3)	12.6	12.4	18.4
Chlormequat 3.0 kg ai (3)	13.0	10.7	15.4
LSD (P<0.05)	5.4	4.4	4.8
Significance	*	*	*
% CV	23.9	21.3	17.5

Table 4.19 Effect of PGR's on germination and viability.

Treatment	Germination (%)	Viability (%)
Control	87.7	90.3
Paclobutrazol (1)	86.0	88.5
Paclobutrazol (2)	83.8	87.8
Paclobutrazol (3)	85.8	89.3
Chlormequat 1.5 kg ai (2)	85.0	91.2
Chlormequat 3.0 kg ai (2)	89.0	91.8
Chlormequat 1.5 kg ai (3)	87.5	92.2
Chlormequat 3.0 kg ai (3)	88.2	92.5
LSD (P<0.05)	5.3	4.8
Significance	NS	NS
% CV	3.5	3.1

Table 4.20 Effect of PGR's on seed yield.

Treatment	Seed yield (g plant $^{-1}$)		% cleaning loss
	harvested	cleaned	
Control	8.92	7.62	14.6
Paclobutrazol (1)	10.14	7.28	28.2
Paclobutrazol (2)	16.26	10.85	33.3
Paclobutrazol (3)	10.57	7.35	30.4
Chlormequat 1.5 kg ai (2)	13.34	9.02	32.3
Chlormequat 3.0 kg ai (2)	12.25	8.36	31.7
Chlormequat 1.5 kg ai (3)	13.99	8.13	41.9
Chlormequat 3.0 kg ai (3)	9.45	7.79	17.6
LSD (P<0.05)	3.86	2.1	
Significance	*	*	
% CV	18.6	14.7	

4.4 DISCUSSION

4.4.1 Plant growth and development

4.4.1.1 Plant height

Paclobutrazol decreased plant height by decreasing both main stem and branch length. However, main stem retardation was consistent only with application at the vegetative stage (Stage 1). The later the application, the lower the paclobutrazol efficacy. Application at first visible bud produced a less persistent effect while application at stem elongation failed to reduce main stem length. This was possibly because the plant had already started to elongate before these applications was made; for example plant height (the length of the main stem) was approximately 7-10 cm at the vegetative stage (stage 1), 20-25 cm at the first-visible-bud stage (stage 2) and 25-30 cm at the stem-elongation stage (stage 3). These results confirmed those from the previous experiment i.e. that the persistence and level of response from paclobutrazol is greatly affected by the time (stage of plant growth) of application. Node numbers were unaffected by paclobutrazol (Table 4.8), and as has been reported in other species (Wample and Culver, 1983; Hampton and Hebblethwaite, 1985a; Li, 1989; Hampton and Young, 1988; Tolentino, 1990), the effect was to reduce internodal cell elongation rather than any reduction in node numbers.

Retardation effects on the lateral branches were consistent only with application at the vegetative growth stage, and then only in those primary lateral branches arising from the middle portion of the main stem (Table 4.3). By peak flowering all paclobutrazol applications had significantly reduced the length of primary lateral branches arising from both the basal and middle portions of the plant but top primary lateral branch lengths were unaffected (Table 4.4). These effects remained the same through to harvest. These results are in contrast to those of the previous experiment (Chapter 3A) where paclobutrazol had no effect on plant height or lateral branch length at seed harvest, but agree with Rounkova (1989) who found that paclobutrazol retarded all above ground parts of dahlia. The contrasting results between the present experiment and that in Chapter 3A are

probably due to the difference in planting (sowing) date. In the present experiment dahlia seeds were sown on 1 November 1989 while in the previous one sowing was 50 days later (21 December 1988). Paclobutrazol efficacy may be more obvious where plants have more vegetative growth; in the present experiment vegetative plant growth at the middle or base of the plant was retarded more than the top position and the retardation results were greater when applied early at the vegetative stage (Tables 4.3,4.4) than at later growth stages. Paclobutrazol retardation effects have also been reported in *Verbena venosa* (Norremark, 1988) and *Callistephus chinensis* (Phetpradap, 1992) although as for dahlia the response was cultivar, rate and timing dependent.

Chlormequat did not affect plant height, main stem or branch length as no significant differences were obtained between chlormequat treated plants and the untreated control. However, chlormequat through visual observation, appeared to have a promotive effect, particularly for the top lateral branches. Although not significantly different from the control, chlormequat treated plants always had longer branches than paclobutrazol treated plant. This effect was most obvious following application at the first visible bud stage, as chlormequat treated plants had longer top and middle branch lengths than plants when paclobutrazol was applied at the same stage. This result confirms the results of the previous experiment (Chaper 3A). It seems likely that the retardation effect of chlormequat as found in this and the previous experiment was not as persistent as that of paclobutrazol in that plant growth after chlormequat application was checked only initially and then resumed, so that the final results did not differ from the control. Similar results showing a lack of effect in reducing stem length following chlormequat application were also reported in *Verbena venosa* (Norremark, 1988), *Holcus lanatus* (Tolentino, 1990) and in pot chrysanthemum (*Chrysanthemum morifolium*) (Cathey and Stuart, 1961).

4.4.1.2 Flower stalk length

The depression in main stem length following early application of paclobutrazol was also followed by a reduction in flower stalk length at the time of first flowering, but this was no longer evident at peak flowering. Surprisingly, chlormequat applied at the lower rate (1.5 kg a.i. ha^{-1}) at the late stage of growth

(stem elongation stage) had a similar but also short term effect on flower stalk length. By peak flowering this effect of chlormequat in reducing flower stalk length had also disappeared.

Neither of the early effects of paclobutrazol and chlormequat on flower stalk length were positional as stalks from flowers borne on the basal, middle or top portions of the plant were not differentially affected.

4.4.1.3 Effect on lateral branches

Despite the effects of early application of paclobutrazol and, in some cases, late chlormequat application, in reducing branch and flower stalk length, these chemicals did not change general plant structure in term of branch (primary and secondary lateral branch) numbers per plant. This overall effect was, however, complicated by the suggestion that late application of chlormequat increased secondary lateral branches at final harvest. The fact that this did not occur at the higher rate (3 kg a.i. ha^{-1}) suggests either that it was an anomaly, or that the secondary lateral branch response to chlormequat development is rate and time dependent. The lack of change in the number of lateral branches agreed with the previous year's experiment and was similar to results reported in *Lotus corniculatus* (birdsfoot trefoil) (Supanjani, 1991). The increase in secondary lateral branches at seed harvest following treatment with chlormequat 1.5 kg a.i. ha^{-1} at stem elongation was possibly due to the promoting effect of this PGR, as leaf dry weight at peak flowering (Table 4.12) was significantly increased.

4.4.1.4 Effect on flowering and flower production

None of the treatments used in this study had major effects in delaying the onset of flowering. Two treatments (paclobutrazol applied at stem elongation, chlormequat 1.5 kg a.i. ha^{-1} at first visible bud) did slightly reduce days to first flowering but days to peak flowering were similar in all treatments. This suggests that none of the chemical/time/rate combinations used in this study were effective in greatly altering flowering duration in dahlia, a feature which could be important in improving the synchrony of flowering and with obvious advantages in terms of seed yield recovery at harvest.

In this study, only paclobutrazol applied at visible bud stage increased total flower production at seed harvest. Increasing number of flowers after paclobutrazol application have been reported in *Lotus corniculatus* (Li, 1989; Supanjani, 1991), *Lotus uliginosus* (Clifford and Hare, 1987; Tabora, 1991), citrus (Mauk *et al.*, 1986), cucumber (Globerson *et al.*, 1989) and *Trifolium repens* (Hampton, 1991).

4.4.2 Plant dry weight

It had been expected from observation that PGR's (paclobutrazol, in particular) would result in reduced plant dry matter. The shorter branches and generally smaller and thickened leaves observed in paclobutrazol treated plants were, however, not reflected in reduced lower main stem, leaf, branch or flower dry weight at first or peak flowering. The effects of chlormequat were similar, except for an increase in flower dry weight, again in plants treated late (stem elongation stage) with chlormequat, but evident only at first flowering. This same treatment also increased leaf dry weight at peak flowering but by this time the earlier increase in flower dry weight had disappeared. At final harvest the only effect of PGR application was a reduction in main stem dry weight in plants treated early with paclobutrazol. These variable, short term or 'one off' effects are difficult to explain agronomically: they are inconsistent and may not be repeatable.

4.4.3 Seed yield and yield components

The response of dahlia plants to PGR application in terms of plant structure was relatively minor, and often inconsistent. For this reason, any seed yield increases would have to come from changes in flower numbers, seed numbers and/or seed weight components. However only paclobutrazol application at first visible bud stage responded in this way, significantly increasing flower number and seedheads per plant at harvest, and the number of brown seedheads at all positions on the plant, although seeds per seedhead and seed weight were not increased. The greater number of brown seedheads meant that these treated plants had better uniformity of seedhead maturity. This resulted in an increase in harvested seed yield of 86 %, and in cleaned seed yield of 42 % compared with the untreated plants. This result confirmed that paclobutrazol applied at visible bud stage

significantly increased cleaned seed yield by up to 42 %. This compares with values of 73 % in Chapter 3A and 30 % in Chapter 4. Although variable in extent, this common increase suggests that the timing of Paclobutrzol to coincide with the onset of visible bud formation is likely to be important. Earlier application of paclobutrazol (vegetative stage), although showing a greater retardation effect, did not increase flower numbers so that seedheads and seed yield were not increased. Late application (stem elongation) produced little retardation and did not change any seed yield components, so that seed yield did not differ. This result was also similar to the previous experiment (Chapter 3).

The effect of chlormequat was to increase seedheads per plant significantly when the chemical was applied at 1.5 kg a.i. ha^{-1} at the stem-elongation stage. This resulted from an increase in the number of green seedheads carried on the middle lateral branches, and ultimately in the brown seedheads on the top lateral branch positions of the plant. Neither seeds per seedhead or seed weight were changed. The earlier (first-visible-bud-stage) application of chlormequat at the same rate also increased brown seedhead numbers on the top of the plant. However, seed yield following chlormequat (1.5 kg a.i. ha^{-1}) application was significant only for the harvested seed yield (+57%), and not machine-cleaned seed yield, presumably because the cleaning loss of 42% included small/immature/light seed. Mathews *et al.* (1982) reported that the overall effect of chlormequat in barley was to produce plants with greater within plant uniformity at the early vegetative growth stages which could use available resources (either nutrients and/or assimilates) more effectively, and thereby produce more ears per plant. Seed-yield increases from this experiment were different from the previous year's experiment in which chlormequat (at the same rate and time of application) increased cleaned but not harvested seed yield. The different result between the two experiments is possibly due to greater cleaning losses of immature seeds caused by an incorrect time of harvest, or as more seedheads were produced, the plant may have been incapable of seed filling to the same extent. Time of planting may also be another possible cause as the present experiment was sown about 50 days earlier than the previous one. Seasonal differences have also been reported in *Lotus uliginosus* by Tabora (1991) who showed that chlormequat application during December increased seed yield in one year but not in the following year.

Three treatments (paclobutrazol at first visible bud, chlormequat 1.5 kg a.i. ha^{-1} (first visible bud) and chlormequat 1.5 kg a.i. ha^{-1} (stem elongation) significantly increased harvested seed yield but only paclobutrazol applied at first visible bud stage significantly increased cleaned seed yield. The ultimate effect of paclobutrazol applied at first visible bud stage in increasing seed yield was somewhat surprising, since as previously shown, this treatment did not increase branch numbers. The yield increase came, however through an improvement in floral site number and fertility, suggesting that more flowers produced were retained to become seedheads, and that more seeds per seedhead were supported through to maturity.

The chlormequat (1.5 kg a.i. ha^{-1}) treatments, although they did not increase cleaned seed yield, are of some potential interest. The later application of chlormequat at this rate increased secondary lateral branches and subsequently seedheads per plant, particularly from branches carried on the top portion of the plant.

4.5 CONCLUSION

The results of this study have shown that paclobutrazol and chlormequat can be used to increase seed yields in dahlia, but they have highlighted the need for precise timing of application to obtain a response from paclobutrazol and the timing/rate relationship which appears to dictate any likely response from the application of chlormequat. Neither chemical affected seed quality. The seed yield responses were sufficiently encouraging to warrant further study. The results however, have highlighted the need for early application (visible terminal bud) of paclobutrazol (1.0 kg a.i. ha^{-1}) and the likelihood of late application (at stem-elongation-stage) responses from chlormequat (1.5 kg a.i. ha^{-1}). These two treatments were therefore chosen for further study on the effect of harvesting time (Chapter 6).

CHAPTER 5

SEED DEVELOPMENT AND REPRODUCTIVE GROWTH STUDIES

5.1 INTRODUCTION

Seed development studies have been valuable in providing information to allow harvesting for both maximum quality and quantity of many different seed crops, e.g. *Medicago sativa* (Kowithayakorn and Hill, 1982), *Lactuca sativa* (Sukprakarn, 1985), *Glycine max* (Chanprasert, 1988), *Lotus corniculatus* (Li, 1989) and many flower crops (STC, 1986). Correct harvest timing is very important, since delayed harvesting can result in much seed being lost because of shattering or shedding (Hawthorn and Pollard, 1954), while harvesting too early, particularly before seed reaches physiological maturity, can reduce seed yield and quality, and subsequent seed storage life (Harrington, 1972).

In dahlia, it is difficult to determine the optimum seed harvesting time because flowering tends to continue for a long time. New flower heads, young and ripe seedheads are often present simultaneously on plants at harvest. In addition, seed shedding occurs at maturity and the duration of flowering can also fluctuate with changes in environmental factors such as photoperiod (Garner and Allard, 1923; Zimmerman and Hitchcock, 1929; Konishi and Inaba, 1966b) and temperature (Konishi and Inaba,1966c). Because of this behaviour, a considerable proportion of total seed yield may be lost either due to the presence of a high number of immature seeds, or seed shedding at harvest. As no information is currently available, more precise knowledge of the pattern of flower and seed development in dahlia would be very useful in helping to determine the optimum harvest time. This study was also prompted by obvious differences in harvest date in previous experiments and the previous reliance on a field observation criterion (more than 80 % of heads brown) rather than defining date of harvest ripeness more precisely.

The primary objective of this study was to investigate the pattern of reproductive growth and development and the sequence of seed development to identify the best time for harvesting the dahlia seed crop.

5.2 MATERIALS AND METHODS

This chapter includes two experiments. The first involved an observation of reproductive growth and development by assessing changes in bud production, flowering pattern and seedhead development. The second part was an investigation of the seed development sequence, which was measured by assessing changes in the fresh weight, dry weight, moisture content, germinability and viability of seeds at different times after flowering.

5.2.1 PLANT GROWTH AND REPRODUCTIVE DEVELOPMENT

5.2.1.1 Establishment

Seeds of dahlia cv. Unwins Dwarf Mixture were thiram dusted (1 g product (80% wettable powder)/100g seed), and sown 2 cm deep in 15 cm diameter and 20 cm deep black polythene bags (five seeds/bag) filled with Smith's potting mix (a sterile mixture of peat, pumice and coarse sand containing balanced proportions of fertiliser and slow release trace elements plus terrazole soil fungicide, Smith Soil Industrial Limited, Auckland, New Zealand) on 1 October 1989. Bags were placed in a 30/20±5 °C glasshouse at the Seed Technology Centre and seedlings were thinned to one plant per bag at 2 weeks after sowing. After 40 days, plants were moved to an ambient temperature (mean air temperature 16-20 °C; Appendix 5.1) glasshouse and randomly allocated with a distance of 30 cm between the bags. There were 30 plants in this study and all were used for the measurement of plant growth and development. Six plants, each of a different flower colour, were then selected at random after flower colour appeared (72 days after sowing) to determine seed yield and yield components.

The plants were hand watered by the daily application of approximately 1 litre per bag from sowing until peak flowering. Subsequently, watering was reduced to every 3 days until harvest. No additional fertilizer was added to that already present in the soil at planting. Plants were sprayed with fungicide and insecticide every two weeks starting one month after sowing and continuing until the end of the experiment. Fungicide and insecticide application was the same as described in Chapter 2.

5.2.1.2 Plant measurements

Begining 40 days after sowing (DAS, 9 November 1989)) the following data were recorded at 3 day intervals:

Number of nodes	- all nodes which developed on the main stem.
Number of lateral branches	- all branches which developed on the main stem and produced at least one visible flower bud.
Plant height	- measured as the distance from the cotyledonary node to the top of the plant.
Main stem length	- measured as the distance from the cotyledonary node to the top node of the main stem.
Number of buds	- all green buds prior to opening.
Number of flowers	- all newly opened flowers (Stage 1, Plate 5.1).
Number of seedheads	- all newly pollinated flower heads with petals shed from the flower head. The numbers included all seedheads (mature and immature; stage 3-5, Plate 5.1).
Number of harvested seedheads	- all fully ripened seedheads before shattering (brown with seedheads started to open; stage 5, Plate 5.1).
Days to first visible flower bud	- days from sowing until flower bud formation was first observed.
Days to first flowering	- days from sowing until the outer petals of the flower head started to open; stage 1, Plate 5.1).
Days to peak flowering	- days to when the number of newly opened flowers reached a maximum as determined by counting at three days intervals.
Days to ripening	- days from sowing until seedhead colour changed from yellow-brown to brown (seedheads started to open; stage 5, Plate 5.1).

5.2.2 SEED DEVELOPMENT

The experiment was carried out in the same area described in Chapter 3A using only the control plots of second year plants (growing from tubers left in the field from the previous year).

Twenty five newly-opened flower heads per replicate were identified with a different coloured wool tag at 3 day intervals from 1 December 1989 to 23 January 1990. All tagged seedheads were collected on 23 January 1990, seedhead colour was noted and seedheads then photographed (Plate 5.1). From each seed age group, the 25 seedheads were divided approximately into two parts. Seeds were then removed from the first part. Two sets of 100 seeds per replicate were weighed immediately to obtain 100 seed fresh weight and then used to determine seed dry weight and seed moisture content by oven drying at 103 °C for 17 hours (ISTA, 1985). Seed colour at different seed ages was also observed. The remaining seedheads (the second part) were air-dried at room temperature for 5 weeks before seeds were removed and four lots of 50 seeds were germinated in rolled paper beginning on 1 March 1990 (36 days after harvest) by pre-chilling the seeds at 5 °C for 5 days and then placing the rolls in a 20/30 °C cabinet. Normal seedlings were counted after 7 and 14 days, with a final count after 21 days (ISTA, 1985) when the percentage of normal seedlings, abnormal seedlings, fresh ungerminated seeds and dead seed was determined. Seeds which showed evidence of life (i.e. normal and abnormal seedlings and fresh ungerminated seeds) were counted as viable seeds.

The method used in this study involved tagging open flowerheads progressively and harvesting all tagged seedheads on one date. It might be suggested that this results in different environmental factors operating during the early stages of pollination and fertilisation and during seed development. Alternatively the tagging of all seedheads on one day with harvesting of samples every 3 days might have been preferable. The decision to conduct the study using the progressive tagging method and single date harvest was made on the grounds of spread workload as the field trial described in Chapter 4 and the seed development study involving different flower colour catagories described in the present Chapter were also being carried out at the same time.

5.3 RESULTS

5.3.1 PLANT GROWTH AND REPRODUCTIVE DEVELOPMENT

5.3.1.1 Plant growth and development

Vegetative growth was slow during early plant establishment. By 40 DAS, plants were only 5 cm high and had 4.7 nodes. Stem then started to elongate and continued until 66 DAS before stem length became relatively constant (Figure 5.1). However, plant height continued to increase rapidly between 40-75 DAS due to the growth of lateral branches. After 75 days further increases in plant height were not significant and plant height remained relatively constant until harvest at an average of 66.5 cm (Figure 5.1).

Node numbers per plant increased to a maximum of 9.3 by 66 DAS. From this point the numbers of nodes on the main stem remained constant until harvest (Figure 5.2). The number of lateral branches increased rapidly from 5.5 at 40 DAS to 16.6 at 66 DAS. No further increase in branch number occurred thereafter (Figure 5.2).

5.3.1.2 Bud production

Flower buds started to appear about 48 DAS and the number increased slowly between 48-61 DAS. After 61 DAS, bud production per plant increased rapidly reaching a maximum of 8.2 at 72 DAS. From 72 DAS the number of buds produced decreased rapidly. By 87 DAS new bud production was low but continued until 96 DAS. Flower bud production occured over a total of 50 days (Figure 5.3) and the total number of buds produced per plant during this period was 55.8 (±6.3).

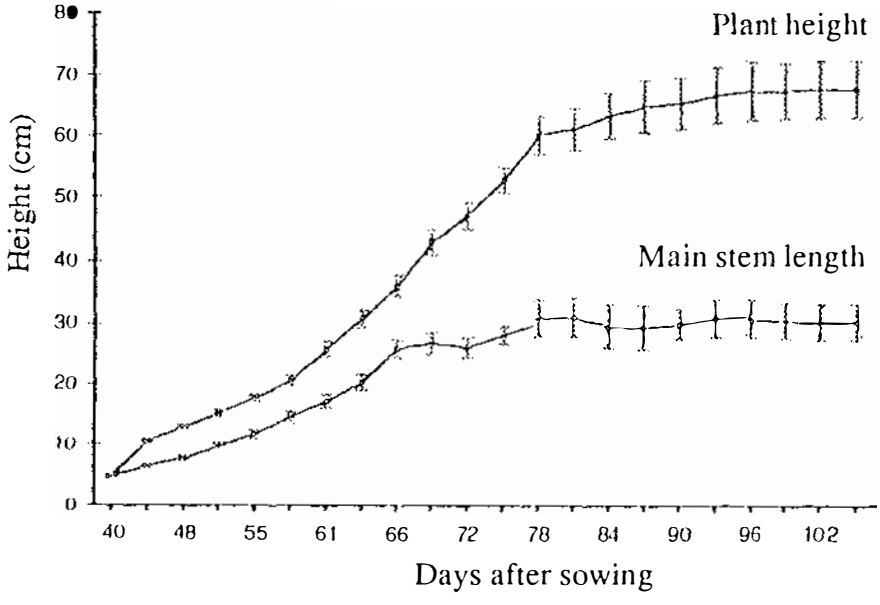

Figure 5.1 Plant height and main stem length at different days after sowing in dahlia cv. Unwins Dwarf Mixture.

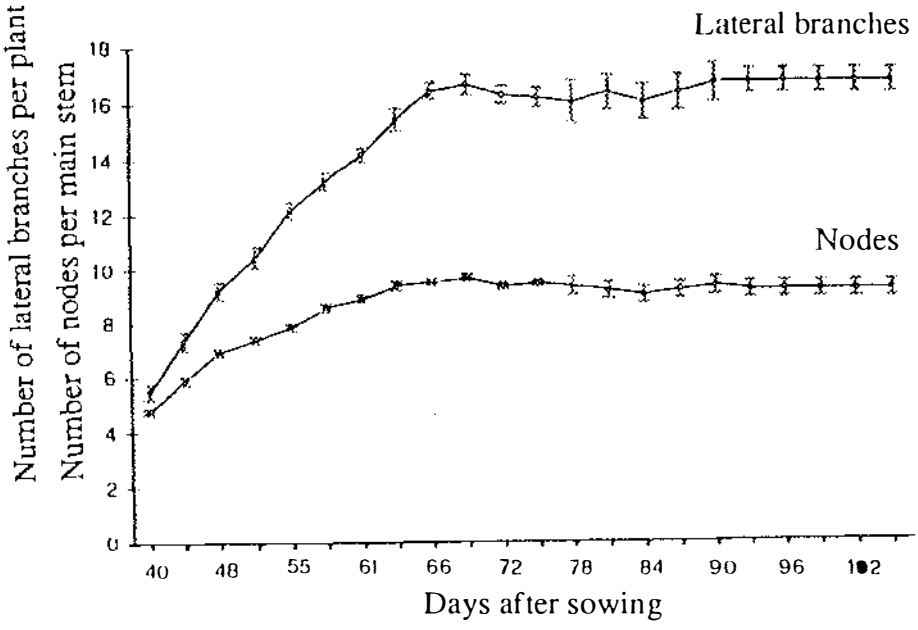

Figure 5.2 Number of nodes on the main stem and lateral branches per plant at different days after sowing in dahlia cv. Unwins Dwarf Mixture.

5.3.1.3 Flowering pattern

It took around 18 days for flower buds to develop colour and start to open. First flowering occured at 66 DAS. Flowering was slow for the first 9 days but became more rapid from 75 DAS and peak flowering was reached at 87 DAS. Flowering then continued but the numbers of flowers were reduced and less than one flower per plant was present after 99 days (Figure 5.3). The total flowering period extended over a period of more than two months from 66 to 132 DAS, and during this time a total number of flowers per plant of 46.9 (±3.06) was recorded.

5.3.1.4 Seedhead formation and maturation

Seedheads started to form at 75 DAS (9 days after first flowering) when the petals of the ray florets dropped and the receptacle bracts closed, resembling a pod. The numbers of seedheads increased rapidly after 78 DAS and reached a maximum by 96 days after sowing (Figure 5.3). A total of 42.8 seedheads per plant were recorded at 111 DAS. Initial seedhead colour was light-green and then gradually changed to green, yellow-brown and brown at maturity (see Plate 5.1 and also 5.3.2). At this stage the bracts dried quickly and the seedheads started to open. Seedheads started to mature at 111 DAS but the numbers were low until 120 DAS (Figure 5.3). The number of mature seedheads reached a maximum at 126 DAS (36 days after peak flowering), at which stage a total of 40.8 seedheads per plant was recorded.

5.3.1.5 Seed yield and yield components

Seed yield per plant increased from 111 DAS to reach a maximum of 3.67 g at 123 DAS and then declined to less than 1 g per plant by 129 days after sowing (Table 5.1). The average number of seeds per seedhead from the earlier harvested seedhead group (111-117 DAS) was 40.1 seeds which was similar to those produced in the middle seedhead group (39.3 seeds average from seedheads harvested during 120-129 DAS). The late-seedhead group (132-138 DAS) had the lowest seed number (21 seeds). The biggest seeds (9.97 g/1000 seeds) were recorded from the early seedheads and seeds became smaller in the later-formed seedheads.

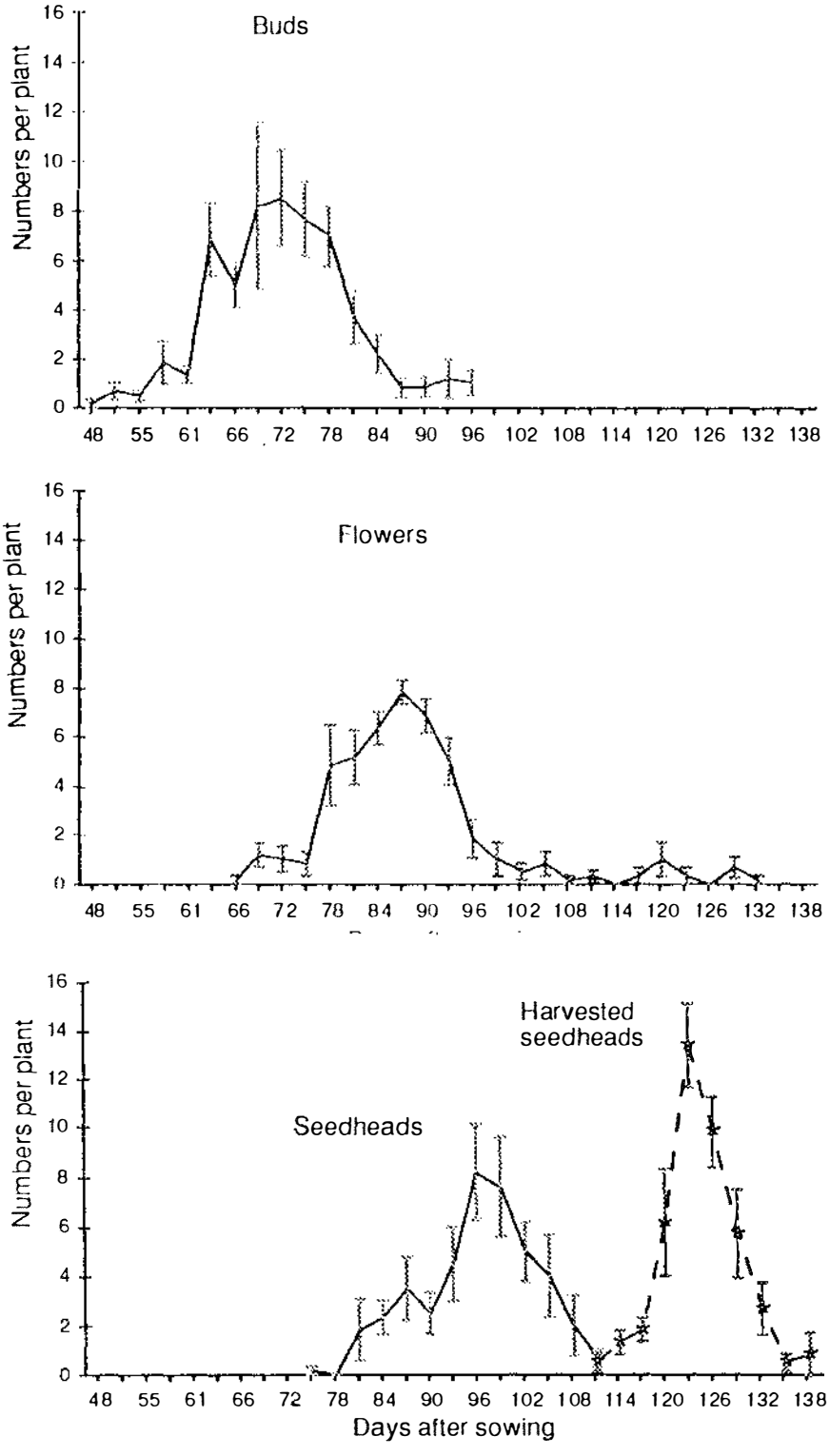

Figure 5.3 Pattern of bud, flower, seedhead and harvested seedhead production of Dahlia cv. Unwins Dwarf Mixture.

The average total seed yield per plant (from 6 plants) was 11.64 g. However these six plants also differed in flower colour and produced different results. The plant with pink flowers gave the highest seed yield (15.47 g) followed by orange, yellow-orange, bright red and yellow. Lowest seed yield (7.73 g) was from the deep-red-flowered plant (Table 5.2). Total seed yield per plant from these different flower colours was related to different seed yield components. The orange-flowered plant produced the greatest number of seedheads (Table 5.3) while the pink and bright red coloured plants produced the highest number of seeds per seedhead with an average of 46 seeds compared to 30-35 from the yellow, orange, yellow-orange and deep-red flowered plants (Table 5.4). Seed weight differences were also recorded (Table 5.5). Although the yellow-orange coloured plant produced fewer seedheads, seeds per plant and seeds per seedhead, it had the heaviest seeds (TSW = 10.4 g).

Table 5.1 Seed yield and yield components of dahlia cv. Unwins Dwarf Mixture.

Days after sowing	Mature seedheads per plant	Seeds per seedhead	1000 seed weight (g)	Seed yield (g/plant)
111	0.5 (0.34)	51.7 (11.20)	9.97(0.35)	0.24 (0.15)
114	1.0 (0.45)	27.0 (4.00)	8.03(0.56)	0.21 (0.15)
117	1.7 (0.33)	41.7 (4.78)	9.14(0.73)	0.71 (0.22)
120	6.2 (2.41)	39.3 (4.32)	8.43(0.68)	1.88 (0.62)
123	13.0 (1.57)	38.6 (3.13)	7.50(0.62)	3.67 (0.16)
126	10.2 (1.54)	37.9 (1.67)	7.51(0.60)	2.76 (0.39)
129	5.3 (1.76)	41.4 (2.14)	7.27(0.59)	1.54 (0.53)
132	2.5 (1.12)	30.4 (7.54)	6.87(0.64)	0.56 (0.27)
135	0.3 (0.21)	22.0 (18.00)	7.00(0.50)	0.05 (0.04)
138	0.2 (0.17)	14.0 (0.00)	5.71(0.00)	0.01 (0.01)

( ) standard error

Table 5.2 Seed yield (g plant^{-1}) from plants of dahlia cv. Unwins Dwarf Mixture with different flower colours.

Days after sowing	Flower colour							
	Pink	Orange	Yellow	Deep red	Bright red	Yellow orange	Mean	SE
111	0.78	0.00	0.00	0.00	0.65	0.00	0.24	(0.15)
114	0.00	0.92	0.19	0.16	0.00	0.00	0.21	(0.15)
117	0.51	0.70	0.23	0.20	1.03	1.60	0.71	(0.22)
120	3.70	3.75	0.91	0.25	0.79	1.89	1.88	(0.62)
123	3.62	3.90	4.21	3.68	3.03	3.57	3.67	(0.16)
126	2.52	3.19	1.44	2.27	2.90	4.26	2.76	(0.39)
129	3.54	0.00	2.61	1.17	1.31	0.60	1.54	(0.53)
132	0.80	0.85	0.07	0.00	1.64	0.00	0.56	(0.27)
135	0.00	0.03	0.26	0.00	0.00	0.00	0.05	(0.04)
138	0.00	0.00	0.08	0.00	0.00	0.00	0.01	(0.01)
Total	15.47	13.34	10.00	7.73	11.35	11.92	11.64	(1.09)

Table 5.3 Harvested seedhead numbers per plant from plants with different flower colours in dahlia cv. Unwins Dwarf Mixture.

Days after sowing	Flower colour							
	Pink	Orange	Yellow	Deep red	Bright red	Yellow orange	Mean	SE
111	2.0	0.0	0.0	0.0	1.0	0.0	0.5	(0.34)
114	0.0	3.0	1.0	1.0	0.0	1.0	1.0	(0.45)
117	1.0	2.0	1.0	1.0	2.0	3.0	1.7	(0.33)
120	8.0	17.0	3.0	1.0	2.0	6.0	6.2	(2.41)
123	9.0	16.0	13.0	19.0	10.0	11.0	13.0	(1.57)
126	9.0	15.0	4.0	12.0	9.0	12.0	10.2	(1.54)
129	12.0	0.0	8.0	6.0	4.0	2.0	5.3	(1.76)
132	3.0	4.0	1.0	0.0	7.0	0.0	2.5	(1.12)
135	0.0	1.0	1.0	0.0	0.0	0.0	0.3	(0.21)
138	0.0	0.0	1.0	0.0	0.0	0.0	0.2	(0.17)
Total	44.0	58.0	33.0	40.0	35.0	35.0	40.8	(3.81)

Table 5.4 Seed numbers per seedhead from plants with different flower colours in dahlia cv. Unwins Dwarf Mixture.

Days after sowing	Flower colour					
	Pink	Orange	Yellow	Deep red	Bright red	Yellow orange
111	40.5	0.0	0.0	0.0	63.0	0.0
114	0.0	35.0	23.0	23.0	0.0	0.0
117	55.0	43.0	28.0	28.0	53.0	43.3
120	57.6	32.7	37.3	45.0	35.0	28.0
123	51.0	37.1	38.4	30.4	43.0	31.4
126	37.3	34.1	44.3	33.7	40.9	36.8
129	40.7	0.0	41.6	36.5	50.0	38.0
132	40.7	35.5	8.0	0.0	37.3	0.0
135	0.0	4.0	40.0	0.0	0.0	0.0
138	0.0	0.0	14.0	0.0	0.0	0.0
Mean	46.1	31.6	30.5	32.8	46.0	35.5
SE	2.65	2.6	4.33	3.1	3.73	2.66

Table 5.5 Thousand seed weight from plants with different flower colours in dahlia cv. Unwins Dwarf Mixture.

Days after sowing	Flower colour					
	Pink	Orange	Yellow	Deep red	Bright red	Yellow orange
111	9.6	0.0	0.0	0.0	10.3	0.0
114	0.0	8.8	8.3	7.0	0.0	0.0
117	9.3	8.1	8.2	7.1	9.7	12.3
120	8.3	6.7	8.1	7.1	8.8	11.3
123	7.8	5.8	7.8	6.4	7.0	10.3
126	7.5	6.2	8.1	5.6	7.9	9.6
129	7.4	0.0	7.8	5.3	6.6	8.5
132	6.6	6.0	8.8	0.0	6.3	0.0
135	0.0	7.5	6.5	0.0	0.0	0.0
138	0.0	0.0	5.7	0.0	0.0	0.0
Mean	8.1	7.0	7.2	6.4	7.7	10.4
SE	0.41	0.43	0.34	2.62	0.54	0.66

5.3.2 SEED DEVELOPMENT

5.3.2.1 Change in seedhead colour

Flowering started from the opening of the florets around the outside of the capitulum and continued with sequential opening through to the innermost florets. It took around 6 days to complete this process before the petals of the ray florets wilted and dropped. The receptacle bracts then closed back, and a flower head became a seedhead from 9 DAF onwards (Plate 5.1, stage 3). At this stage the colour of the seedhead was green-yellow. Seedheads increased in size with time, and their colour gradually changed to yellow-brown (Plate 5.1, stage 4). At 42 DAF, seedheads became brown in colour and started to open as the outer part of the seedhead dried-out (Plate 5.1, stage 5). The scale-like bracteoles which arose from the receptacle interspersed with the seeds became loose as the seeds continued to ripen (Plate 5.1, stage 6). The seeds started to shed after 42 DAF and were totally shed from the seedheads at 54 DAF.

5.3.2.2 Change in seed colour

The pollinated flower heads started to develop into seedheads by shedding all their petals at 5-6 DAF. At this stage the seeds were white in colour and gradually changed to grey at 12 DAF, before becoming black by 15-24 DAF and light-brown by 27-30 DAF. After 30 DAF, the seed colour became darker and changed to dark-brown when the seeds were fully ripe (42 DAF) (Plate 5.1).

5.3.2.3 Change in seed weight

Seed fresh weight increased rapidly between 6-12 DAF and continued to increase slowly until 36 DAF before gradually decreasing (Figure 5.4). Seed dry weight gradually increased and reached a maximum of 0.65 g/100 seeds at 45 DAF. However, seed dry weights between 33-54 DAF were not significantly different (Figure 5.4).

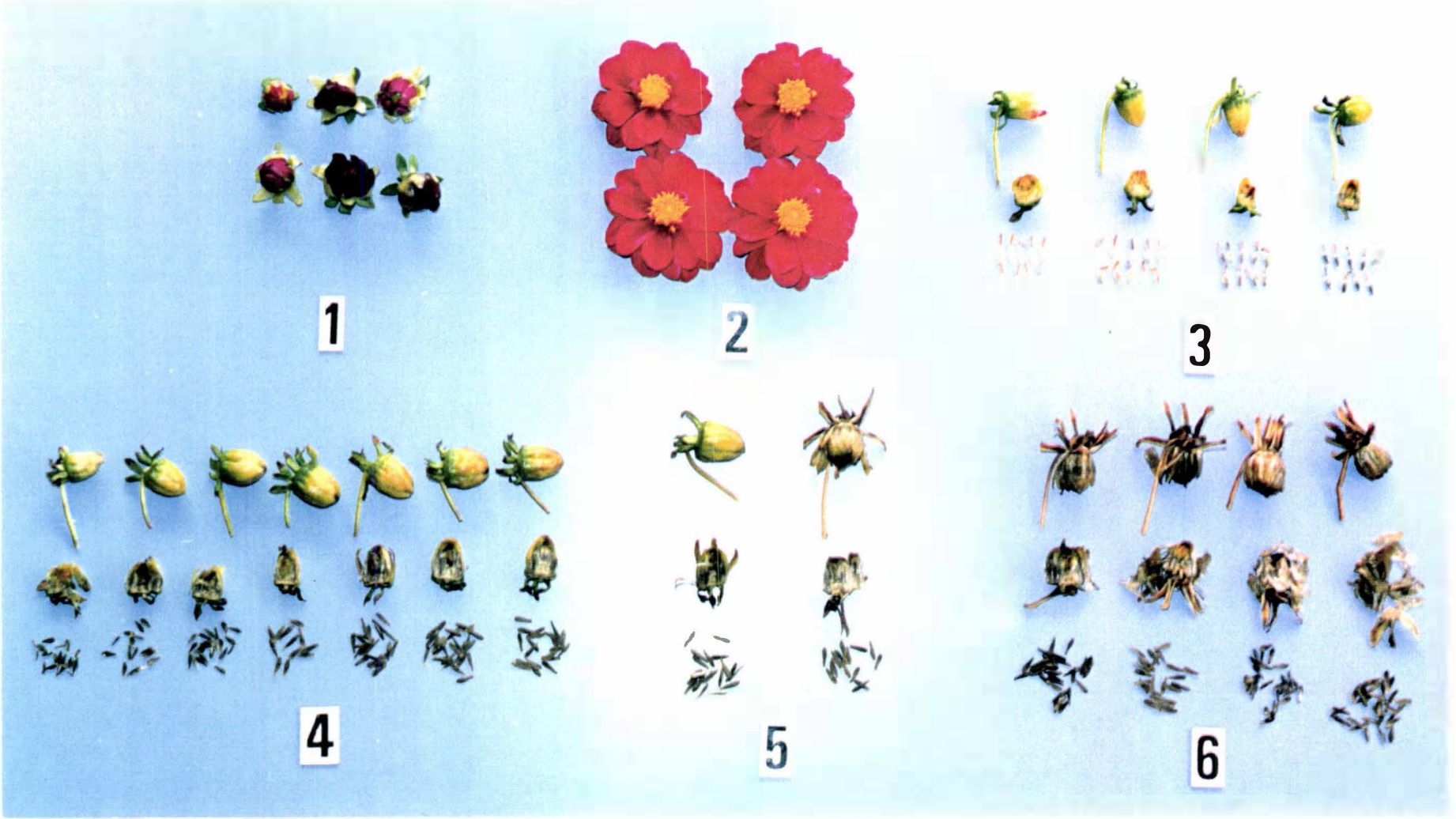

Plate 5.1 Stages of development of dahlia seedheads from flowering to maturity.
1 = Opening buds (1 day)
2 = Open flowers (3 days after flowering; DAF)
3 = 6,9,12,15 DAF
4 = 18,21,24,27,30,33,36 DAF
5 = 39,42 DAF
6 = 45,48,51,54 DAF

5.3.2.4 Seed moisture content

Seed moisture content fell from around 85 % at 15 DAF at a rate of around 1.0 % per day until it reached 65 % at 36 DAF. Subsequently, seed dehydration increased to a rate of around 1.6 % per day and the rate of loss dropped rapidly after 48 DAF. At 45 DAF when the seedheads were open and a few seeds had started to shed, the seed moisture content was approximately 43 %. The moisture content had fallen to 9 % at 54 DAF when shedding was complete.

5.3.2.5 Seed germination and viability.

Some seeds were viable as early as 9 DAF and as seed development continued, seed viability increased to nearly 90 % over the next 12 days (Figure 5.4).

Seed germination increased rapidly between 9 and 24 DAF, and then more gradually to a maximum at 33 DAF. Seed germination capacity after this stage was relatively constant at 91-93 % (Figure 5.4). During germination testing, fresh ungerminated seeds and abnormal seedlings with no root, no shoot or decayed seedlings were recorded. These effects were a particular feature of immature seeds.

5.4 DISCUSSION

5.4.1 REPRODUCTIVE DEVELOPMENT

Results from this experiment agree with the report by Philipson (1948) in *Dahlia gracilis* that axillary buds do not remain dormant until the apex of the main axis is committed to flowering, but develop shortly after they are formed below the stem apex. In this experiment, 5-6 lateral branches were already present at 40 DAS when dahlia plants were only 5 cm high. As these buds grew out into leafy shoots, the habit of the plant was that of a pyramid of ever-increasing size. The buds of dahlia did not appear to be restrained, each growing as it was formed and thus reaching the flowering condition in basipetal sequence down the secondary branches, and in a similar sequence down the tertiary branches (Philipson, 1948).

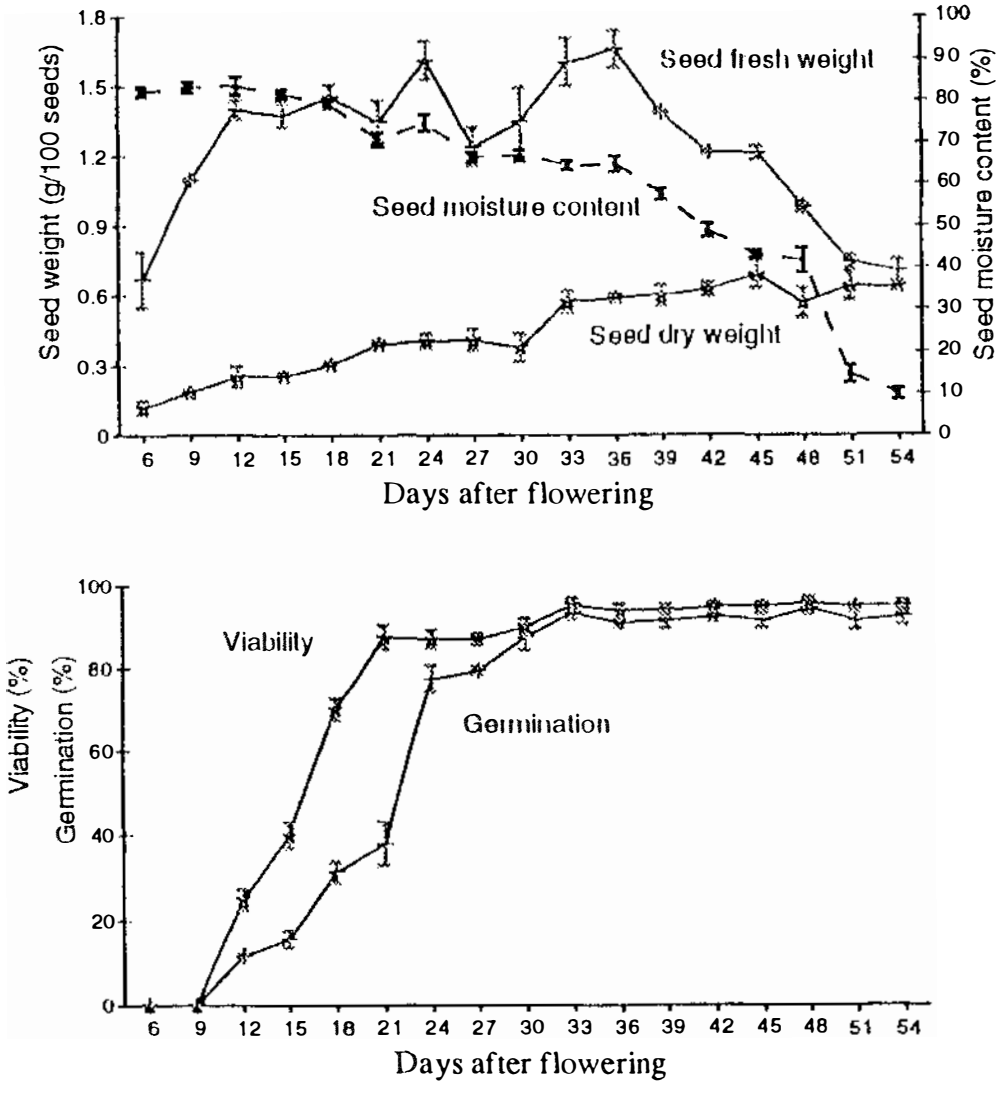

Figure 5.4 Change in seed fresh weight, seed dry weight, seed moisture content, germination and viability of dahlia cv. Unwins Dwarf Mixture.

There may therefore be competition in dahlia, either between vegetative and reproductive sites, or within reproductive growth, as abortion of reproductive structures occurred at various development stages. Results from the production pattern of buds, flowers and seedheads showed that 8.9 buds per plant aborted or failed to flower (15.9 % of the total of 55.8 buds produced), 4.1 flower heads failed to form a seedhead (7.3 %) and 2.0 seedheads (3.6 %) were lost because seed was already shed before the next harvest (3 day interval). Most abortion occurred in early produced buds. These may have aborted because they were developing at the same time as the rapid growth of both the main stem and lateral branches between 48-66 DAS. Buds produced between 66-78 DAS may also be affected as they may have to compete with lateral branch growth and early flower development. The cause of this bud abortion is not known, but competition for assimilate may be implicated. Reduced partitioning of assimilate to the reproductive sinks (particularly following competition between young flower buds and vegetative apices, developing leaves, fruits or storage organs) may be reflected in flower bud abortion when the supply of essential assimilate is inadequate. Similar responses have been reported in *Rosa species* (roses; Mor and Halevy, 1979), in *Lycopersicon esculentum* (tomato; Monselise and Goldschmidt, 1982), in *Glycine max* (soybean; Chanprasert, 1988) and in *Callistephus chinensis* (China aster; Phetpradap, 1992). Competition between plant parts, particularly flowers and developing seeds, has long been known and used in horticultural management. For exhibition dahlia bloom production, Hammett (1980) recommended that dahlia blooms should be removed when their disc florets are clearly visible and before any florets start to fall, to prevent competition between seeds developing in the older blooms, and vegetative growth and further flowering. After removal of spent flowers down each stem, nodes are stimulated into growth and new flowers soon replace those which have been removed. This practice is also used for tidying the plants, leaving only buds and fresh blooms on them, and prevents spent florets from falling onto the foliage. This eliminates a source for the establishment of fungal infection caused by *Botrytis* and *Sclerotinia* (Hammett, 1980).

The results from this experiment also showed that 7.3 % of flowers failed to form seedheads. This may be due again to a lack of assimilate, or because of

pollination or fertilization problems such as self-incompatibility. However the causes are not known, and like bud abortion, need further investigation.

The total flowering period extended for more than two months from 66 to 132 DAS (Figure 5.3). Although the flowering period was long, flowers formed during a period of around 20 days (75-96 DAS) contributed over 80 % of the total flowers produced. Early (before 75 DAS) and later (after 96 DAS) produced flowers together contributed less than 20 % of the flower population. This shows that although dahlia has a very long flowering period, most flowers are produced over a comparatively short period of time. Thus any treatments (i.e. PGR's) that confer advantage to only the first flowers, and are not effective at peak flowering, fail to show overall improvement in seed yield as the majority of the flowers are not altered.

Another interesting point is that although the flowering period and subsequent seedhead formation was long, contracted seedhead maturation occurred, i.e. early seedheads took a longer time to mature (45 days), while later seedhead maturation was accerelated which resulted in seedheads which ripened much more evenly. It is possible that these early seedheads were affected by shading, as they were situated in the bottom layer of the canopy. In contrast late produced seedheads were always at the top part of the plant which received more light and had advanced seedhead maturity. Higher temperature may be another possible reason for the accelerated late seedhead maturation as seedhead maturation started on 21 January (when average monthly temperature was 18.0 °C) and continued to 22 February 1990 (20.1 °C).

5.4.2 Seed yield and yield components

Results for seed yield and yield components (Table 5.1) showed that seed yield was related to seedhead numbers rather than seed number or seed weight. Thus the uniformity of seedhead maturation was the most important factor for high seed yield production. It is also suggested that the optimum time for harvesting the maximum quantity of dahlia seed was from 120-129 DAS (33-42 DAF). During this period, the majority of mature seedheads were recorded and seed

number and seed weight were also relatively high. As seedhead maturation may also be affected by environmental conditions (Hill and Watkin, 1975; Hare and Lucas, 1984; Sukprakarn, 1985), a greater variability in seedhead maturation would be expected under field grown conditions due to a greater environmental fluctuation.

Total seed yield per plant from different flower colours was related to different yield components. The plant with pink flowers showed the greatest seed yield (15.47 g/plant) which resulted from more harvested seeds per plant, more seeds per seedhead and heavier TSW. Conversely, the plant with deep-red coloured flowers showed the lowest yield (7.73 g) as a result of fewer harvested seeds per plant, fewer seeds per seedhead and lower seed weight. These differences in seed yield and yield components between the sample plants with different coloured flower may be due to several reasons. One reason for this extreme variation in plant growth (i.e. flower or seedhead numbers and seed weight) is the fact that this species has the complex genetic make-up of any hybrid which combines various specific characters brought together during the descent of the genus *Dahlia* from a primeval stock, coupled with multiplication of chromosome numbers (Emsweller, 1961). As dahlia is self-sterile, cross pollination is enforced. Another possible reason for the difference in seed numbers may be that the flower colours may differ in their attractiveness to pollinating insects, particularly bees, which were observed as the major pollinators at this site. Generally bees prefer blue and violet, are indifferent to yellow and seem to avoid scarlet. Scarlet sweet peas mingled with blue are left unvisited, while the latter swarms with bees (Meeuse, 1961). However, Mogford (1978) demonstrated that in fact bees are attracted by the ultraviolet light which the flower reflects and not by the colour (both man and bees see coloured flowers in a different way). Red poppies were shown to attract bees by the ultraviolet light which the poppies reflect, and not by the red petal colour (Meeuse, 1961). In the present experiment, it is possible that dahlias with pink or bright red flower colour may have attracted bees in the same way as red poppies which thus resulted in higher seed numbers per seedhead. In contrast, the deep red colour of this cultivar and the white colour of cv. Figaro White (Chapter 3B) may not be attractive to bees. However, this suggestion needed further experimental confirmation. The plants of Unwins Dwarf Mixture chosen for use in the flower colour study (Table 5.2) included six

different colours. It would have been useful to have had the opportunity to include white flowers in this colour range in an attempt to obtain more information on the problems encountered with the white flowered cultivar (Figaro White) in Chapter 3B. Unfortunately, although white flowered plants are occassionally produced in Unwins Dwarf Mixture no such plants occurred in the present crop. It is also possible that as only one plant of each flower colour was used to determine seed yield, the results are a result of random variation and therefore may not be repeatable. This also requires further investigation.

5.4.3 SEED DEVELOPMENT

Seed development results in this study showed that seed dry weight increased up to 33 DAF before remaining relatively constant through the remainder of the seed development sequence. Changes in seed weight of dahlia during seed development follow three distinct phases, which are: development of the embryo; accumulation of food reserves; and ripening stage, as described by Thomson (1979) and similar to those previously reported in *Medicago sativa* (Kowithayakorn and Hill, 1982) and in other flower crops (STC, 1986; Phetpradap, 1992). In dahlia, the growth stage involved the period up to 12 DAF. This stage is marked by an increase in both seed size and seed weight due to rapid cell division in both the embryo and cotyledons (Hyde, 1950). Seeds at this stage were small and soft, white or greyish-white in colour and the moisture content was over 80 %. Seedheads were green-yellow and were gradually swelling. The food reserve accumulation stage occurred from 12-33 DAF. During this second stage of development, the dry weight of seed increased around three times and the moisture content fell to about 63 %. Seed was enlarged and became hard, the colour gradually changing to dark-grey and then to light brown at the end of this stage. Maximum germination and viability were also obtained at the end of this food reserve accumulation stage. Seedhead enlargement was also evident with the yellow colour becoming slightly brown and greenness being gradually lost (Plate 5, stage 4). The time taken for the third stage i.e. from seed maturity to seed ripeness, was 21 days, during which the seed dried from 63 % to 9 % SMC. Loss of moisture was accompanied by colour changes in the seedhead much more than in the seed (Plate 5, stage 4). While the brown seed only became darker, the

whole seedhead turned to a brown colour after 39 DAF and started to open (Plate 5, stage 5). Once the seedhead opened, seed moisture dropped drastically from 40 % to 14 % within 3 days and seeds were easily lost by shedding. Germination and seed viability remained constantly high.

These results indicate that the optimum harvest time for dahlia seeds at this site and in this season was between 33-42 DAF. At this time, seeds had reached physiological maturity (the point at which seed reaches maximum dry weight (Shaw and Loomis, 1950, Harrington, 1972)), had gained maximum germination and viability and seed loss was minimal. Earlier harvest may cause lower yield due to seed immaturity, a factor which has been noted as important in poor seed storage life (Thompson, 1936). Delay in harvesting may cause seed yield loss due to seed shedding, and reduced quality due to weathering. It is also suggested from this study that seedhead colour could be used as an important guide for deciding correct time of harvest. For maximum seed yield and quality, seedheads should be harvested when they stop swelling and the colour changes to brown but before they open. In India, Salunkhe *et al.* (1987) also reported that dahlia seedheads are harvested when they turn yellow, after which they are dried on canvas. Pod colour has also been recommended for use as a guideline for deciding harvest timing in *Lotus corniculatus* (Li and Hill, 1988) and *L. pedunculatus* (Hare and Lucas, 1984). However, seasonal weather conditions may also influence the onset of colour changes (Hill, 1971) and the time for seed development, particularly for the ripening stage (Thomson, 1979). Cool and moist weather conditions prolong the ripening stage as reported in *Medicago sativa* (Kowithayakorn and Hill, 1982). On the other hand, high temperature and low relative humidity hasten seed maturity and shattering in *Lactuca sativa* seed (Sukprakarn, 1985) and in *Lotus uliginosus* (Hare and Lucas, 1984). Therefore, the results of this study agree well with the suggestion by Hammett (1980) that in favourable climates (cool and dry) it is best to allow seed pods to ripen on the plant to minimize the cost of drying and seed damage because if harvested any earlier, seed moisture content is still very high (50-60%). However seeds are already viable before they are dry, so that if a period of wet weather occurs, the seeds may well sprout prematurely, while still in the seedhead, or may rot. Alternatively, frost may occur which damages seed which has not dried. Where such situations are likely to occur, the seedheads should be cut once they appear to have stopped swelling and removed from the field to dry.

5.5 CONCLUSION

The results from both experiments in this Chapter highlight the difficulty in accurately timing the best date for a single harvest of dahlia seed. Although seedhead maturity was contracted to 20 days from the total spread of flowering over 2 months, seed loss always occurred and is a major problem. Loss of dahlia seed was due to seed shedding and/or removal of immature seed during cleaning. Dahlia seeds should not be harvested before 33 DAF at which stage seeds have reached physiological maturity, but should not be left any longer than 42 DAF, as seedheads remained intact for only 9 days after physiological maturity before seeds begin to shed. From the potential harvestable seed yield in Table 5.1, the best time for harvesting dahlia seeds was at 120 DAS (33 DAF) because the largest proportion of seeds were already matured. On this day the maximum seed yield from a single harvest was 71.3 % of the total potential harvestable seed yield (8.31 g from 11.64 g). Seed yield loss due to shedding (10 %) and immature seeds (18.6 %) was still relatively low. Harvesting carried out prior to 120 days prevented seed loss due to shedding (3.9 %) but seed yield dropped to 53.8 % due to extremely high levels of immature seed (42.3 %). If harvesting was delayed for a further 3 days (to 123 DAS) some continued development of seed in late seedheads was achieved but maximum actual seed yield dropped to 68.5 %, seed loss due to shedding increased to 26.1 %, although immature seed levels were reduced (5.4%). A further 3 day delay (126 DAS) further deteriorated this situation. Although immature seed levels were minimized (0.5 %) seed yield dropped to 41.8 % and seed shedding increased to 57.6 %. However, this suggestion may be not always correct as the rate of seed development can be altered by environment (particularly temperature during the seed ripening stage).

CHAPTER 6

EFFECTS OF PACLOBUTRAZOL AND CHLORMEQUAT ON DAHLIA SEED YIELD AND DETERMINATION OF OPTIMUM HARVEST TIME.

6.1 INTRODUCTION

One of the most important problems arising from the previous experiments in this study related to the best time to harvest the crop. Harvest timing is critical if a single harvest is desired, particularly since dahlia seed crops do not ripen uniformly. Seeds in early formed seedheads had ripened and were ready to shed well before seeds in later formed seedheads, which were still developing. Delay in harvesting to allow these later seedheads to ripen may not give additional yield if seed loss due to shedding in the earlier seedheads is also high (Hill, 1973). The habit of dahlia plant growth is that of a pyramid of ever-increasing size (Philipson, 1948), and seedheads from flowers present within ±20 days of peak flowering constitute a large proportion of the seed crop. These seedheads are always easier to see as they are situated in the upper layer of the plant. Shedding losses from early seedheads situated in the lower parts of the plant canopy may be severe before they are observed, particularly when a harvesting decision is based on eye assessment.

Previous results (Chapter 3 A) showed that greater seed yields could be obtained by the application of paclobutrazol at 1.0 kg a.i. ha^{-1} when the terminal flower buds were visible, and from chlormequat applied at 1.5 kg a.i. ha^{-1} during stem elongation. However, seed yield responses were variable between different cultivars (Chapters 3A and 3B) and in different seasons and environmental conditions (Chapters 3A and 4). Paclobutrazol has been reported to delay seed maturity in *Lolium perenne* (Faulkner, 1981; Hampton, 1983; Hampton and Hebblethwaite, 1985a). As a result, Hampton (1983) showed that paclobutrazol treated plots were at a disadvantage if they were harvested at the same time as untreated plots. Wiltshire and Hebblethwaite (1990) also reported that seed yield of *Lolium perenne* following triapenthenol (also in the triazole group) application was significantly influenced by harvest timing. Triapenthenol significantly

increased seed yield as harvest was delayed primarily because the chemical delayed crop maturity and seed was shed from untreated plots. Since the optimum harvest time in PGR treated plants may be different from that of untreated plants, it was considered useful to investigate the effects of time of harvesting on seed yield of paclobutrazol and chlormequat treated plants.

The objective of this study was therefore to determine the effect of time of harvest on seed yield and quality of dahlia (cv. Unwins Dwarf Mixture) in untreated plants and then to determine whether PGR's changed this response.

6.2 MATERIALS AND METHODS

6.2.1 Experimental site

The experiment was conducted at the same site and adjacent to the area used in a previous experiment (Chapter 4). Soil preparation procedures and general management, unless otherwise stated, were the same as previously described (Chapters 3 and 4).

6.2.2 Plant materials and establishment

Seeds of dahlia cv. Unwins Dwarf Mixture were dusted with thiram (1g product (80% wettable powder) per 100 seeds) and direct field sown by hand on 10 December 1989. Approximately four seeds per hole were sown at a depth of 1 cm with a square hole spacing of 30 x 30 cm. Thinning to one plant per hole was done 21 days after sowing. Missing plants were replaced by transplanting seedlings of the same age from surplus seedlings planted near to the experimental plot.

6.2.3 Treatments and experimental design

The experiment utilised a split plot design with three replicates. Main plots were plant growth regulators (PGR's) as follows:

Control: untreated
Paclobutrazol: 1.0 kg a.i. ha^{-1} applied at the visible terminal flower bud stage (45 days after sowing, DAS) (24 January 1990).
Chlormequat: 1.5 kg a.i. ha^{-1} applied during stem elongation (60 DAS) (8 Febuary 1990).

The plot size was 3.5 x 4 metres. There were 154 plants per plot (11 plants/m^2). Each main plot was divided into five randomly assigned harvesting dates (subplots) as follows:

Harvest 1 : 36 days after peak flowering (DAPF) (17 April 1990)
Harvest 2 : 42 days after peak flowering (DAPF) (23 April 1990)
Harvest 3 : 48 days after peak flowering (DAPF) (29 April 1990)
Harvest 4 : 54 days after peak flowering (DAPF) (5 May 1990)
Harvest 5 : 60 days after peak flowering (DAPF) (11 May 1990)

Statistical analysis was carried out using the SAS program (SAS, 1988). Treatment mean comparisons are presented using Least Significant Differences with 5 % probability. Analyses of varience are presented in Appendices 6.1-6.11.

6.2.4 Data collection

Unless otherwise stated, definitions and methods of plant measurement used in this experiment were the same as have been previously described (Chapters 3 and 4).

6.2.4.1 Flowering pattern

The total number of flower heads per plant was counted twice weekly on three plants per plot between 12 March-8 April 1990. These plants had been selected at random and identified by means of a numbered cane placed beside each plant. Newly opened flowers were calculated by deducting the total flowers present at the previous count, to establish flowering pattern.

6.2.4.2 Seed yield and yield components

Samples for seed yield determination were taken from 9 plants in each plot on each of the 5 dates. At each harvest, the number of buds, flowers, and seedheads were counted. All seedheads were also removed and then separated into:

mature seedheads: seedheads green or yellow-brown in colour before beginning to open (Plate 6.1 A); average SMC was 63 %.

ripe seedheads: brown seedheads at all stages from starting to open to already fully opened at harvest (Plate 6.1 B); average SMC was 38 %.

empty seedheads: seedheads which contained no seeds.

Twenty-five seedheads from each group were randomly sampled and used to determine the number of seeds per seedhead and thousand seed weight (TSW). All remaining seedheads were dried separately at ambient temperature for 2-3 weeks before being threshed and cleaned. Seed yields from ripe and mature seedheads were determined separately and all data were corrected to 0 % SMC.

All seeds from each treatment (ripe and mature) and each replicate were mixed and randomly sampled for germination and viability testing on 6 August 1990. All tests and evaluations were done according to the prescription in the ISTA Rules (1985) as already described (Chapter 3).

6.3 RESULTS

6.3.1 Flowering pattern.

Although first flowering occurred at 60 days after sowing (DAS), flowering patterns during 82-109 DAS were similar for all treatments (Figure 6.1) with peak flowering at 92 DAS. The number of flowers produced by chlormequat treated plants was always greater than in other treatments, although the differences were generally not significant. Paclobutrazol tended to restrict the production of late flowers (Figure 6.1).

6.3.2 Total number of seedheads per plant

The number of total harvested seedheads (ripe, mature and empty), flower heads and buds at each harvesting date are presented in Table 6.1. All treatments had a similar pattern of seedhead development. The number of ripe seedheads increased as harvest time was delayed while mature seedheads, flowers and buds decreased. Sprouting seedheads were observed only at the last two harvests (54 and 60 DAPF) (Plate 6.2).

There were no significant differences in the mean number of seedheads per plant among PGR applications (Table 6.2, Appendix 6.1). However, the mean number of seedheads per plant at the last harvest (60 DAPF) was significantly higher than for plants harvested at the first harvest (36 DAPF). No significant differences occurred with time of harvest from the second (42 DAPF) to the last harvest (60 DAPF).

Control plants harvested at 60 DAPF had significantly higher seedhead numbers than plants at 36, 42 and 54 DAPF but not at 48 DAPF. No significant differences for time of harvest were recorded within plants treated either with paclobutrazol or chlormequat.

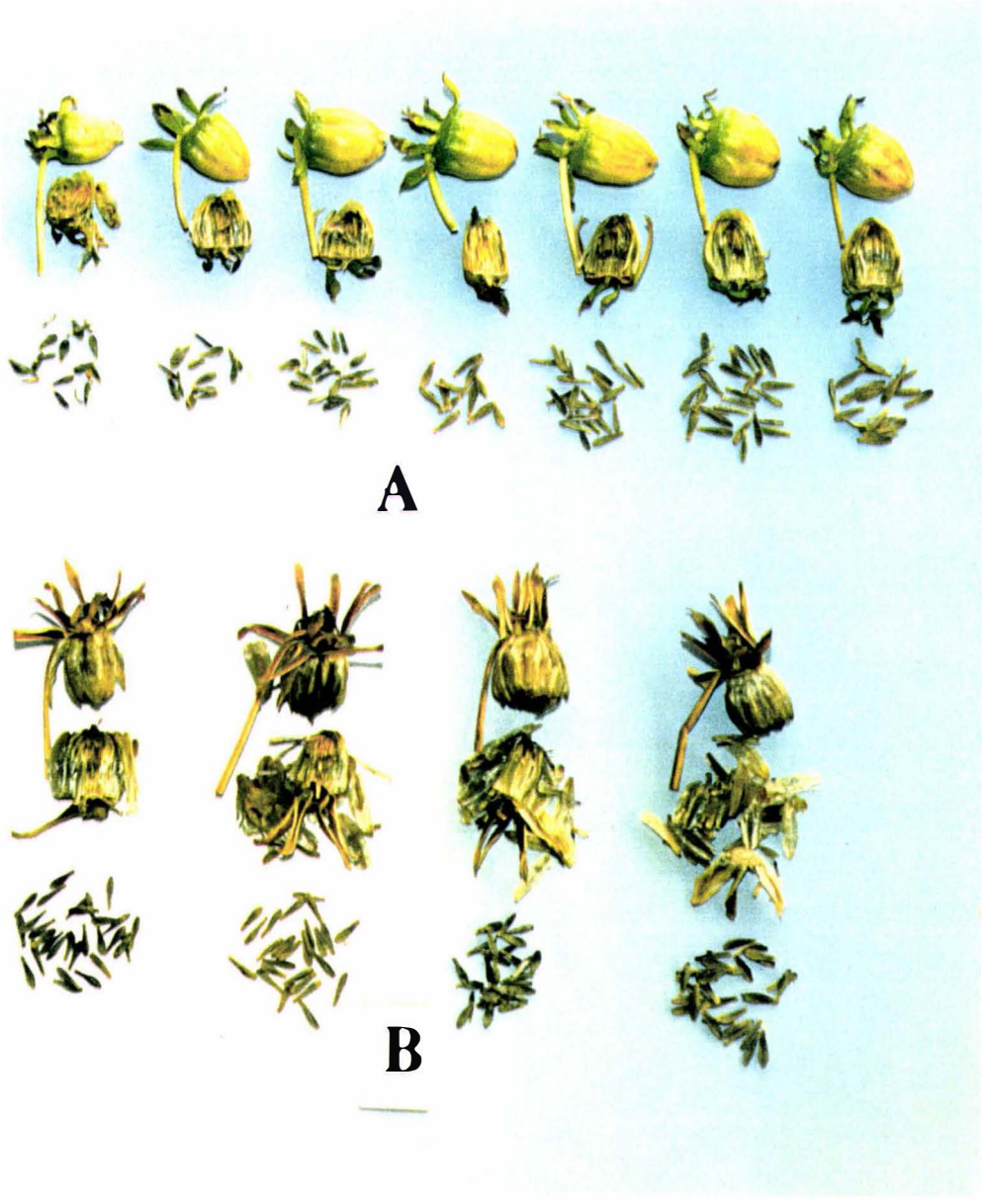

Plate 6.1 Appearance of seedheads at harvest.
A = mature seedheads.
B = ripe seedheads.

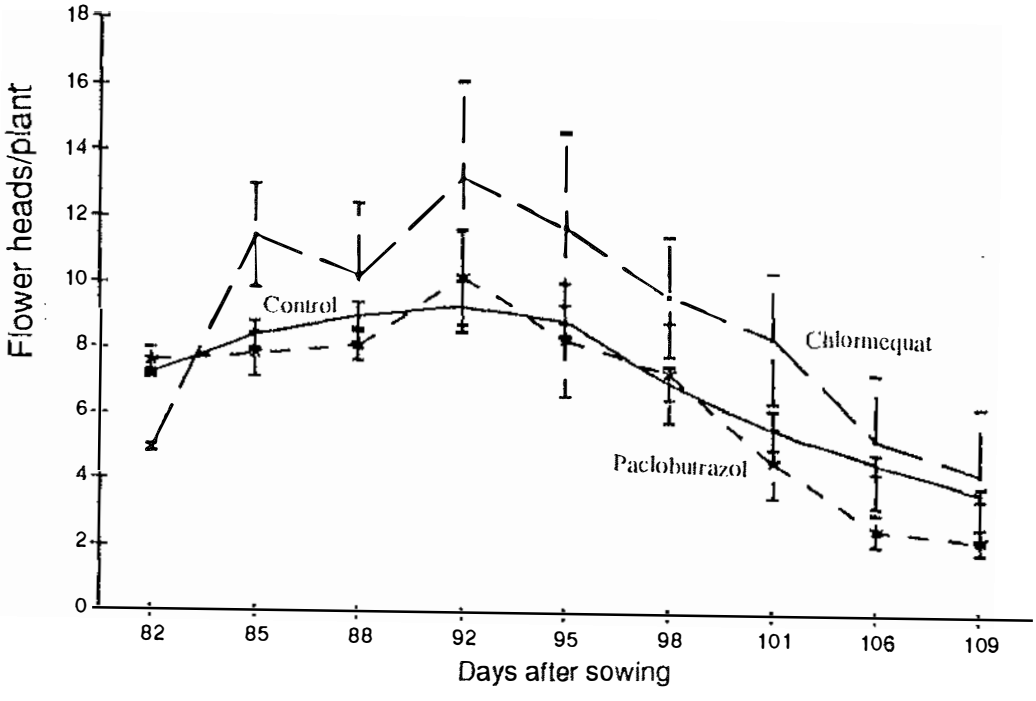

Figure 6.1 Effect of plant growth regulators on flowering pattern.

Table 6.1 Number of seedheads (ripe, mature and empty), flowers and buds per plant at each harvest.

Treatment	Days after peak flowering				
	36	42	48	54	60
Control					
Ripe seedheads	5.3 (2.2)	11.3 (0.3)	16.3 (2.5)	17.1 (2.9)	26.1 (2.5)
Mature seedheads	28.0 (3.0)	23.9 (0.6)	20.8 (2.8)	18.7 (0.6)	17.0 (1.8)
Empty seedheads	2.3 (0.9)	1.9 (0.4)	2.5 (1.8)	2.3 (0.6)	4.4 (1.3)
Flowers	6.2 (1.4)	3.3 (0.3)	1.7 (0.5)	0.7 (0.3)	0.0 (0.0)
Buds	2.7 (1.0)	1.7 (0.3)	1.1 (0.3)	0.7 (0.3)	0.0 (0.0)
Paclobutrazol					
Ripe seedheads	4.8 (0.5)	15.8 (2.3)	15.3 (1.7)	16.4 (1.0)	18.9 (1.1)
Mature seedheads	36.2 (0.8)	25.2 (2.4)	24.7 (3.3)	21.7 (4.9)	19.1 (2.0)
Empty seedheads	0.9 (0.5)	1.1 (0.3)	1.2 (0.1)	1.2 (0.5)	2.4 (0.7)
Flowers	4.7 (0.8)	1.8 (0.7)	0.9 (0.3)	0.1 (0.1)	0.0 (0.0)
Buds	2.0 (0.1)	1.0 (0.2)	1.0 (0.6)	0.4 (0.1)	0.0 (0.0)
Chlormequat					
Ripe seedheads	4.6 (1.2)	8.9 (1.1)	11.6 (0.7)	18.8 (0.6)	21.0 (0.5)
Mature seedheads	31.2 (3.6)	32.0 (2.1)	25.9 (2.7)	23.8 (2.7)	22.4 (0.4)
Empty seedheads	2.4 (0.3)	4.8 (0.9)	2.9 (0.7)	0.9 (0.4)	1.1 (0.4)
Flowers	6.6 (1.0)	2.9 (0.7)	1.1 (0.4)	0.3 (0.0)	0.5 (0.2)
Buds	2.6 (0.5)	1.9 (0.9)	1.1 (0.5)	0.3 (0.2)	0.0 (0.0)

( ) = standard error

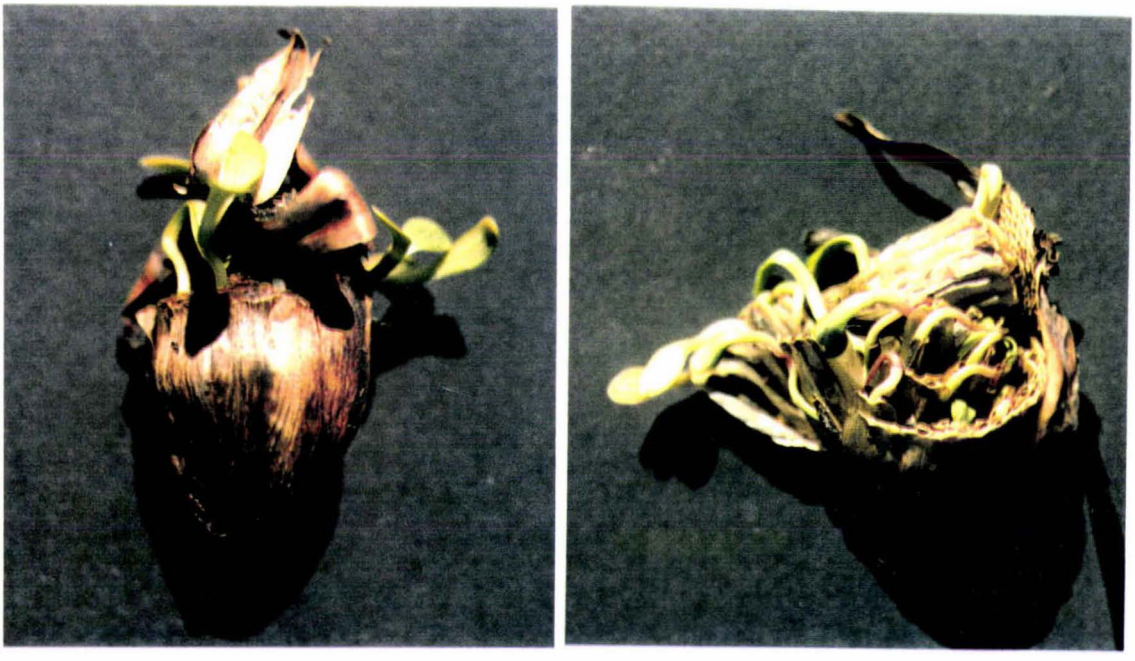

Plate 6.2 Seed sprouting in the head.

Table 6.2 Effects of PGR's on total seedheads per plant at each harvest.

Treatment	Days after peak flowering					
	36	42	48	54	60	PGR means
Control	35.6	37.1	39.7	38.3	47.8	39.7
Paclobutrazol	41.9	42.1	41.2	39.7	40.6	41.1
Chlormequat	38.2	45.7	40.4	44.0	44.8	42.6
Time means	38.6	41.6	40.4	40.7	44.4	41.1

%CV = 11.78

LSD (P<0.05) for comparing PGR means	= 3.65
LSD (P<0.05) for comparing time means	= 4.71
LSD (P<0.05) for comparing times within a PGR treatment	= 8.17
LSD (P<0.05) for comparing PGRs, either at the same or at different times (PGR x Time)	= 6.08

At the first harvest (36 DAPF), paclobutrazol significantly increased the total number of seedheads per plant. Chlormequat also significantly increased total seedhead number at 42 DAPF. However at the fifth harvest (60 DAPF), paclobutrazol had a significantly lower number of seedheads per plant than the control.

6.3.3 Number of mature seedheads

PGR's significantly increased the mean number of mature seedheads (Table 6.3, Appendix 6.2). The highest number of mature seedheads were recorded at the first harvest (36 DAPF) but they were then significantly reduced as the time of harvest was delayed, so that the lowest number of mature seedheads was recorded at the last harvest (60 DAPF). However this did not differ from the fourth harvest (54 DAPF).

The highest number of mature seedheads from the control treatment was recorded at the first harvest (36 DAPF) but this did not differ from 42 and 48 DAPF. The lowest number of mature seedheads was recorded at the last harvest (60 DAPF) but did not differ from the fourth harvest (54 DAPF). Chlormequat treated plants had the highest number of mature seedheads at the second harvest (42 DAPF) but this did not differ from 36 or 48 DAPF. As harvest time was delayed the number of mature seedheads decreased and the lowest number was also recorded at the last harvest (60 DAPF).

For plants treated with paclobutrazol, the highest number of mature seedheads was also recorded at the first harvest (36 DAPF) and the lowest number was recorded at the last harvest (60 DAPF). However, no differences in the number of mature seedheads were recorded among the plants harvested from the second to the last harvest.

Paclobutrazol significantly increased the number of mature seedheads at the first harvest (36 DAPF), while chlormequat increased them at 42 and 60 DAPF. No significant differences among the PGR treatments were recorded at 48 and 54 DAPF.

Table 6.3 Effects of PGR's on number of mature seedheads at each harvest.

Treatment	Days after peak flowering					
	36	42	48	54	60	PGR means
Control	28.0	23.9	20.8	18.7	17.0	21.7
Paclobutrazol	36.2	25.2	24.7	21.7	19.1	25.4
Chlormequat	31.2	32.0	25.9	23.8	22.4	27.1
Time means	31.8	27.0	23.8	21.4	19.5	27.7

%CV = 17.78

LSD (P<0.05) for comparing PGR means	= 2.86
LSD (P<0.05) for comparing time means	= 4.27
LSD (P<0.05) for comparing times within a PGR treatment	= 7.40
LSD (P<0.05) for comparing PGRs, either at the same or at different times (PGR x Time)	= 5.31

6.3.4 Number of ripe seedheads

There were no significant differences in the mean number of ripe seedheads per plant among PGR applications (Table 6.4, Appendix 6.3). However, the mean number of ripe seedheads was significantly increased when the harvest time was delayed. The lowest number was recorded at the first harvest (36 DAPF) and the highest was at the last harvest (60 DAPF).

The time of harvest also affected the number of ripe seedheads within the treatments. The lowest number of ripe seedheads from the control treatment was found at the first harvest (36 DAPF), and numbers significantly increased as the harvesting time was delayed, while the highest number was recorded at the last harvest (60 DAPF). However, no significant differences were recorded at 48 and 54 DAPF. Chlormequat-treated plants showed similar results to the control, the lowest number of ripe seedheads being recorded at 36 DAPF and the highest at 60 DAPF, but this did not differ from 54 DAPF. For plants treated with paclobutrazol, the lowest number of ripe seedheads was also recorded at the first harvest (36 DAPF) and the highest number was recorded at the last harvest (60 DAPF). However, no differences in the number of ripe seedheads were recorded among the plants harvested from the second to the fourth harvest.

There were no significant differences among PGR treatments for the number of ripe seedheads from the first to the fourth harvests, but at the latest harvest (60 DAPF), both paclobutrazol and chlormequat significantly reduced the number of ripe seedheads.

Table 6.4 Effects of PGR's on number of ripe seedheads at each harvest.

Treatment	Days after peak flowering					
	36	42	48	54	60	PGR means
Control	5.3	11.3	16.3	17.1	26.1	15.2
Paclobutrazol	4.8	15.8	15.3	16.4	18.9	14.2
Chlormequat	4.6	8.9	11.6	18.8	21.0	13.0
Time means	4.9	12.0	14.4	17.4	22.0	14.1

%CV = 17.07

LSD (P<0.05) for comparing PGR means	= 4.65
LSD (P<0.05) for comparing time means	= 2.35
LSD (P<0.05) for comparing times within a PGR treatment	= 4.07
LSD (P<0.05) for comparing PGRs, either at the same or at different times (PGR x Time)	= 5.02

6.3.5 Seed number per seedhead

Paclobutrazol treated plants produced more seeds per seedhead than the control (Table 6.5, Appendix 6.4). Plants harvested at 36 DAPF had similar seed numbers per seedhead to plants harvested at 42 DAPF but significantly fewer than seedheads harvested at 48 or 54 DAPF. The greatest seed numbers per seedhead were recorded at the final harvest (Table 6.5).

The number of seeds per seedhead from the control treatment was increased when the harvesting time was delayed. Plants harvested at 36 and 42 DAPF had less seeds than at 48, 52 and 60 DAPF. The highest seed numbers per seedhead were recorded at the last harvest (60 DAPF).

Paclobutrazol also showed similar results to the control. Plants harvested at 36 and 42 DAPF had less seeds per seedhead compared to 48, 54 and 60 DAPF. The highest seed numbers per seedhead were also recorded at the last harvest. For plants treated with chlormequat, however, the first harvest (36 DAPF) had the lowest seeds while the highest seed numbers were recorded at both 54 and 60 DAPF.

No significant differences were recorded for the number of seeds per seedhead at 36 and 54 DAPF. However at 42, 48 and 60 DAPF, paclobutrazol significantly increased seed numbers per seedhead, but chlormequat increased them only at 42 DAPF.

6.3.6 Thousand seed weight (TSW)

No significant differences in mean thousand seed dry weight were recorded among PGR treatments (Table 6.6, Appendix 6.5). However, the mean TSW at the first harvest (36 DAPF) was significantly lighter than the second and third harvests (42 DAPF and 48 DAPF) (Table 6.6).

Table 6.5 Effects of PGR's on number of seeds per seedhead at each harvest.

Treatment	Days after peak flowering					
	36	42	48	54	60	PGR means
Control	42.8	38.8	47.8	47.7	52.2	45.9
Paclobutrazol	42.5	46.3	53.9	51.1	57.7	50.3
Chlormequat	42.4	46.0	45.3	48.4	48.4	46.1
Time means	42.6	43.7	49.0	49.1	52.8	47.4

%CV = 5.74

LSD (P<0.05) for comparing PGR means	= 3.10
LSD (P<0.05) for comparing time means	= 2.65
LSD (P<0.05) for comparing times within a PGR treatment	= 4.59
LSD (P<0.05) for comparing PGRs, either at the same or at different times (PGR x Time)	= 4.01

Table 6.6 Effects of PGR's on TSW at each harvest.

Treatment	Days after peak flowering					
	36	42	48	54	60	PGR means
Control	6.9	7.6	7.5	7.4	7.4	7.4
Paclobutrazol	6.8	7.3	7.4	7.2	7.2	7.2
Chlormequat	7.0	7.8	7.4	7.1	7.2	7.3
Time means	6.9	7.6	7.4	7.2	7.3	7.3

%CV = 6.27

LSD (P<0.05) for comparing PGR means	= 0.44
LSD (P<0.05) for comparing time means	= 0.44
LSD (P<0.05) for comparing times within a PGR treatment	= 0.77
LSD (P<0.05) for comparing PGRs, either at the same or at different times (PGR x Time)	= 0.62

No significant effects of time of harvest on TSW occurred in either the control or the paclobutrazol treatments. Chlormequat treated plants at first harvest (36 DAPF) were significant lighter than the second harvest (42 DAPF). However no significant differences for time of harvest were recorded from the second to the last harvest.

No significant differences among the treatment were recorded for TSW at each harvesting time.

6.3.7 Harvested seed yield

Paclobutrazol significantly increased mean harvested seed yield per plant (Table 6.7, Appendix 6.6). However, harvested seed yield varied with different time of harvest, the earliest harvest (36 DAPF) producing the lowest harvested seed yield while the latest harvest (60 DAPF) produced the greatest harvested seed yield. Plants harvested at 42, 48 or 54 DAPF did not differ significantly in yield (Table 6.7).

There were no significant differences for harvested seed yield from the control treatment from the first to the fourth harvests, but harvested seed yield was significantly increased at the last harvest (60 DAPF). For plants treated with paclobutrazol, the lowest harvested seed yield was recorded at 36 DAPF while the greatest was at the last harvest (60 DAPF). In chlormequat treated plants, the lowest harvested seed yield was recorded at the first harvest (36 DAPF), while the second harvest produced the greatest seed yield, but this did not differ from that at 48, 54 or 60 DAPF.

No significant differences among the treatments for harvested seed yield were recorded at the first (36 DAPF) and fourth harvest (54 DAPF). However, both paclobutrazol and chlormequat significantly increased harvested seed yield per plant at the second harvest (42 DAPF), while at the last harvest (60 DAPF), chlormequat significantly reduced harvested seed yield.

Table 6.7 Effects of PGR's on harvested seed yield (g/plant) at each harvest.

Treatment	Days after peak flowering					
	36	42	48	54	60	PGR means
Control	10.61	10.98	14.23	13.49	18.34	13.53
Paclobutrazol	12.05	14.25	16.57	14.78	16.88	14.91
Chlormequat	11.33	16.41	13.50	15.15	15.66	14.41
Time means	11.33	13.88	14.77	14.47	16.96	14.28

%CV = 15.65

LSD (P<0.05) for comparing PGR means	= 1.20
LSD (P<0.05) for comparing time means	= 2.17
LSD (P<0.05) for comparing times within a PGR treatment	= 3.77
LSD (P<0.05) for comparing PGRs, either at the same or at different times (PGR x Time)	= 2.60

6.3.8 Total cleaned seed yield

There were no significant differences in the mean total cleaned seed yield among PGR treatments (Table 6.8, Appendix 6.7). Lowest mean total cleaned seed yield was recorded at the first harvest (36 DAPF). However, total cleaned seed yields at subsequent harvests after 42 DAPF were not significantly different (Table 6.6). The lowest total cleaned seed yield from the control treatment was recorded at the first harvest but this did not differ from the second, third and fourth harvests, while the greatest was recorded at the last harvest. No significant harvesting time differences were recorded for paclobutrazol or chlormequat treatments.

No significant differences among treatments were recorded for the total cleaned seed yield at any one harvest time.

6.3.9 Cleaned seed yield from mature seedheads

Paclobutrazol significantly increased the mean cleaned seed yield of mature seedheads (Table 6.9, Appendix 6.8). However, plants harvested at the last harvest (60 DAPF) had a lower cleaned seed yield from mature seedheads. The greatest cleaned seed yield from mature seedheads was recorded at the first harvest but this did not differ from the second, third and fourth harvests.

The time of harvest did not affect cleaned seed yield from mature seedheads of the control treatment. For plants treated with paclobutrazol the greatest cleaned seed yield from mature seedheads was recorded at the first harvest but this did not differ from the second, third and fourth harvests. The lowest seed yield was recorded at the last harvest (60 DAPF). Similar results were also recorded from chlormequat treated plants; the latest harvest had the lowest cleaned seed yield from mature seedheads, while the highest was recorded at the second harvest. However no significant differences occurred in cleaned seed yield from mature seedheads between chlormequat treated plants harvested at 36, 42, 48 and 54 DAPF, and also between 54 and 60 DAPF.

At each harvesting time, paclobutrazol significantly increased cleaned seed yield from mature seedheads at the first (36 DAPF) and the fourth harvest (54 DAPF),

while chlormequat significantly increased yield only at the second harvest (42 DAPF). No significant differences were recorded at 48 and 60 DAPF.

6.3.10 Cleaned seed yield from ripe seedheads

No significant differences in the mean cleaned seed yield from ripe seedheads were recorded among PGR treatments (Table 6.10, Appendix 6.9). The lowest mean cleaned seed yield from ripe seedheads was recorded at the first harvest (36 DAPF). The second harvest (42 DAPF) was also lower than at 48, 54 and 60 DAPF. No differences in cleaned seed yield from ripe seedheads were recorded at 48 and 54 DAPF while the greatest seed yield was recorded at the last harvest (60 DAPF).

The different times of harvest affected cleaned seed yield from ripe seedheads from the control treatment. Plants harvested at the last harvest (60 DAPF) significantly outyield those harvested at 36, 42, 48 and 54 DAPF. The lowest seed yield was recorded from the first harvest (36 DAPF).

Paclobutrazol treated plants showed a similar result to the control. The greatest cleaned seed yield from ripe seedheads was recorded at the last harvest (60 DAPF) and the lowest was recorded at the first harvest (36 DAPF). Plants harvested at the second harvest (42 DAPF) also produced a lower cleaned seed yield from ripe seedheads than at 48, 54 and 60 DAPF. No significant differences between plants harvested at 48 and 54 DAPF, and between 54 and 60 DAPF occurred.

For plants treated with chlormequat, cleaned seed yield from ripe seedheads increased as the time of harvest was delayed. The greatest seed yield was recorded at the last harvest (60 DAPF) while the lowest was recorded at the first harvest (36 DAPF).

No significant differences among treatments were recorded for cleaned seed yield from ripe seedheads at any one harvest time.

6.3.11 Germination

Plants treated with chlormequat had a slightly increased mean percentage germination, when compared with plants treated with paclobutrazol and the untreated control (80.2-82.4 %) (Table 6.11, Appendix 6.10).

Time of harvest also affected the percentage germination. The highest mean percentage germination was recorded from the latest harvested plants (60DAPF) (Table 6.11). The second, third and fourth harvests (42, 48 and 54 DAPF) also produced a significantly higher percentage germination than the first harvest (36 DAPF).

Within the control treatment, the highest percentage germination was recorded from plants harvested at 60 DAPF but this did not differ from 42 and 48 DAPF. The lowest percentage germination was recorded at the first harvest (30 DAPF) but this did not differ from 54 DAPF. For paclobutrazol treated plants, the highest percentage germination was also recorded at 60 DAPF but did not differ from that at 42, 48 or 54 DAPF. The lowest percentage germination was also obtained from the first harvest (30 DAPF). Similar results were also recorded for chlormequat treated plants, the highest percentage germination being obtained at 60 DAPF but this did not differ from 42 and 54 DAPF. At 48 DAPF, the percentage germination was also lower than at 60 DAPF. The lowest pecentage germination was recorded at the first harvest (30 DAPF).

Lower germination percentages were recorded from both paclobutrazol and chlormequat at the third harvest (48 DAPF). However, no significant differences from the control were recorded at 36, 42, 54 and 60 DAPF.

6.3.3.12 Viability

There were no significant differences in the mean percentage seed viability between PGR treatments (Table 6.12, Appendix 6.11). The first and second harvests (36 and 42 DAPF) had a significantly lower viability when compared to the third harvest (48 DAPF). The highest percentage seed viability was recorded at the third harvest (48 DAPF) but this did not differ from the fourth or fifth harvests (54 and 60 DAPF).

No significant differences in seed viability were recorded for the time of harvest within the same treatment from the control, paclobutrazol or chlormequat treated plants.

No significant differences among the treatments within each time of harvest were recorded for seed viability percentage.

Table 6.8 Effects of PGR's on total cleaned seed yield (g/plant) at each harvest.

Treatment	Days after peak flowering					
	36	42	48	54	60	PGR means
Control	6.50	8.03	9.5	8.93	10.53	8.70
Paclobutrazol	8.40	10.10	11.13	11.88	9.40	10.18
Chlormequat	7.57	9.67	9.33	9.77	9.90	9.25
Time means	7.50	9.27	9.94	9.99	10.18	9.38

%CV = 22.15

LSD (P<0.05) for comparing PGR means	= 2.80
LSD (P<0.05) for comparing time means	= 2.02
LSD (P<0.05) for comparing times within a PGR treatment	= 3.50
LSD (P<0.05) for comparing PGRs, either at the same or at different times (PGR x Time)	= 3.36

Table 6.9 Effects of PGR's on cleaned seed yield (g/plant) from mature seedheads at each harvest.

Treatment	Days after peak flowering					
	36	42	48	54	60	PGR means
Control	5.10	5.13	4.87	4.90	3.50	4.70
Paclobutrazol	7.27	5.93	6.77	6.73	4.20	6.18
Chlormequat	6.37	7.33	6.33	5.57	3.77	5.87
Time means	6.24	6.13	5.99	5.73	3.82	5.6

%CV = 23.95

LSD (P<0.05) for comparing PGR means	= 1.48
LSD (P<0.05) for comparing time means	= 1.30
LSD (P<0.05) for comparing times within a PGR treatment	= 2.25
LSD (P<0.05) for comparing PGRs, either at the same or at different times (PGR x Time)	= 1.94

Table 6.10 Effects of PGR's on cleaned seed yield (g/plant) from ripe seedheads at each harvest.

Treatment	Days after peak flowering					
	36	42	48	54	60	PGR means
Control	1.4	2.9	4.6	4.1	7.0	4.0
Paclobutrazol	1.2	3.5	4.3	5.4	6.5	4.2
Chlormequat	1.2	2.3	3.0	4.2	6.1	3.4
Time means	1.3	2.9	4.0	4.6	6.6	3.8

%CV = 22.76

LSD (P<0.05) for comparing PGR means	= 2.12
LSD (P<0.05) for comparing time means	= 0.85
LSD (P<0.05) for comparing times within a PGR treatment	= 1.48
LSD (P<0.05) for comparing PGRs, either at the same or at different times (PGR x Time)	= 2.20

Table 6.11 Effects of PGR's on seed germination at each harvest.

Treatment	Days after peak flowering					
	36	42	48	54	60	PGR means
Control	74.0	80.8	84.1	76.1	86.0	80.2
Paclobutrazol	75.0	82.8	81.2	82.3	83.3	80.9
Chlormequat	76.3	83.9	80.4	83.1	88.3	82.4
Time means	75.1	82.5	81.9	80.5	85.9	81.2

%CV = 4.0

LSD (P<0.05) for comparing PGR means	= 1.42
LSD (P<0.05) for comparing time means	= 3.16
LSD (P<0.05) for comparing times within a PGR treatment	= 5.74
LSD (P<0.05) for comparing PGRs, either at the same or at different times (PGR x Time)	= 3.67

Table 6.12 Effects of PGR's on seed viability at each harvest.

Treatment	Days after peak flowering					
	36	42	48	54	60	PGR means
Control	94.6	94.3	97.3	96.5	96.9	95.9
Paclobutrazol	95.7	94.9	96.8	95.8	95.6	95.8
Chlormequat	94.5	94.4	96.2	95.4	95.3	95.2
Time means	94.9	94.5	96.8	95.9	95.9	95.6

%CV = 1.84

LSD (P<0.05) for comparing PGR means	= 1.85
LSD (P<0.05) for comparing time means	= 1.71
LSD (P<0.05) for comparing times within a PGR treatment	= 2.97
LSD (P<0.05) for comparing PGRs, either at the same or at different times (PGR x Time)	= 2.50

6.4 DISCUSSION

6.4.1 PGR effects on seed yield

The results of this experiment showed that although paclobutrazol (1.0 kg a.i. ha $^{-1}$ applied at the visible-terminal-flower-bud stage) did not significantly alter flowering pattern or increase flower numbers, harvested seed yield was increased due to a significant increase in seed numbers, a response similar to that reported in Chapter 3A. However, cleaned seed yield was increased only from the mature seedheads, as seed yield from ripe seedheads did not differ from the control. The failure to increase seed yield in early formed seedheads can not be explained, but the response is similar to that reported by Tabora (1991) in *Lotus uliginosus*, where paclobutrazol increased seed yield (through reducing abortion) in seedheads produced from 'mid season' flowers, but not from 'early' or 'late' season flowers. This may be due to intra-plant competition for assimilate, which was possibly more severe during filling of early seedheads, and which coincides with the time of rapid vegetative growth of both the main stem and lateral branches (Chapter 5). However this remains to be determined.

Chlormequat (1.5 kg a.i. ha^{-1} applied during stem elongation) tended to increase flowering sites (as a result of an increase in secondary lateral branch numbers, Chapter 4) so that a higher number of flowers was always observed. However, the results suggested that seed formation was also likely to occurr under severe assimilate competition. This competition for assimilate was expressed by increased seed abortion and the presence of more empty seedheads in chlormequat treated plants (particularly obvious at the second harvest; Table 6.1).

6.4.2 Effects of time of harvest

In control plants, delaying harvest until 60 DAPF produced the greatest harvested seed yield because a greater number of ripe seedheads were present. However many of the seedheads must have contained very light or immature seed, because after cleaning, yield at 60 DAPF did not differ from that at 42 DAPF i.e. cleaning losses were 27 % at 42 DAPF, but 43 % at 60 DAPF. In addition, shedding had begun by 60 DAPF, and seed sprouting in the seedhead was observed at the last

two harvests (Plate 6.2). The results suggest that seeds reached physiological maturity (as recorded by maximum dry weight) approximately 42 DAPF. This was about one week later than reported in Chapter 5. The delay in the present experiment is likely to be explained by less favorable environmental conditions, and the fact that seed age was more accurately measured on individual tagged heads in Chapter 5. The seed development study (Chapter 5) showed seed shedding began in individual seedheads as little as 3 days after seed ripeness (42 DAF). This suggests that seedhead shatter is an important factor in the issue of when to harvest. The results in the harvesting study described in this Chapter also suggest, however, that similar seed yields can be obtained in the field over a considerable time period. Although seed shedding from ripe seedheads in the population is obviously a factor, this appears to be largely offset by a compensatory increase in the dry weight of previously immature seeds. As a result 'once-over' harvesting of a field crop of dahlia cv. Unwins Dwarf Mixture at any time from 42 to 60 days after peak flowering resulted in similar seed yields. The present experiment was sown in early summer directly into the field (10 December 1989) while in Chapter 5 seeds was sown in spring (1 October 1989) in black polythene bags and raised in an ambient temperature glasshouse. Also, the mean temperature during seed ripening was higher (20.1 °C, February 1990) in the previous chapter compared with only 14 °C (April 1990) in the present study. A delay in seed development as a result of lower temperature has also been reported in lettuce (*Lactuca sativus*) (Sukprakarn, 1985), *Lotus uliginosus* (Hare and Lucas, 1984) and ryegrass (*Lolium perenne* L.) (Hill, 1971).

AT 42 DAPF, seeds were ready to harvest, as viability after this time did not increase significantly with delayed harvest. Therefore the previous suggestion (Chapter 5) of around 42 DAPF for optimum harvesting of dahlia seed would seem to be supported. In this season there was certainly no yield advantage from delaying harvesting beyond 42 DAPF. Whether this result would be repeatable in different seasons, or with different sowing times within a season requires further investigation.

6.4.3 PGR and time effects

Both paclobutrazol and chlormequat significantly increased harvestable seed yield (by 30 % and 50 % respectively) when harvesting was done at 42 DAPF. The

increased seed yield following paclobutrazol application was due to a significant increase in the number of seeds per seedhead. In chlormequat treated plants, however, the number of seeds per seedhead and seedheads per plant were both significantly increased. At 42 DAPF, cleaned seed yield was also increased 26 % and 20 % following paclobutrazol and chlormequat application respectively and seed yield was 17 % and 33 % greater at 48 and 54 DAPF following paclobutrazol application. Cleaning losses were always highest for chlormequat treated plants, as seed yield was mostly from the mature green seedheads rather than ripe seedheads. PGR treatements did not delay seed maturity as physiological maturity and high viability were attained at the same time as the control. As harvest was delayed, any PGR yield advantage disappeared until at 60 DAPF seed yield from the control reached a maximum due to a significantly greater number of ripe seedheads than in either PGR treatment.

6.5 CONCLUSION

Sequential flowering in dahlia caused seed yield to be spread over a long period. Early harvest may reduce seed yield because of the presence of immature seeds and a high number of green mature seedheads which need a longer drying period. Delayed harvesting can reduce seed yield and quality due to seed shedding or weather damage (sprouting and frost). To minimize these risks, dahlia seeds should be harvested as soon as the majority of the seeds reach maximum dry weight (around 42 DAPF in this trial). Even in the absence of weather damage, later harvest did not significsntly increase cleaned seed yield because although harvested seed yield increased a greater proportion of seeds were removed during seed cleaning. Application of paclobutrazol 1.0 kg a.i. ha^{-1} at the visible-terminal-flower-bud stage significantly increased seed yield because of a greater number of seeds per seedhead. Chlormequat 1.5 kg a.i. ha^{-1} applied at stem elongation also increased harvested seed yield due to the increased number of seeds per seedhead and seedheads per plant. However, this advantage was obvious only when harvesting was done at 42 DAPF, and tended to be reduced as harvest was delayed.

CHAPTER 7

GENERAL DISCUSSION AND CONCLUSION

Dahlias are a popular bedding plant highly valued for their rapid and vigorous growth and long flowering season (Zimmerman and Hitchcock, 1929; Philipson, 1948; Haliberton, 1976; Barrett and DeHertogh, 1978b; Hammett, 1980; Still, 1988) from late spring to late autumn (Rowell, 1981). Like other indeterminate species e.g. *Vicia faba* L. (Attiya *et al.*, 1983), *Daucus carota* (Hiller and Kelly, 1985), *Lotus corniculatus* (Li, 1989; Supanjani, 1991), *Lotus uliginosus* (Tabora, 1991), varying proportions of flower buds, open flowers, and immature, ripening and shattered seedheads can be present on the plant at the same time. This lack of uniformity in growth habit and protracted flowering increases the problems for seed production (Still, 1988). Pinching and chemical manipulation were therefore used in an attempt to contract the flowering period and improve both seed yield and quality.

Variation in the days to flowering in dahlia is due to differences in the time of flower initiation (Barrett and De Hertogh, 1978a). This differs from the chrysanthemum, where variation in the days to flowering is due to differences in the rate of development after initiation (Doorenbos and Kofranek, 1953) and from China aster, where differences are due to both time of flower initiation and flower development (Phetpradap, 1992).

The date of sowing of Unwins Dwarf Mixture in the 5 field trials reported in this study ranged from 1 October (Chapter 5) to 21 December (Chapter 3A). This difference of 53 days was, however, not associated with variation in the length of the vegetative growth period before plants showed the first visible signs of flower bud formation. Despite major differences in sowing date, plants in all trials showed first visible flower buds 45-48 days after sowing. This suggests a remarkably consistent physiological plant age influence in determining when plants of this cultivar become reproductive. Reproductive development of plants in all trials occurred within a daylength range of 14.5-15.5 hours. Konishi and

Inaba (1966a, 1966b) state that dahlia is a quantitative short day plant which flowers at any daylength below 16 hours but that 10 hours is the optimum daylength for initiation and 13 hours is optimum for flower development. The present study does not confirm this suggestion, since plants of Unwins Dwarf Miture flowered under an increasing daylength of 14.5 hours (Chapters 3A and 5), a maximum daylength of 15.5 hours (Chapters 2 and 3B) and under a decreasing daylength of 14.5 hours (Chapter 3A and 6). This suggests that, the cultivar Unwins Dwarf Mixture is a day-neutral rather than a short day requiring plant, since it flowers as soon as plants reach an age of 45-48 days after sowing. This requires further investigation.

Pinching (hand removal of the shoot tip above node 3, 4 and 5 on the plant) delayed the onset of flowering and therefore improved uniformity of lateral branch growth. However, a spread of flowering still occurred, as flowers were produced continuously on secondary branches. Although more flowers per plant were often produced as a result of pinching, cleaned seed yield was not usually significantly increased, particularly as a greater proportion of cleaning losses often occurred (e.g. 46 % cleaning loss for pinching at node 5 compared with 37 % from unpinched plants). This suggests the pinched plants were not capable of supporting all the seeds set, as seed lost during cleaning were either immature or of very low thousand seed weight. The reason for this failure to support seed is not known, but could be associated with secondary lateral branch growth i.e. these sites of vegetative growth were a stronger sink than developing seeds, a result previously recorded in *Lolium perenne* (Hampton, 1983) and *Lotus uliginosus* (Tabora, 1991). This requires further investigation. A similar response was recorded from chlormequat treated plants. When chlormequat was applied at 1.5 kg a.i. ha^{-1} at the stem elongation stage, a significant increase in secondary lateral branches was recorded, and flower sites were increased. A greater harvested seed yield was obtained due to an increase in the number of brown seedheads produced on the top lateral branches on the plant (Chapter 4). However treated plants also continued to have late vegetative growth and therefore seeds from these later flowers may once more have been outcompeted for assimilate for seed filling, and thus lost during the cleaning process (28-42 % losses).

Paclobutrazol decreased plant height by decreasing main stem and lateral branch length. The decrease in the main stem height was due to shortened internodal

length rather than reduced node numbers. However, general plant structure (the number of nodes, lateral branches and secondary branches) and dry weight did not alter. The results also highlighted the importance of the application time of this chemical. The earlier the application, the greater the retardation effect, a result also recently recorded in Chiana aster (Phetpradap, 1992) and previously in herbage species (e.g. Hampton, 1983; Li, 1989; Tabora, 1991).

The transient effects of paclobutrazol in dahlia is somewhat surprising, since paclobutrazol treated plants in this study were retarded only at early stages of growth (up to peak flowering) and these effects had mostly then disappeared by harvest. It may be possible that the rate used in the present study was not high enough to compete with the higher level of endogenous gibberellin induced by active plant growth at later stages. Optimum paclobutrazol rate still needs further investigation.

Seed yield increases following the application of paclobutrazol (1.0 kg a.i. ha^{-1}) at first visible bud were obtained from both harvested (Chapters 4 and 6) and cleaned seeds (Chapter 3A, 4 and 6). The increased seed yield was due to a significantly increased number of flowers and subsequently seedheads per plant (Chapters 4 and 6) and/or seeds per seedhead (Chapters 3 and 6). Results from all experiments, especially Chapter 4, also showed that paclobutrazol increased the uniformity of seed maturity, as the number of brown seedheads produced on lateral branch positions was significantly higher than the control at harvest (Chapter 4) and more mature seedheads were present at early harvest (36 DAPF, Chapter 6).

Seed may be lost because it is shed from the earlier produced seedheads, but no record of this source of loss was maintained. However, in each trial there were large differences between harvested and cleaned seed yields, which varied from 11-33 % in paclobutrazol treated plants (Chapter 3A and 4). It is likely that assimilate competition within the plant occurred both within and between flower heads (Chapter 5). Paclobutrazol appeared to reduce this competition, particularly within seedheads, as the number of seeds per seedhead was increased. However, once again, this increased number of seeds could not be filled, as cleaning losses were still high. Assimilate competition leading to seed abortion or a greater

proportion of partly filled or immature seeds at harvest has been reported in many crops (Thomas *et al.*, 1982; Chanprasert, 1988; Supanjani, 1991; Tabora, 1991). Information on the uptake, movement and fate of PGR's applied to dahlia, and their capacity to alter the pattern of assimilates, is still lacking and requires further study.

High variation between sample plants was common in all experiments in this study. This may be because of genetic variation. The present-day dahlias have arisen as a result of continuous crossing between several wild species and varieties (Sorensen, 1969; Barrett and De Hertogh, 1978a; Hammett, 1980; Runger and Cockshull, 1985; Salunkhe *et al.*, 1987). According to Sorensen (1969) modern cultivars are tetraploids and crosses between single and double flowered types which produce a continuous range of form and colour. More sample plants, bigger plot size or close spacing are alternative choices to reduce this error, and need further investigation.

In China aster, different seed yields between cultivars were reported to be due to differences in plant branching capacity. At the lowest density (4.2 plants m^{-2}), plants of cv. Kurenai had 11 lateral branches and 26 flower heads more than cv. Powderpuff (Phetpradap, 1992). This greater number of floral sites may be one reason for higher seed yield in this cultivar. In contrast, seed yield of dahlia cv. Unwins Dwarf Mixture was higher, although the number of branches and flowers was less than cv. Figaro White (Chapter 3). Selection for genotypic differences has led to the development of cultivars with widely differing characteristics. Responses to PGR application may also differ. Figaro White is a dwarf cultivar, and it is possible that because of its early flowering and dwarf habit endogeneous giberellin biosynthesis levels may be reduced compared with other taller cultivars. If this is so, then a PGR such as paclobutrazol which is an 'antigibberellin' may have little effect because it has reduced activity.

Increasing plant density results in decreased seed yield per plant, but may increase seed yield per unit area, as has been reported in plants such as marigold (Bhati and Chitkara, 1988),carrot (Hiller and Kelly, 1985) sugar beet (Scott and Longden 1978) and cowpea (*Vigna unguiculata*) (Kwapata and Hall, 1990). Seed yield of certain bush-type cowpea cultivars can be substantially increased by increasing

plant density from 100,000 to 400,000 plants ha^{-1} (Kwapata and Hall, 1990). Brown and Archie (1986) reported lower seed yield of prairie grass *(Bromus willdenowii)* from a seeding rate of 7.5 kg seed ha^{-1} than from a higher seeding rate. Scott and Longden (1978) also reported that seed yield of both monogerm and multigerm varieties of sugar beet was greater in narrow than in wide rows and yields declined as plants were grown further apart in widely spaced rows. Crops with high plant populations ripened earlier and the germination percentage was generally slightly greater in seed from crops grown in narrow rows. Herbert and Hill (1978) also reported similar results in lupin where, at dense populations, plants produced fewer inflorescence orders, thus resulting in a shorter flowering period.

In flowering pot plants and cut flower crops there are many reports of the effects of plant spacing on growth and yield for flower production. For example, Bhati and Chitkara (1988) reported that flower yield per plant of marigold (*Tagetes erecta*) was highest at the widest spacing (50x50 cm) but yield per unit area was highest with the closest spacing (40x40 cm). Armitage (1987) also reported the influence of spacing on field-grown perennial crops (*Achillea* 'Coronation Gold', *A. millefolium* 'Rose beauty', *Physostegia virginiana* L., *Liatris pycnostachya* Michx., and *Salvia leucantha* Cav.). All species responded to spacing treatments by producing more flowering stems per plant with wider spacing but production per unit area was reduced as spacing increased.

Plant density was reported to have little effect on seed yield in white clover (Marshall and Hides, 1987) and in China aster (Phetpradap, 1992) as white clover stolon or aster branch growth compensated at all but the very lowest plant density used (9 plants/m^2 white clover or 4 plants/m^2 China aster).

The increased seed yields reported by growing at high density have been due to a shorter flowering period (Herbert and Hill, 1978), more even seed maturity (Gray, 1987) or ease of seed harvest. In dahlia, harvested and cleaned seed yields were increased 32 % (from 752.4 to 994.3 kg ha^{-1}) and 17 % (from 473.2 to 554.9 kg ha^{-1}) when plant density was increased from 40,000 to 111,108 plants ha^{-1} (Chapter 2 and 3A respectively). This density effect may be one reason why increases in seed yield in the Chapter 3A experiment were not as great as in the

Chapter 2 experiment (40 % and 32 %; and 22 % to 26 % for harvested and cleaned seed respectively). Because PGR application was not a reliable and effective method for increasing yield or even improving uniformity in dahlia, perhaps planting at high density to allow only the terminal flower of the lateral branches to grow and to restrict the production of flowers on secondary branches would be the best management method to reduce the spread of flowering and inhibit the fluctuation of individual plant responses. High plant density to overcome these problems has been successfully used for carrot (Gray, 1987). However, the optimum plant density for dahlia, and whether this suggestion would produce the desired outcome, require investigation.

Dahlia is a self-incompatible species (Hammett, 1980). Introduction of insect pollinators is therefore necessary and this also requires further research. In the present study, honey bees (*Apis melliflera* L.) and bumble bees (*Bombus spp.*) were present because they had been introduced to the area for another study and were also being used for pollinating pears growing on an adjacent block of land. Dahlia flowers were continuously visited by these bees. However, flower colour may affect bee activity. The white petal colour appeared to be less attractive to bees and these flowers often failed to set seed, a result also reported in white flowers of *Clarkia* and *Cylindrica* (Lewis, 1953) and *Pseudomuscari azureum* (Garbari, 1972). However, these were only observations, and experimentation may be required. Receptive timing and other pollination limitations have also not yet been studied.

Plants respond to long days by producing high levels of gibberellin (Hillman, 1962; Biran *et al.*, 1974). Cathey (1964) and Larson (1985) reported that vegetative growth of plants under long photoperiods was not prevented by chlormequat. Since this experiment was conducted during summer, it is possible that because of high levels of endogeneous gibberellins produced by the plants during long day conditions (Appendix 3A.1), plant growth regulators which are antigibberellin in action were less effective in reducing cell elongation of the plant at the rate of a.i. applied. However, although higher rates of a.i. could be trialled, it could be difficult on economic terms to justify their use.

The correct harvesting timing for obtaining high seed yield and quality is important and requires further investigation. Suitable methods of harvest, with or

without chemical pre-treatment of the crop, may also need to be studied. For example in calendula (*Calendula officinalis*) cutting in swaths, allowing seed to dry in the field for 12-14 days, and the threshing from the swath, proved better than threshing either directly after desiccation using Reglone (diquat) or without desiccation (Nordestgaard, 1990). However, whether machine harvesting of dahlia is feasible is not known and also requires investigation.

It was perhaps disappointing that neither pinching nor chemical treatment of dahlia plants ultimately resulted in significantly increased seed yields. However, this should be put into an economic context. Paclobutrazol, for example is 'expensive' (current New Zealand retail price $ 350-400 per litre). In the present study 1.0 kg a.i. ha^{-1} was used in all experiments (4 l ha^{-1} commercial product) at a cost of $ 1400-1600 ha^{-1}. Despite this, the retail price of seed of Unwins Dwarf Mixture is currently NZ $ 400 kg^{-1} and $ 1600 kg^{-1} for seed of Figaro White (Kieft, 1992). This suggests that extremely small increases in seed yield (4 kg ha^{-1} for Unwins Dwarf Mixture and 1 kg ha^{-1} Figaro White) are needed to recover the cost of paclobutrazol application. This is certainly a far more cost effective situation than can be claimed in some field crops (particularly herbage grasses and legumes) where the unit price of product is low.

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APPENDICES

Appendix 1.1 Glossary of botanical terms.

Achene : A small, dry, indehiscent, 1-seeded fruit having a thin pericarp that is free from the seed.

Alternate : The arrangement of leaves or other parts when not opposite or whorled on the stem.

Annual : A plant which grows to maturity in one vegetative year.

Anther : The distal part of the stamen, bearing the pollen.

Anthesis : The time of blooming or flowering.

Apex : The top or summit of a leaf, inflorescence, petal, sepal or even the plant itself.

Axillary : Said of buds, stem or inflorescences found in an axil.

Bracts : A more or less modified leaf subtending a flower or flower cluster.

Calyx : The outer whorl of floral envelopes enclosing the petals, the sepals

Capitulum : An inflorescence composed of many sessile flowers arranged densely together in a flat disk.

Cultivar : A plant which has originated in cultivation, not normally to be given a name of Latin form. Thus, Unwin is a dahlia cultivar.

Cyme : A broad, more or less flat-topped, determinate flower cluster, with central flowers opening first.

Daisy-eyed : The stage where a double flower has developed to the point of exposing its central disc florets. It is then said to be "daisy-eye"and no longer of any use for exhibition.

Determinate : A habit of growth in which the terminal growing point produces an inflorescence or flower, and any further growth of the plant develops from lateral buds.

Disk : The central part of the head.

Disk flowers : Those produced in the central part of the head; they are tubular in shape.

Distal : At the outer end, farthest from the point of attachment.

Double flower : Flowers that have more than the usual or normal number of floral envelopes, particularly of petals.

Fertile : Having the capacity to bear seeds or fruits, also said of pollen bearing anthers.

Floral induction: The physiological changes in response to external stimuli (light quality, daylength, etc.) that occur in vegetative meristems and subsequently allow them to become reproductive meristems and undergo floral initiation.

Floral initiation: The morphological changes in the development of a reproductive meristem from a vegetative meristem.

Floret : A small flower of a larger head such as in the disc and ray-florets of Asteraceae.

Flower stalk : The elongated support of a flower (pedicel or peduncle), leaf (petiole) or fruit (pedicel).

Head : A dense cluster of flowers, a capitulum.

Herbaceous : Plant stems which are usually soft and which die to the root each year.

Incurved : Where the ray florets of a bloom curve forward along their length toward the face of the flower.

Indeterminate : Said mainly of an inflorescence whose axis is not limited by terminal flowers.

Internode : The part of a stem between two nodes or joints.

Involucral bracts: A close collection of bracts surrounding an inflorescence or flower.

Node : The joints in a stem from which may issue leaves and buds.

Ovate : Egg-shaped,the broadest part below the middle.

Perennial : A plant lasting for more than two years, correctly including hard-wooded plants such as trees and shrubs but more usually applied to those of a soft-wooded kind whether they bear persistent stems like the Carnation or herbaceous stem like a perennial Phlox.

Pompon : A spray-type, having a flower shaped like a ball.

Raceme : An indeterminate inflorescence having a simple, unbranched rachis or stem and from which occur the pedicelled flowers.

Ray florets : A marginal strap-like floret of a daisy flower head.

Receptacle : The enlarged summit of the peduncle of a head to which the flowers are attached.

Recurved : Curving backwards or outwards.

Reflexed : Bent sharply backwards.

Self-pollinated: The introduction of pollen from the stamens of the pistil of the same flower.

Spatulate : Shaped like a spatula, oblong, sometimes a little broader toward the upper end, and with a round apex.

Sterile : Barren, lacking in an essential sexual part such as stamens without pollen.

Stopping : The operation of pinching shoots back so as to make them break into lateral growths.

Terminal bud : Flower bud which occurs at the end of a main stem. It is flanked by two wing buds.

Tuber : A modified, underground stem usually acting as a storage organ, having buds from which new shoots develop.

Whorl : A ring of three or more parts around an axis as in leaves, petals, etc.

Wing buds : Buds produced either side of a main or terminal bud.

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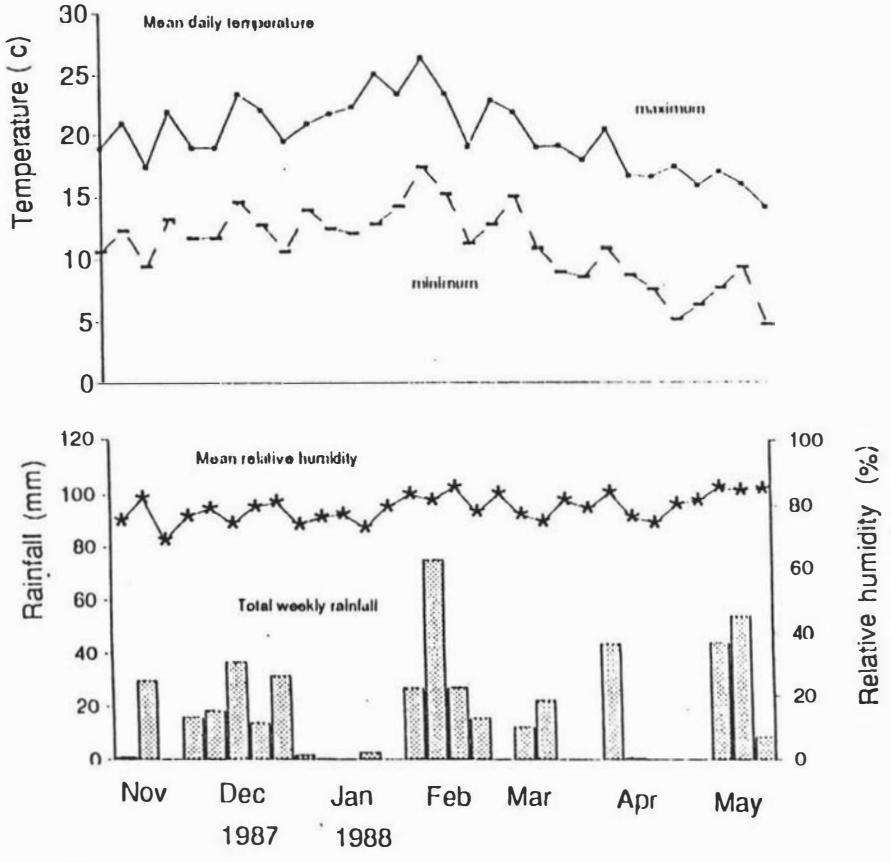
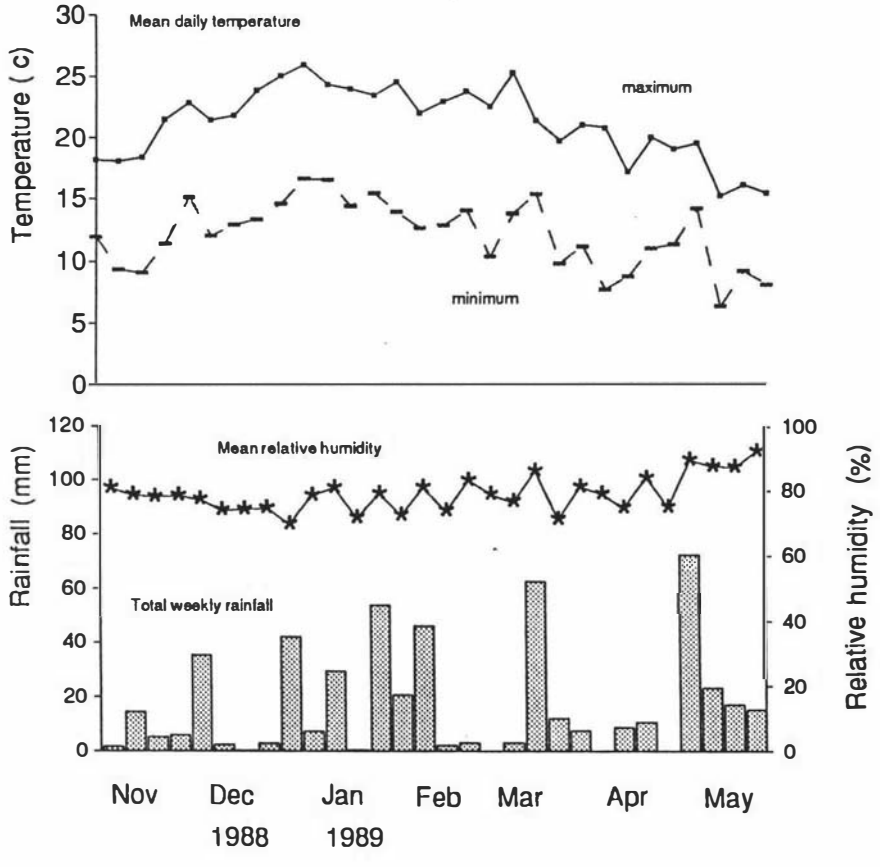


Appendix 2.1 Weather data at Palmerston North, New Zealand during November 1987 - May 1988.

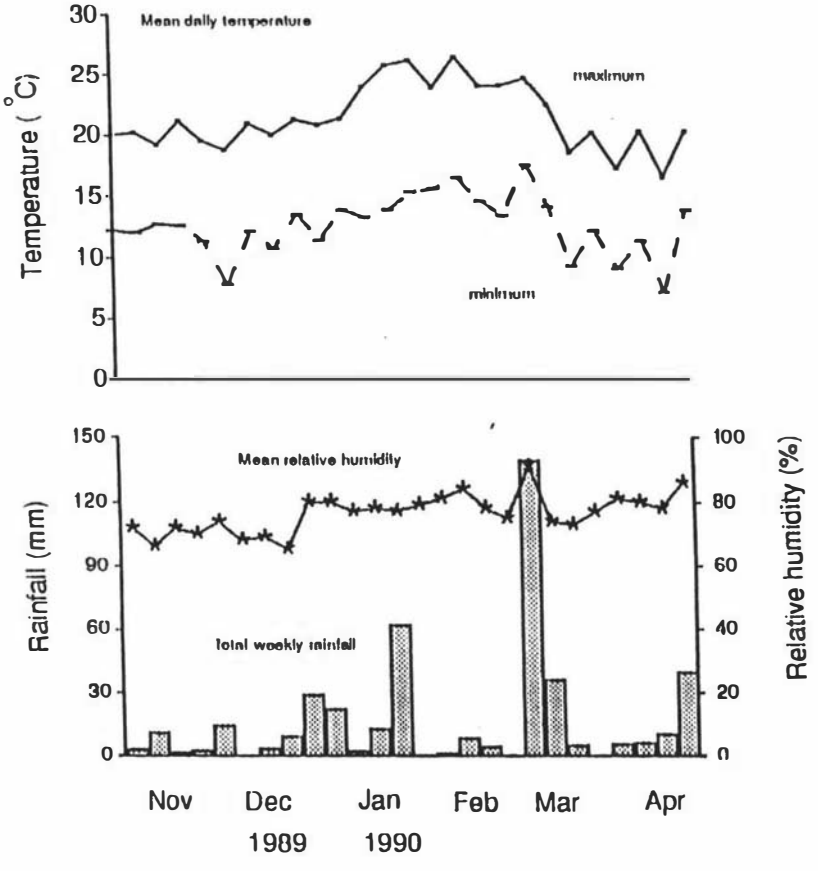
Appendix 2.2 Soil sample test results (MAF Computerised Fertiliser Advisory Service.)

Element	Parts per million
Phosphorus	51
Potassium	9
Magnesium	21
Calcium	12
Sodium	6

Soil pH = 6.5



Appendix 3.1 Weather data at Palmerston North, New Zealand during November 1988- April 1989.



Appendix 4.1 Weather data at Palmerston North, New Zealand during November 1989 - April 1990.

Appendix 5.1 Monthly records of temperature, sunshine and daylength from January 1988 to May 1990.

Month	Air temperature (°C) Max (°C)	Min (°C)	Mean (°C)	DifN (°C)	Sunshine Actual (h)	Daylength Actual (h.m)	(h.ts)
1988							
January	22.4	12.7	17.6	-0.1	240	14.47	14.78
February	22.9	14.6	18.8	+0.7	135	13.55	13.93
March	20.3	11.0	15.7	-0.7	130	12.55	12.92
April	17.9	8.1	13.0	-1.1	166	10.59	10.98
May	15.7	7.0	11.4	+0.2	124	9.48	9.80
June	13.7	6.0	9.9	+1.1	67	9.15	9.25
July	13.5	5.7	9.6	+1.5	99	9.31	9.52
August	13.8	5.7	9.8	+0.5	143	10.30	10.50
September	15.6	9.4	12.5	+1.5	69	11.41	11.68
October	17.1	10.2	13.7	+1.1	138	13.07	13.12
November	19.8	10.9	15.4	+1.0	182	14.25	14.42
December	22.9	13.4	18.2	+1.8	225	15.13	15.22
1989							
January	24.1	15.2	19.7	+2.0	223	14.47	14.78
February	23.1	12.9	18.0	+0.1	193	13.55	13.93
March	22.0	12.4	17.2	+0.4	172	12.55	12.92
April	19.2	9.8	14.5	+0.4	175	10.59	10.98
May	15.4	8.4	11.9	+0.7	64	9.48	9.80
June	13.1	4.9	9.0	+0.2	73	9.15	9.25
July	12.3	3.1	7.7	+0.4	141	9.31	9.52
August	14.2	5.3	9.8	+0.5	124	10.30	10.50
September	16.5	8.3	12.4	+1.4	151	11.41	11.68
October	18.0	9.6	13.8	+1.2	130	13.07	13.12
November	20.0	12.0	16.0	+1.6	192	14.25	14.42
December	20.2	11.2	15.7	-0.7	158	15.13	15.22
1990							
January	23.0	13.0	18.0	+0.3	201	14.47	14.78
February	24.9	15.2	20.1	+2.0	223	13.55	13.93
March	22.2	13.6	17.9	+1.1	172	12.55	12.92
April	18.6	10.2	14.4	+0.3	111	10.59	10.98
May	15.8	8.0	11.9	+0.7	113	9.48	9.80

The temperature and sunshine data were taken by DSIR, Palmerston North, New Zealand (about 1 km from trial site and 34 m above sea level).

The daylength data were taken from the Carter Observatory, Wellington, New Zealand (about 100 km from trial site).

Normal observation is the mean of thirty years of weather observation.

DifN - difference from normal.

h.m - hours and minute.

h.ts - hours and tenths.

Appendix 6.1 Analysis of variance for total seedheads per plant

Source	DF	Anova SS	Mean Square	F Value	Pr > F
Model	20	629.91911111	31.49595556	1.34	0.2440
Error	24	563.44666667	23.47694444		
Corrected Total	44	1193.36577778			
BLK	2	110.43244444	55.21622222	4.25	0.1023
TRT	2	64.29911111	32.14955556	2.48	0.1996
TRT*BLK	4	51.934222	12.983556	0.55	0.6987
HAR	4	162.748000	40.687000	1.73	0.1756
TRT*HAR	8	240.505333	30.063167	1.28	0.2993

%C.V.= 11.78

Appendix 6.2 Analysis of variance for mature seedheads

Source	DF	Anova SS	Mean Square	F Value	Pr > F
Model	20	1329.9857778	66.4992889	3.44	0.0023
Error	24	463.3386667	19.3057778		
Corrected Total	44	1793.3244444			
BLK	2	99.76844444	49.88422222	6.28	0.0584
TRT	2	226.41244444	113.20622222	14.25	0.0151
TRT*BLK	4	31.779556	7.944889	0.41	0.7986
HAR	4	854.480000	213.620000	11.07	0.0001
TRT*HAR	8	117.545333	14.693167	0.76	0.6393

% C.V. = 17.78

Appendix 6.3 Analysis of variance for ripe seedheads

Source	DF	Anova SS	Mean Square	F Value	Pr > F
Model	20	1770.8484444	88.5424222	15.16	0.0001
Error	24	140.1426667	5.8392778		
Corrected Total	44	1910.9911111			
BLK	2	16.66711111	8.33355556	0.40	0.6971
TRT	2	38.04311111	19.02155556	0.90	0.4748
TRT*BLK	4	84.3168889	21.0792222	3.61	0.0193
HAR	4	1464.5955556	366.1488889	62.70	0.0001
TRT*HAR	8	167.2257778	20.9032222	3.58	0.0072

% C.V. = 17.07

Appendix 6.4 Analysis of variance for number of seeds per seedhead

Source	DF	Anova SS	Mean Square	F Value	Pr > F
Model	20	1063.6204444	53.1810222	7.17	0.0001
Error	24	177.9560000	7.4148333		
Corrected Total	44	1241.5764444			
BLK	2	7.66711111	3.83355556	0.41	0.6882
TRT	2	189.85644444	94.92822222	10.18	0.0270
TRT*BLK	4	37.31689	9.32922	1.26	0.3137
HAR	4	638.12756	159.53189	21.52	0.0001
TRT*HAR	8	190.65244	23.83156	3.21	0.0126

% C.V. = 5.74

Appendix 6.5 Analysis of variance for TSW

Source	DF	Anova SS	Mean Square	F Value	Pr > F
Model	20	4.85644444	0.24282222	1.16	0.3571
Error	24	5.00266667	0.20844444		
Corrected Total	44	9.85911111			
BLK	2	0.82977778	0.41488889	2.18	0.2288
TRT	2	0.20844444	0.10422222	0.55	0.6162
TRT*BLK	4	0.7608889	0.1902222	0.91	0.4726
HAR	4	2.5724444	0.6431111	3.09	0.0349
TRT*HAR	8	0.4848889	0.0606111	0.29	0.9623

% C.V. = 6.27

Appendix 6.6 Analysis of variance for harvested seed yield

Source	DF	Anova SS	Mean Square	F Value	Pr > F
Model	20	256.83592444	12.84179622	2.57	0.0145
Error	24	119.90270667	4.99594611		
Corrected Total	44	376.73863111			
BLK	2	25.67032444	12.83516222	9.14	0.0323
TRT	2	14.62149778	7.31074889	5.20	0.0771
TRT*BLK	4	5.6195689	1.4048922	0.28	0.8872
HAR	4	146.8238756	36.7059689	7.35	0.0005
TRT*HAR	8	64.1006578	8.0125822	1.60	0.1761

% C.V. = 15.65

Appendix 6.7 Analysis of variance for total cleaned seed yield

Source	DF	Anova SS	Mean Square	F Value	Pr > F
Model	20	112.81377778	5.64068889	1.31	0.2632
Error	24	103.54933333	4.31455556		
Corrected Total	44	216.36311111			
BLK	2	4.40711111	2.20355556	0.29	0.7638
TRT	2	16.80177778	8.40088889	1.10	0.4162
TRT*BLK	4	30.5502222	7.6375556	1.77	0.1678
HAR	4	43.8564444	10.9641111	2.54	0.0660
TRT*HAR	8	17.1982222	2.1497778	0.50	0.8454

% C.V. = 22.15

Appendix 6.8 Analysis of variance for cleaned seed yield from mature seedheads

Source	DF	Anova SS	Mean Square	F Value	Pr > F
Model	20	77.92311111	3.89615556	2.18	0.0352
Error	24	42.93600000	1.78900000		
Corrected Total	44	120.85911111			
BLK	2	6.76577778	3.38288889	1.59	0.3098
TRT	2	18.30577778	9.15288889	4.31	0.1004
TRT*BLK	4	8.4915556	2.1228889	1.19	0.3419
HAR	4	36.2524444	9.0631111	5.07	0.0042
TRT*HAR	8	8.1075556	1.0134444	0.57	0.7946

% C.V. =23.95

Appendix 6.9 Analysis of variance for cleaned seed yield from ripe seedheads

Source	DF	Anova SS	Mean Square	F Value	Pr > F
Model	20	170.40711111	8.52035556	11.05	0.0001
Error	24	18.50266667	0.77094444		
Corrected Total	44	188.90977778			
BLK	2	2.64044444	1.32022222	0.30	0.7542
TRT	2	5.87511111	2.93755556	0.67	0.5594
TRT*BLK	4	17.43022222	4.35755556	5.65	0.0024
HAR	4	138.97422222	34.74355556	45.07	0.0001
TRT*HAR	8	5.48711111	0.68588889	0.89	0.5397

% C.V. = 22.76

Appendix 6.10 Analysis of variance for seed germination.

Source	DF	Anova SS	Mean Square	F Value	Pr > F
Model	20	739.32444444	36.96622222	3.50	0.0020
Error	24	253.13866667	10.54744444		
Corrected Total	44	992.46311111			
BLK	2	4.89911111	2.44955556	1.25	0.3781
TRT	2	37.10977778	18.55488889	9.49	0.0303
TRT*BLK	4	7.82222	1.95556	0.19	0.9437
HAR	4	556.35422	139.08856	13.19	0.0001
TRT*HAR	8	133.13911	16.64239	1.58	0.1839

% C.V.= 4.00

Appendix 6.11 Analysis of variance for seed viability

Source	DF	Anova SS	Mean Square	F Value	Pr > F
Model	20	56.25511111	2.81275556	0.91	0.5851
Error	24	74.52400000	3.10516667		
Corrected Total	44	130.77911111			
BLK	2	3.17644444	1.58822222	0.47	0.6533
TRT	2	4.49377778	2.24688889	0.67	0.5606
TRT*BLK	4	13.39289	3.34822	1.08	0.3892
HAR	4	28.68578	7.17144	2.31	0.0871
TRT*HAR	8	6.50622	0.81328	0.26	0.9724

% C.V. = 1.84