CHAPTER 5

Effects of low temperatures at various stages of growth of mungbean (*Vigna radiata* L. Wilczek.)

5.1. INTRODUCTION

From earlier glasshouse and field studies, phenological development and yield of mungbean showed large variations in response to temperature. It appeared that temperature, particularly from flowering onwards, could be an important factor affecting grain yields.

Two identical experiments were set up using combinations of periods of growth in the tropical and temperate glasshouses to study the effects of low temperatures at specific phenological growth stages on growth, phasic development, and grain yield.

5.2. MATERIALS AND METHODS

5.2.1. Temperature

Two temperature conditions, using the tropical glasshouse (average max. 34°C and min. 19°C) and the temperate glasshouse (average max. 24°C and min. 13°C) were used to compare the effect of cooler temperatures on different phenological stages of mungbean, using the cultivar Satin. The daily temperatures ranged from 12°-39°C for the tropical glasshouse and between 4°-31°C for the temperate glasshouse during the experimental period.

5.2.2. Experimental design

Two concurrent experiments (A and B) were carried out using a randomised complete design with five treatments; there were two controls (G1 and G5) and three cool temperature treatments at different phenological growth stages (vegetative, flowering and grain filling stages) with four replications. The objective was to examine the comparative effects of low temperature at different growth stages on the duration of the growth phases and on growth and seed yield. In experiment

A the cool temperature treatments we e applied in chronological sequence. In experiment B the treatments were applied at the same ti ne but the plants were planted on different dates to have plants at the appropriate stages during the treatment period.

The five treatments were as follows: G1= complete growth in the tropical glasshouse, G2= plants transferred to temperate glasshouse for the vegetative stage, G3= transferred to the temperate glasshouse for the flowering stage, G4= transferred to temperate glasshouse for the grain filling stage and G5= complete growth in the temperate glasshouse. All the treatments, except G5, were returned to the tropical glasshouse after completing their specific growth stages in the temperate glasshouse.

In experiment A, seeds of all the treatments were sown on 2nd April 1994 and in experiment B, three different sowing dates were used to synchronise the developmental stages with the plants in experiment A. The sowing dates for experiment B were 24th February 1994 for G1 and G4, 2nd April 1994 for G3 and G5, and 28th April 1994 for G2. Seeds for all treatments were inoculated with inoculum Group-1.

Seeds were sown and germinated in the tropical glasshouse (mean day/night temperatures of 34°/19°C). The seedlings were then exposed to temperate glasshouse conditions (mean day/night temperatures of 24°/13°C) at the required growth stages.

5.2.3. Sampling procedures

For both experiments, leaf area and plant height were measured at the seedling, vegetative, flowering, grain filling and harvest stages. Days to phenological development were recorded as the first date of visual expression of each individual phenological stage (vegetative, flowering, grain filling and harvest). Data on other parameters such as total plant dry weight, root weight, pod number, seed number and seed yield were also collected after harvest.

At each specific growth stage, leaf area was measured using a non-destructive method by measuring length and breadth. Final leaf area was then calculated by multiplying the length x

breadth x 0.688 (Musande et al., 1982).

5.2.4. Statistical analyses

Recorded data was analysed by analysis of variance to determine treatment effects (P<0.001, P<0.01, P<0.05) using a NEVA computerised statistical package. Statistical differences between the treatment means were assessed using the DMRT or lsd. Only results which were significant at least P=0.05 will be discussed in the following experimental sections.

5.3. RESULTS

5.3.1. Temperatures

During the growing period the recorded daily minimum, maximum and average temperatures in tropical and temperate glasshouses are shown in Figures 5.1 and 5.2 respectively.

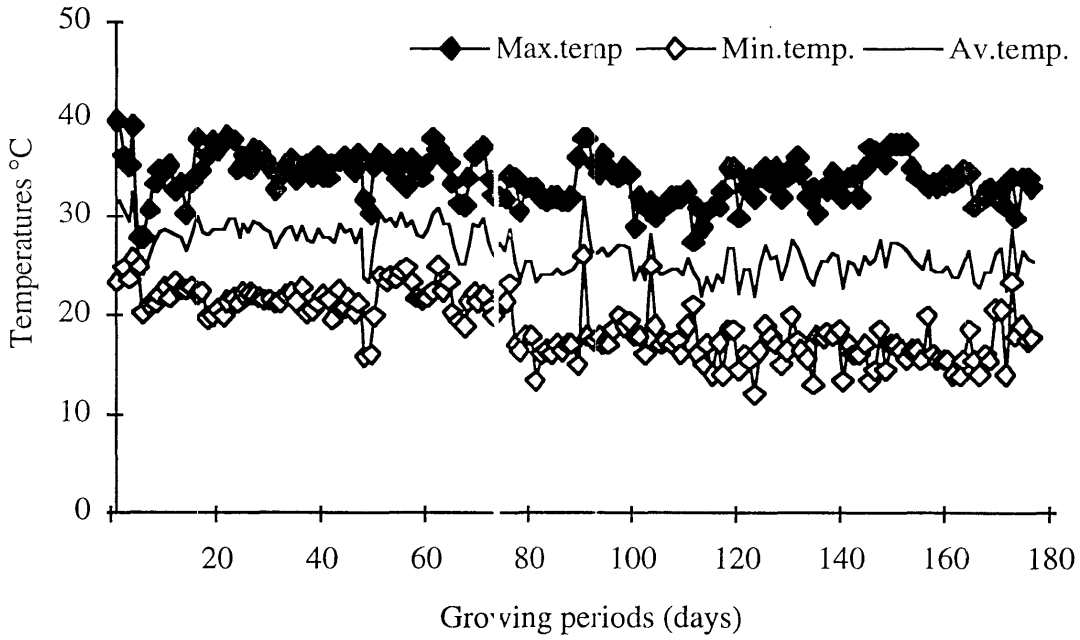

Figure 5.1 Daily minimum, maximum, and average temperatures in the tropical glasshouse for the period of 24th February, 1994 to 9th August, 1994.

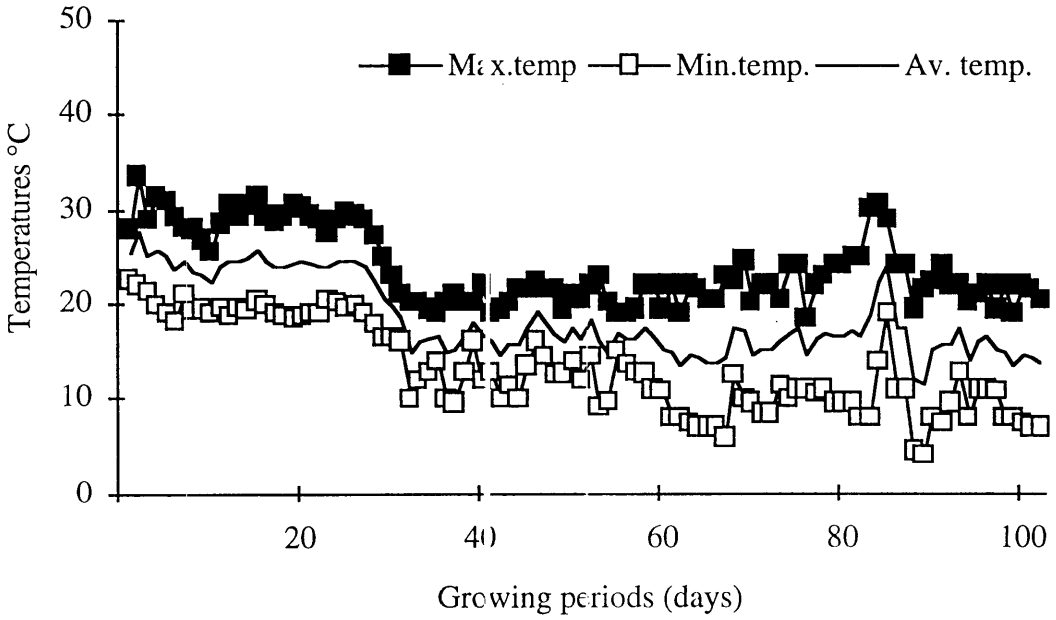

Figure 5.2 Daily minimum, maximum and average temperatures in the temperate glasshouse for the period of 15th April, 1994 to 19th July, 1994.

The mean temperatures during particular phenological stages are presented in the Table 5.1. For the grain filling treatment in experiment B the plants flowered at a lower temperature (25.2°C) because they flowered later than other treatment and the temperature in the tropical glasshouse were lower at that time.

Table 5.1 Mean temperatures (°C) for the tropical and temperate conditions during the different phenological stages of growth.

Experiments	Conditions		Phenological stages			
		Tropical	Vegetative	Flowering	Grain filling	Temperate
Expt. A	Tropical	26.6	29.3	29.8	26.7	-
	Temperate	-	22.9	17.0	10.6	18.8
Expt.B	Tropical	29.3	29.3	30.8	29.3	
	Temperate	-	18.8	21.9	22.9	18.8

5.3.2. Phenological development

The effects of temperature on the length of the growth stages in the two experiments are presented in Figure 5.3 and Figure 5.4 In experiment A, the G5 and G2 treatments required the greatest number of days (38.5 and 36.1) to complete vegetative development. In experiment B,

the vegetative stage was longest (44.1 days) in the G2, and shortest (26.4 days) in G3 treatment. The longer duration was due to slow growth under low temperatures. The difference in G2 treatment between the experiments was probably due to the lower temperatures experienced in experiment B following later planting time.

In experiment A, the flowering phase was longer in the low temperatures (G5 and G3, Table 5.1). In experiment B, the flowering phase was longest in the G5 and G2 treatments, again associated with the low temperature effect. The absence of the G5 treatment at grain filling in Figures 5.3 and 5.4 was associated with the lack of pod formation in this treatment.

Low temperature at any growth stage induced an increase in the total growing period compared to the tropical conditions (G1).

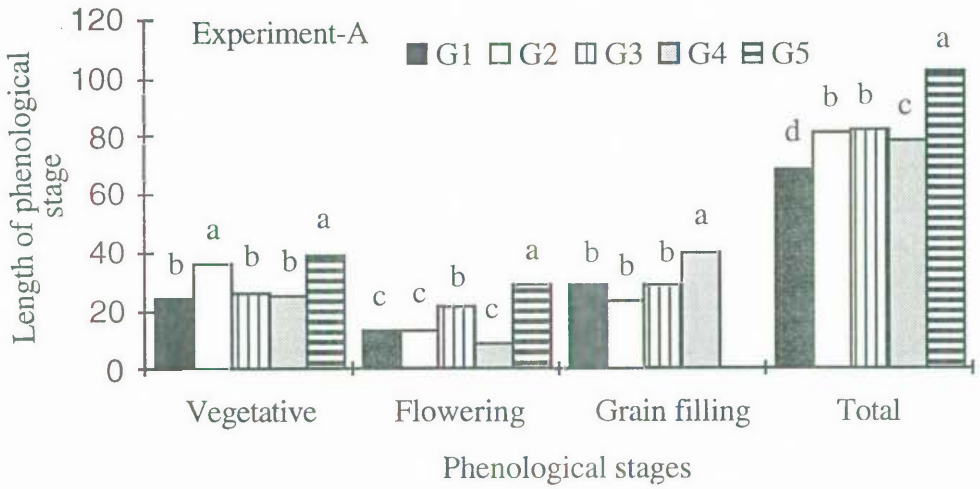

Figure 5.3 Length of phenological stages in experiment A. Within each phenological stage, treatments followed by the same letter are not different at 5%, DMRT. (Total = Sowing to harvest).

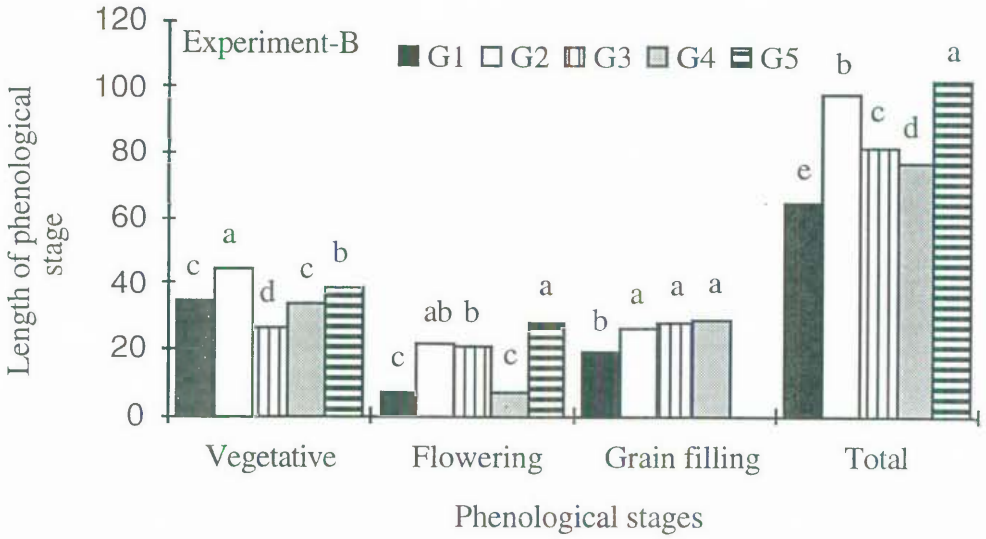

Figure 5.4 Length of phenological stages in experiment B. Within each phenological stage, treatments followed by the same letter are not different (P=0.05), DMRT. (Total = Sowing to harvest; in G5 to end of experiment).

5.3.3. Growth parameters

Plant height

There were no differences in plant height between the temperature treatments in experiment A except for the grain filling stage (Figure 5.5). In experiment B, where seeds were sown on three different dates, the plants were exposed to different growing temperatures (apart from the treatments). However, in both experiments (A and B) treatment G2 produced the tallest plants during the later stages of growth (Figures 5.5 and 5.6), i.e. a period of low temperature during the vegetative stage (G2) increased plant height but not continuous low temperature (G5).

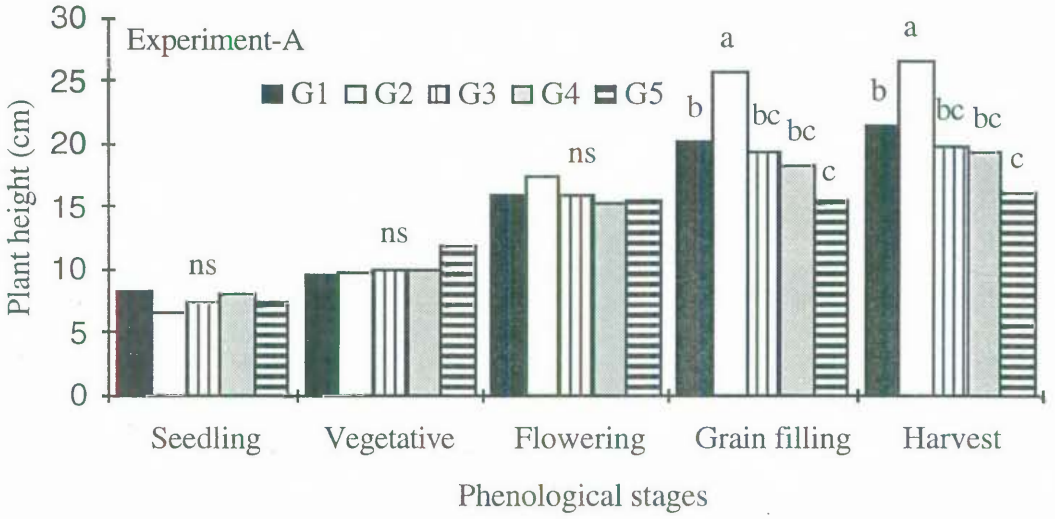

Figure 5.5 Plant height of *Vigna radiata* L. at different phenological stages. Within each phenological stage, means followed by a common letter are not different at 5% lsd, DMRT.

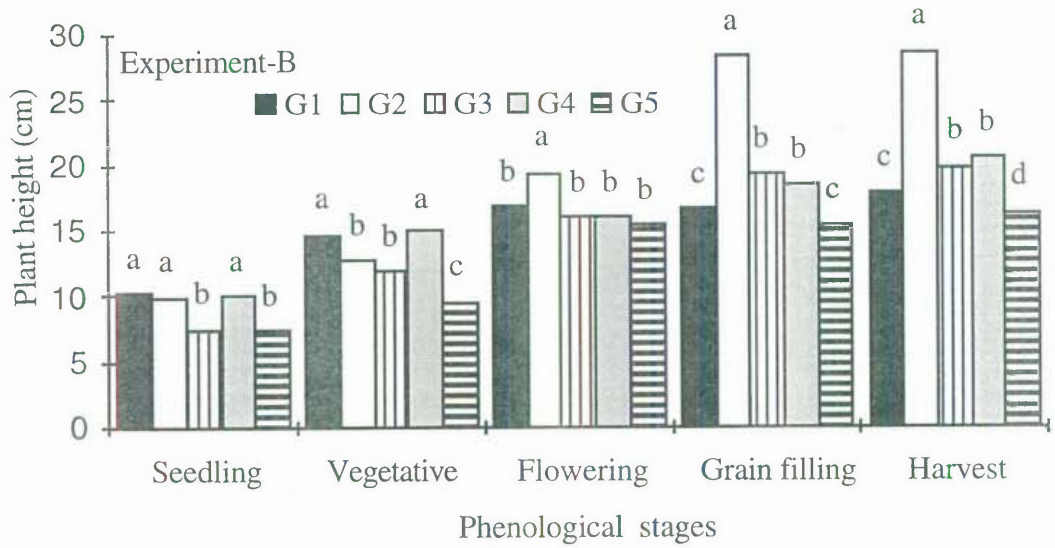

Figure 5.6 Plant height of *Vigna radiata* L. at different phenological stages. Within each phenological stage, means followed by a common letter are not different at 5% lsd, DMRT.

Leaf area

Temperature changes during growth induced no significant effects on leaf area in experiment B but in experiment A, cooler conditions at specific growth stages caused different responses in leaf area production. Compared to the tropical (G1) treatment, cool conditions reduced leaf area at the vegetative and flowering stages in the G2 and G5 treatments. Plants in the G5 and G2 treatments had the lowest leaf area production in the vegetative and flowering periods but this

was apparently reversed for G2 by the grain filling stage (Figure 5.7).

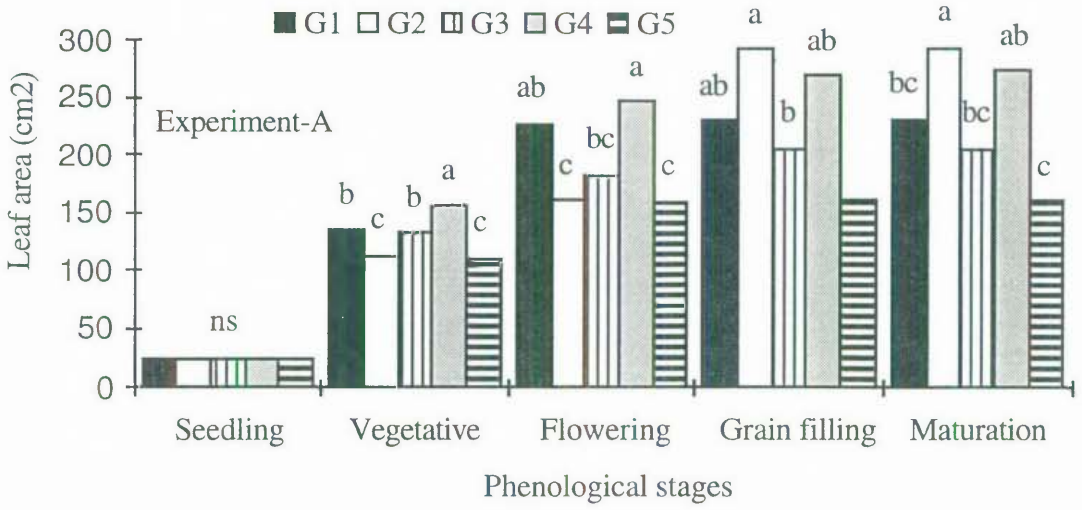

Figure 5.7 Leaf area of *Vigna radiata* L. at different phenological stages. Within each phenological stage, treatments with a common letter are not different (P=0.05), DMRT.

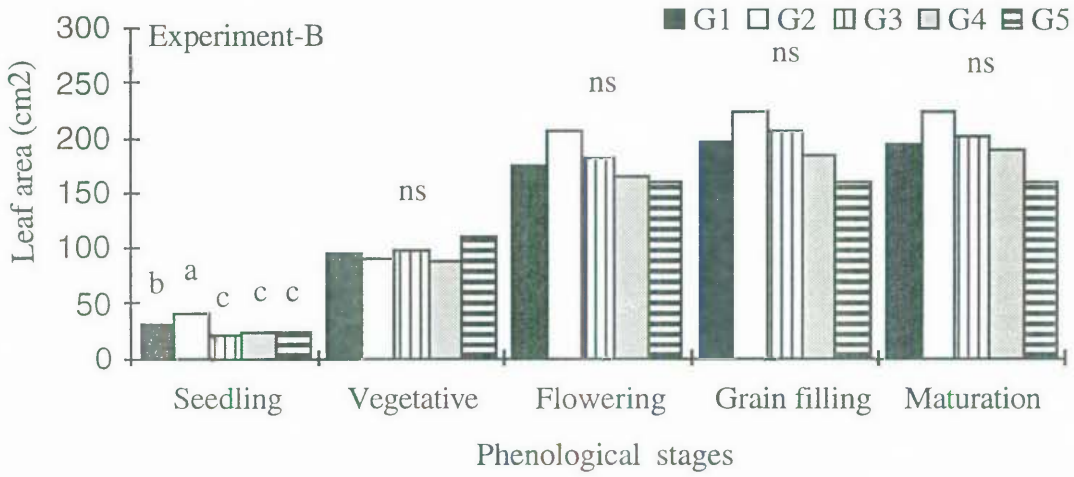

Figure 5.8 Leaf area of *Vigna radiata* L. at different phenological stages. Within each phenological stage treatments with a common letter are not different (P=0.05), DMRT.

Dry matter production and partitioning

Total dry weight production and most of its components (pod, seed yield and root dry matter per plant) increased significantly in treatment G2 (compared to the tropical treatment G1) in experiment A (Figures 5.9); other treatments generally produced similar dry matter yields. This advantage of the G2 treatment compared to G1 was not carried through to experiment B although most treatments had higher shoot and root dry weights than G1 (with the exception of

G4).

Cool conditions at flowering or throughout growth (G3 and G5) markedly reduced the growth of reproductive parts resulting in low yields of pod and seed in the G3 treatment and completely inhibiting their growth in G5 treatments (Figure 5.10).

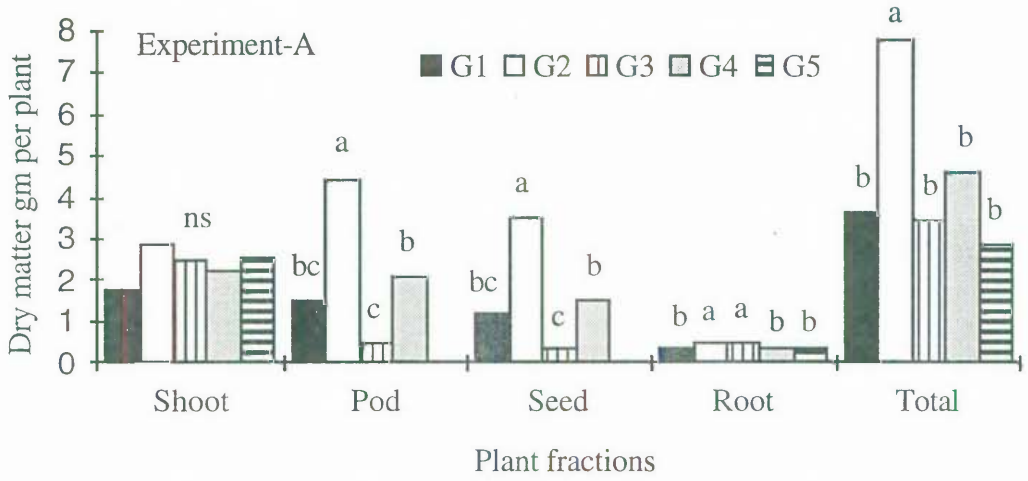

Figure 5.9 Dry weight and its partitioning into different plant fractions (Experiment A). Within each plant fraction treatments with the same letter are not different (P=0.05), DMRT.

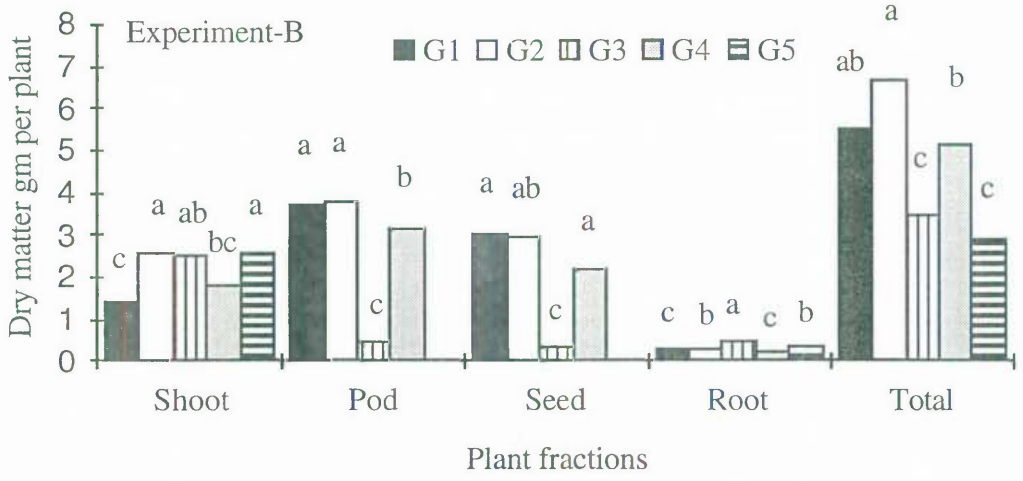

Figure 5.10 Dry weight and its partitioning into different plant fractions (Experiment B). Within each plant fraction treatments with the same letter are not different (P=0.05), DMRT.

5.3.4. Yield and yield components

Seed yield per plant

Seed yield per plant was markedly reduced in both experiments by cool temperatures at flowering and no seed was produced in the temperate glasshouse treatment (G5, Figure 5.11). Seed yield per plant was maximised in the G2 treatment in experiment A but G1 and G2 treatments were similar in experiment B.

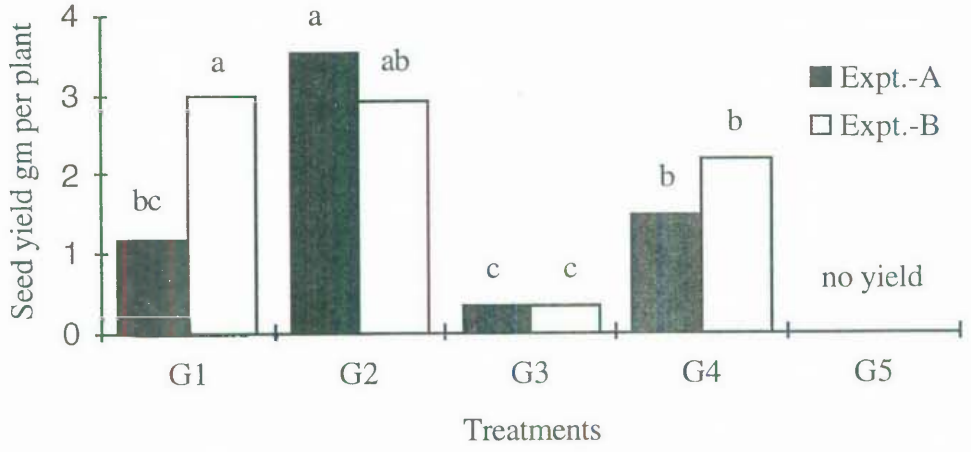

Figure 5.11 Seed yield from experiments A and B for mungbean under different treatments. Within each experiment, treatments (mean of eight plants) with a common letter are not different (P=0.05), DMRT.

Seed number per plant

Seed number per plant was affected in the same way as seed yield by temperature in both experiments (Figure 5.12).

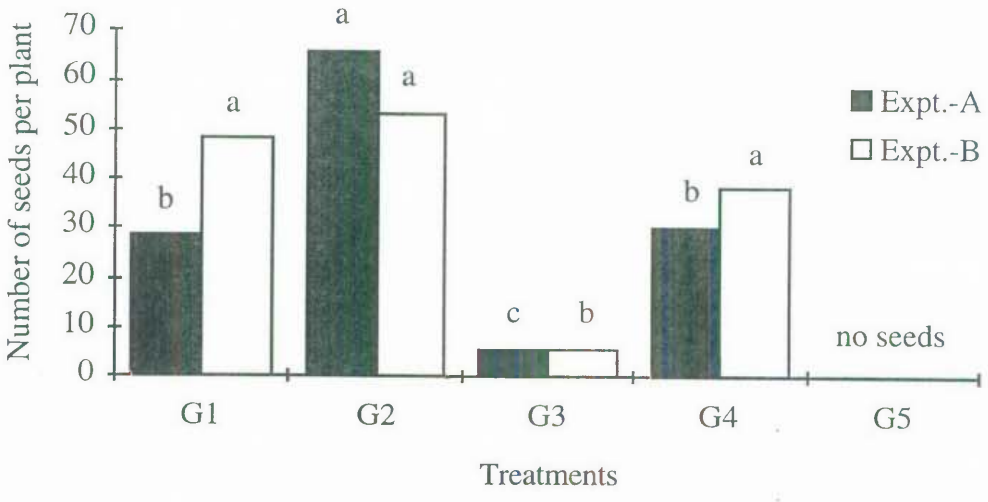

Figure 5.12 Number of seeds per plant under different treatments. Within the experiments treatments with the same letter are not different (P=0.05), DMRT.

Number of pods per plant

The temperature response in pod number per plant was similar to that for seed number per plant except that the reduction with the G3 treatments in both experiments appeared less than for the seed number per plant. There were no pods produced in the G5 treatments (Figure 5.13).

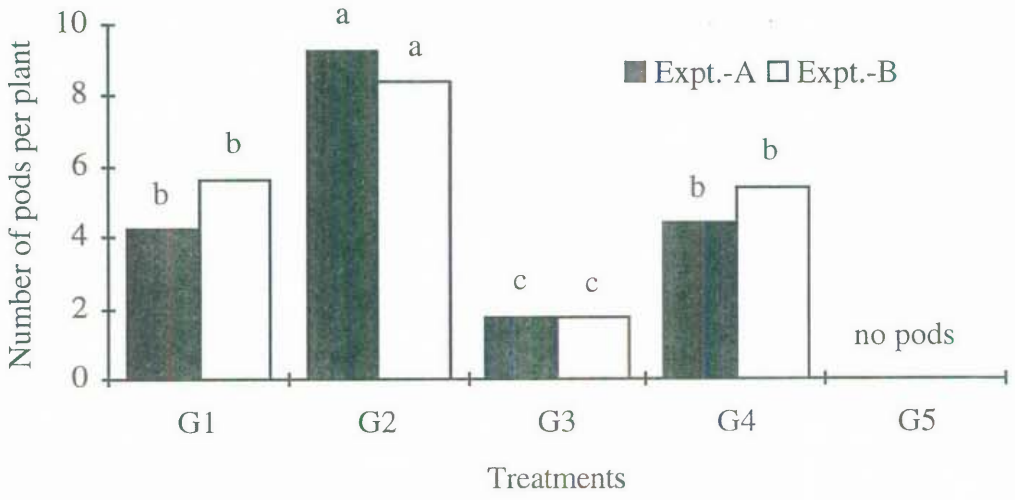

Figure 5.13 Number of pods per plant in *Vigna radiata* L., cultivar Satin. Within the experiment mean of eight plants, treatments with the common letter are not different (P=0.05), DMRT.

5.4. DISCUSSION

The hypothesis that 'low temperatures at particular phenological stages may be important for growth and yield of mungbean', was tested by subjecting the vegetative, flowering and grain filling stages to cool temperatures compared to a control treatment (G1) which was grown continuously under tropical conditions.

Low temperatures (Table 5.1) lengthened the duration of the vegetative, flowering and grain filling stages (Figures 5.3 and 5.4). All these phenological stages were slower when exposed to low temperatures of 16°C to 21°C compared to the tropical temperatures of 25°C to 30°C. The longer length at the vegetative stage in experiment B compared to experiment A was associated

with the later planting time.

Mungbean is known to be susceptible to low night temperatures, and below 16°C (Farlow et al., 1979), growth and development greatly declined (Lawn, 1979b; Searle et al., 1980). Low temperatures also delayed flowering in mungbean (Aggarwal and Poehlman, 1977; Imrie and Lawn, 1990). Van Schaik and Probst, (1958), Huxley et al., (1976), Seddigh, (1983) and Sionit et al., (1987) also observed that high temperatures enhanced the early vegetative growth of seedlings and subsequently shortened the length of phenological development of mungbean. In both experiments A and B, low temperatures slowed the rate of plant development and growth. The exposure to low temperatures (Table 5.1) at each phenological stage delayed the development of that particular phase compared to plants kept under high tropical temperatures.

Exposure to low temperatures during the vegetative stage increased plant height; the reasons for this compensatory growth after the cool period is unclear. The shorter plants in the (G5) treatments under continuous low temperatures may be due to the reduced rate of cell multiplication and elongation. These results have confirmed the findings of Lawn, (1979b) who reported that low temperatures slowed down the overall growth and development of mungbean.

Leaf area is an index of physiological activity and a higher leaf area may contribute to an increase in final yield. Leaf area development was very slow where plants were kept under lower temperatures of 18°C throughout growth. A comparative study of leaf area development before and after changing from high to low temperatures showed that the reduction in leaf area under low temperatures was greatest in the vegetative stage followed by the flowering and grain filling stages. In the grain filling stage, the highest leaf area was recorded in the G2 treatment in both experiments, suggesting that the plants had the ability to recover from low temperature stress imposed at the vegetative stage when they were once again exposed to higher temperatures during later stages of development.

Total dry matter production was reduced by continuous low temperatures (G5; Figure 5.9 and Figure 5.10). Similar results were observed in green gram (Farlow et al., 1979) and soybean

(Mangat, 1982; Sionit et al., 1987); low temperatures, below 16°C reduced the dry matter production and also reduced the leaf area in soybean (Hofstra and Hesketh, 1975). Low temperature at the vegetative stage increased dry weight; this might be due to reduced respiration resulting in greater accumulation of carbohydrate. This accumulated carbohydrate may also enable compensatory growth when the plants return to higher temperature. On the other hand the highest root dry weight (Figure 5.9 and Figure 5.10) was recorded in the G3 and G2 treatments in both sets of experiments. A possible explanation is that in the absence of any reproductive structures the assimilates produced by the vegetative parts were directed to the roots.

Seed yield is the combined result of the yield components such as pod and seed number. In experiment A, the highest pod number, seed number and seed yield per plant (Figure 5.11) were recorded in the G2 treatment where only the vegetative stage of mungbean plants grew under cool temperatures; the lowest yield was in the G3 treatment where the flowering stage was in cool temperatures. Thus cool temperatures prior to flowering may not adversely affect grain yield; earlier sowing under cool conditions may be possible in regions with a short growing season. There was no seed yield in the G5 treatment where plants were grown with cool night temperatures (down to 12°C). It was observed that in both G3 and G5 treatments the abscission of flowers occurred within 72 hours of their opening.

The reproductive structures are very sensitive to low temperature, and flower abscission under low temperature may be attributed to the lack of fertilisation due to slow growth of the pollen tube. Low temperatures (8°-12°C) prevented pod formation in all cultivars of tropical soybean (Lawn and Hume, 1985) and was also found to be detrimental to seed set in mungbean (Searle et al., 1980). The lack of assimilate flow to the developing pod under low temperatures may also increase the flower death.

5.5. CONCLUSIONS

Low temperature affected all the stages of phasic development but the flowering phase was most affected. Low temperatures at the vegetative stage prolonged this stage and ultimately extended

the total maturity period but increased seed yield. A similar response pattern was observed in Chapter 3 where low temperature reduced seed yield drastically compared to plant development under tropical conditions.

The experimental results demonstrate clearly the detrimental effects of low temperatures on flower development, flower set and pod set in mungbean, but it is not clear which range of temperatures would produce optimum flower and pod set. This is the subject of further studies in a separate controlled environment (Chapter 6).

CHAPTER 6

Effects of night temperatures during flowering of mungbean (*Vigna radiata* L. Wilczek).

6.1. INTRODUCTION

Low temperatures during growth lengthened phenological development in mungbean which consequently extended the total growing season. Experience from previous experiments (Chapters 3 and 5) indicated that the low temperatures drastically reduced total dry matter and seed yield. The flowering stage appeared most sensitive to low temperatures which reduced the number of flowers drastically and completely inhibited the flower set when plants were grown continuously under low mean temperatures of 18°C. Whilst it appeared that mungbean can tolerate low temperatures during the pre-flowering phase, more information would be helpful to determine minimum temperatures for the flowering phase.

Hume and Jackson (1981) suggested that a single cold night of 8°C was sufficient to inhibit pod set in soybean when the flowering phase subjected to a range of day and night temperatures of 15°-19°C and 7°-15°C respectively. Low night temperatures also affected the pod set in mungbean (Searle et al., 1980).

The present experiment was carried out under controlled environmental conditions to study the effects of a range of night temperatures on flowering and pod set in mungbean. Low night temperatures can be accounted in the cooler Tablelands region of northern New South Wales and this may limit mungbean production in this region.

6.2. MATERIALS AND METHODS

6.2.1 Temperature treatments

The experiment used eight different night temperature treatments during flowering (6°C, 9°C,

12°C, 15°C, 18°C, 21°C, 24°C and 27 °C) with a day temperature of 30°C in the growth cabinet plus a control treatment (T9) kept co ıtinuously under tropical glasshouse temperatures. The night temperature range in the tropic ıl conditions was 17°C to 24°C. Seeds were sown under tropical conditions with a temperature ange from 19°C minimum and 41°C maximum and grown under these conditions up to the day b ɜfore opening of first flower in each treatment. Flowering plants were then moved to different te nperature treatments in growth cabinets for ten days. At the end of each treatment period, th ɜ plants were moved back to the tropical temperature conditions for the remaining period of ɡ rowth u ntil harvest.

6.2.2 Experimental design

The experiment was carried out us ng a completely randomised design with eight night temperature treatments and four replic ations; each temperature treatment (one growth cabinet) contained four pots with two plant s. Seeds of cultivar Satin were sown under tropical temperature conditions on four differe ı t dates at an interval of eight to ten days. All the cultural practices including inoculation, fertilis ɜ tion, w atering and mulching were followed according to the previous experiments.

6.2.3. Sampling procedures

The number of open flowers were c ɔunted every day from the beginning of flowering and continued until the end of the flowerin ɡ stage. The percentage pod set was calculated from the total number of matured pods and th ɛ total r umber of flowers reaching anthesis by using the following equation:

Plant heights were measured at harv ɛ st together with pod number, seed yield and the total vegetative dry weight after harvest. All recorded data was analysed as in Chapter 5. Only treatment means which were statistically different at a probability of 5% ($P<0.05$) or better have been discussed in the text.

6.3. RESULTS

6.3.1. Temperatures

During the experimental period, the recorded daily minimum, maximum, average and mean of daily average temperatures in the tropical glasshouse conditions are shown in the Figure 6.1.

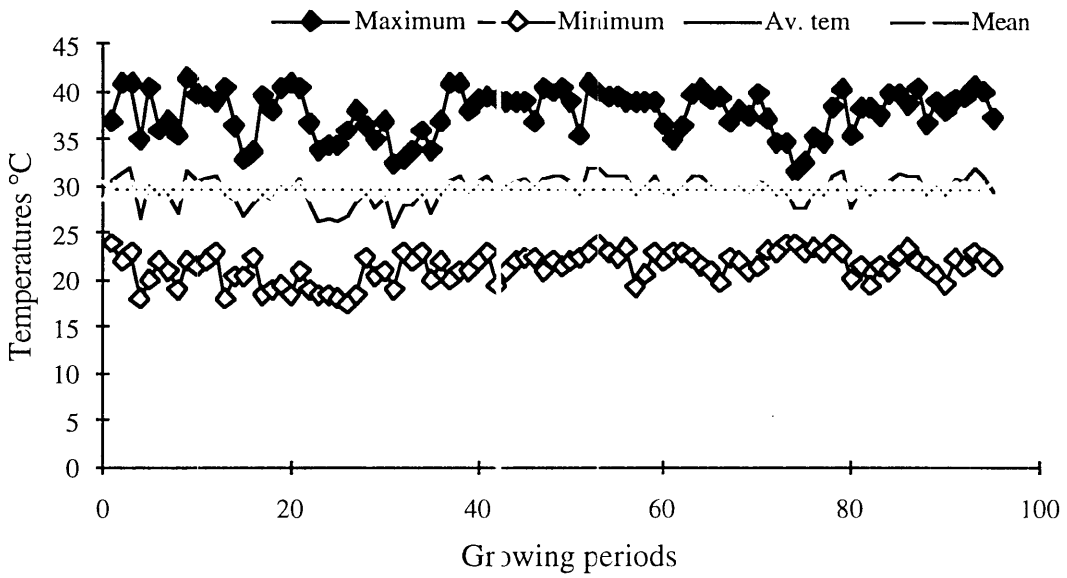

Figure 6.1 Daily minimum, maximum, average and mean temperatures in the tropical glasshouse for the period of 15th October, 1994 to 18th January, 1995.

6.3.2. Days to harvest

The time from sowing to harvest did not appear to be affected by a range of low night temperatures; even the lowest night temperature (6°C) did not induce any lengthening of the time to harvest (Figure 6.2).

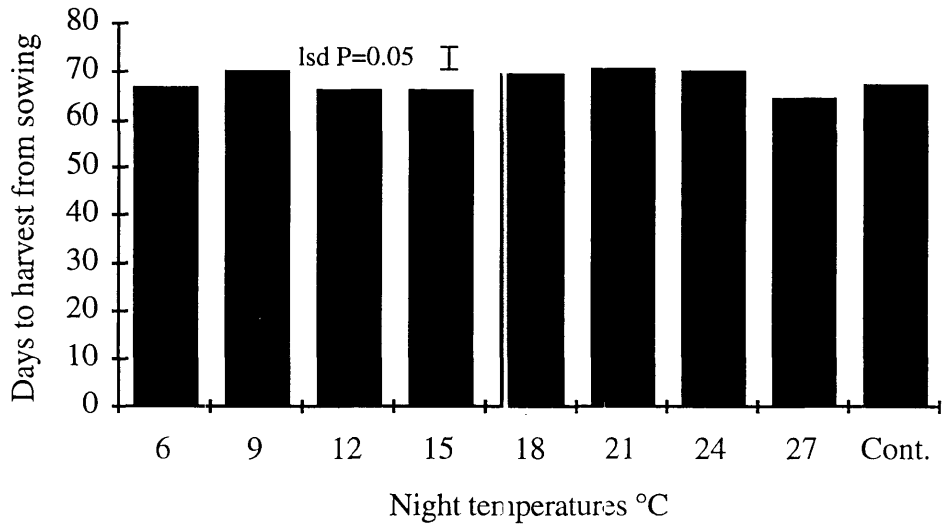

Figure 6.2 Days to harvest of mungbean under different night temperature treatments. Each value is the mean of eight plants; treatments followed by the common letters are not different at 5% level, DMRT. (Cont.= continuously under tropical glasshouse)

6.3.3. Total vegetative dry weight

Dry weight production (Figure 6.3) is an important growth parameter and was much higher under lowest night temperature of 6°C but the remaining treatments produced similar dry weights to the control (T9).

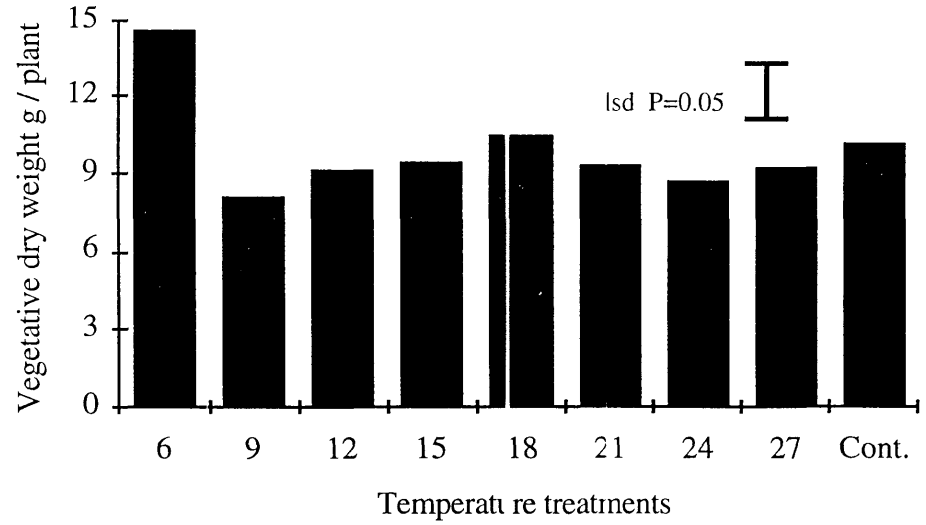

Figure 6.3 Total vegetative dry weight of mungbean under the different night temperature and control treatments.

6.3.4. Plant height at harvest

Plant height at harvest varied with night temperatures during flowering but no uniform trend could be detected. Night temperatures of 9°, 12° and 15°C produced the shortest plants (Figure 6.4).

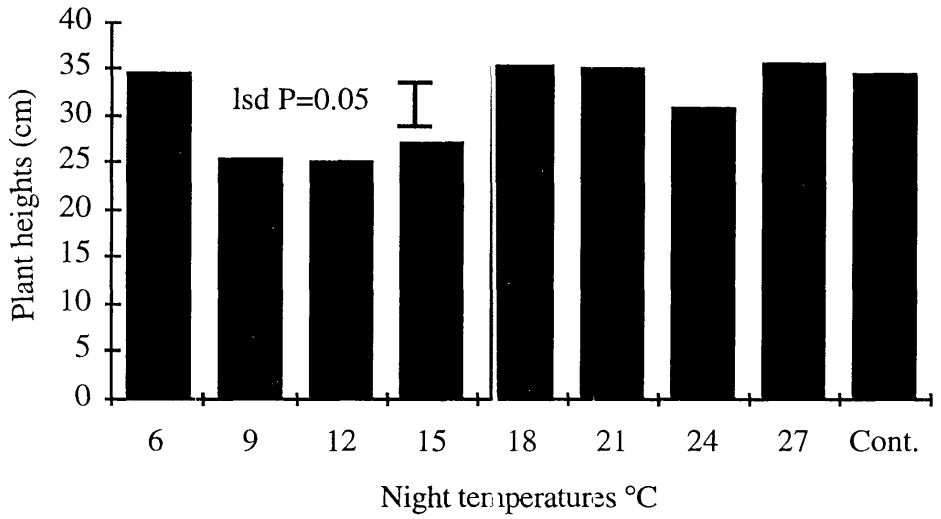

Figure 6.4 Plant height of mungbean at the time of harvest under different night temperature treatments.

6.3.5. Flower number and percentage pod set

Reduced night temperatures reduced flower production in some cases but there was no uniform trend with decreasing temperature and no differences in percentage pod set (Table 6.1). The results indicated that low night temperatures alone were not a major cause of reduced pod production and the percentage pod set.

There was no consistent change in pod or seed number with temperatures (Table 6.1). There was a strong suggestion in the yield component data however that 18°C optimised pod number, pod set % and seed number per plant and had less detrimental effects compared to the other reduced night temperatures.

Table 6.1 Total number of fertilised flowers per plant and the percentage pod set under different night temperatures and control treatments including yield contributing characters.

Treatments Characters/plant	6°C	9°C	12° C	15° C	18°C	21° C	24° C	27° C	Cont.	lsd P=0.05
Flower no.	19.5	15.8	21.4	23.6	26.0	20.6	17.9	19.9	26	ns
Pod no.	8.9	6.4	9.9	10.9	11.8	7.3	7.6	7.9	11.3	***(2.5)
Pod set %	45.6	40.5	46.3	47.4	46.2	35.4	42.5	39.7	43.5	ns
Seed no.	103	70.5	83.4	89.3	121	66.3	69.8	85.1	107.8	***(20.9)
Seed size (gm)	0.05	0.05	0.04	0.04	0.04	0.05	0.05	0.03	0.04	ns
Thousand seed weight (gm)	50	47	41	39	42	47	48	34	43	ns

Values within the parenthesis are the lsd at P=0.05.

6.3.6. Yield

With the exception of the 6°C night temperature treatment, low night temperatures appeared to reduce seed yield compared to the control treatment. The increased seed yield of the 6°C treatment compared with night temperatures of 9°, 12°, 21° and 24°C was associated with the increased seed number (Table 6.1). The reduced seed yield under 27°C treatment was associated with reduced seed size and percentage pod set.

Seed yield was positively correlated (r^2=0.90) with the total foliage dry weight (Y= -0.2548+ 0.399x)

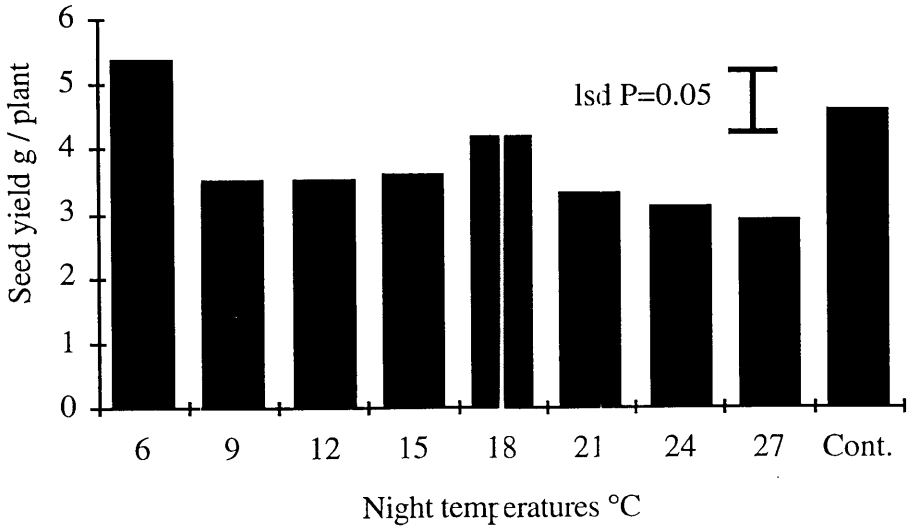

Figure 6.5 Seed yield of mungbean under different night temperature treatments.

6.4 DISCUSSION

The present study was undertaken with a view to improving our understanding of flowering and pod set under different night temperatures particularly with regard to the influence of low night temperatures. Such temperatures might be common in the higher cooler regions (such as the Tablelands) into which mungbean cropping may expand.

The current experimental results contradict the results of those in experiment 1, 2 and 3, where low temperatures delayed the crop maturity. However, only the flowering phase was exposed to the cool night temperatures in the present development and this may have allowed compensation in the latter stage of growth.

Seed yield at both 18° and 6°C appears a typical of the general downward trend in yields as a result of reduced night temperatures (compared to 30°C). This increased grain yield was matched by higher dry matter production and by high seed numbers per plant; earlier data suggests that these two parameters were strongly correlated with grain yields. The lack of a uniform reduction in grain and dry matter production with decreasing night temperatures means that this experiment needs repeating (probably with both Satin and another cultivar) to clarify these findings.

This increased dry matter accumulation at 6°C also needs verification with further experimental work; such a strong effect may be related to reduced respiration and hence better carbon accumulation.

The lack of effect of a low night temperatures on flowering is contrary to the results of Lawn and Hume (1985) and Saito et. al. (1967), where soybean plants subjected to the low night temperatures of 8°-12°C and low day/night temperatures of 18°/12°C showed decreased number of pods and consequently reduced the seed yield. This aspect of the low temperature effects on mungbean also requires further study.

6.5 CONCLUSIONS

This final experiment suggests that mungbean plants may be able to grow and maintain seed and vegetative yield under a wide range of night temperatures; this is a strong indication of its plasticity in response to temperatures. The number of fertilised flowers and the percentage pod set were similar over a wide range of night temperatures; this suggests the ability to be widely adapted to cooler regions with lower night temperatures possibly Tableland type environments. However, further studies will be necessary to confirm these results.

CHAPTER 7

General Discussion

Initial experimental work in this study indicated the importance of both nutritional status and temperature in determining both the phenological development and the growth and yield of mungbean. Once the nutritional requirements had been satisfied, a number of temperature studies aimed to clarify the effects of temperature generally and low temperatures in particular, on cultivars with different phasic development patterns. Since a range of newer Australian cultivars are now available, it was considered important to examine their temperature requirements and in particular their ability to yield under cooler conditions.

The germination and emergence of mungbean seeds were found to be earlier under high temperature regimes but delayed under low temperature regimes. A linear relationship between germination times and increasing temperatures (from 15°C up to 40°C) with a correlation coefficient r^2=0.998 has been reported in mungbean (Fyfield and Gregory, 1989) with the fastest germination at 40°C when water was non limiting. This supports the results from the Chapter 4, where seed germination was earliest under the tropical treatment compared to field conditions. Early emergence in the field situation can initiate early photosynthesis and better utilisation of photoassimilates and also promote early maturity by shortening the total growing period.

Hypocotyl elongation in mungbean is also a function of temperature and it is related to the structural and functional changes in membranes (Raison and Chapman, 1976). Temperatures between 15°-28°C increase the sugar transport to the growing hypocotyl tissue thus providing an energy source which may increase hypocotyl elongation. Longer hypocotyl length has a commercial importance in bean sprout production. From this thesis it is evident that under tropical temperatures, hypocotyl elongation was the longest (Figure 4.7). Similar results have been reported by Hatfield and Egli (1974) and Chang (1978).

Lower temperature extended the length of the growth phases of mungbean; under field conditions

this was associated with large increases in dry matter production (Figure 4.11) and high yields (Figure 4.12). Such yields need verification under more extensive experiments but if sufficiently early sowings can be achieved, the summer temperatures of the northern Tablelands do not appear to be a limiting factor for mungbean production.

All mungbean cultivars studied required either a short growing period under high temperature or a longer period under low temperature in order to satisfy the heat unit (HU) requirements. The slower rate of accumulation of HU under field conditions, associated with cooler day and night temperatures, delayed crop maturity to almost double the length of time compared to tropical glasshouse conditions (Figure 4.3). The number of days required for each stage of phasic development was closely correlated (r^2=0.99) with the cumulative degree days with a base temperature of 10°C under all four temperature conditions. These results were supported by the findings of Nathalie et al., (1993) who reported that in soybean, the duration of the three reproductive stages increased linearly as a function of cumulative degree days with a base temperature of 6°C.

Plant height and total vegetative dry weight production are indicators of plant growth and they are usually positively correlated. In experiment 1, it was found that there was a positive correlation between mungbean growth and tropical conditions (Figure 3.5). Mungbean grown under tropical temperatures (T1) with a high rate of fertiliser (8 gm/5L of water) produced healthy plants with green shiny leaves and attained maximum plant height. Those grown under low temperatures (T2) and with the same rate of fertiliser became chlorotic with reduced plant height (Figure 3.5). These results suggest that the mungbean cultivars used, require moderate to high temperatures and relatively high rates of fertiliser for their early vegetative growth (Figure 3.3). These results are in agreement with those of Edje et al., (1975); Brevidan et al., (1978) and Sinha et al., (1988).

In experiment 2, mungbean plants grew tallest and vegetative growth was found to be more vigorous under outside glasshouse conditions and field site treatments. Under field conditions, plants produced the highest node number, branch number, branch length, leaf area, etc. and

attained maximum height (Figure 4.8) probably because they had access to a greater rooting zone and a longer maturation period.

Total vegetative dry weight (TVDM) of mungbean was highest under field conditions and reduced (Figure 4.11) with increasing temperatures from T3> T2> T1. High temperatures have been found by Lawn (1979c) to increase the dry matter production of Vigna spp. under field conditions, and this contradicts the findings from the present glasshouse experiments. The reasons for such a large reduction in TVDM production in relatively high temperatures (18°-42°C) was not clear. But it may be associated with the increased rate of respiration and the shortening of maturity period. High temperatures (31°-39°C) decreased the carbohydrate content compared to low temperatures (27°-32°C) in *Phaseolus vulgaris* L. (Mack and Singh, 1969).

In experiment 3, total dry matter (TDM) was greatest when the vegetative stage (G2) of the plants was exposed to low temperatures (4°-31°C) and the other phases were maintained at tropical temperatures (12°-39°C). Such an increase was probably due to the reduced respiration rate at a low temperature and increased carbon accumulation resulting in the higher dry weight. This could occur under field conditions especially where early sowing into cooler temperatures could happen. The higher root dry weight (Figures 5.9 and 5.10) in G3 in experiment 3 suggests the diversion of photo-assimilates to the root system from the shoot due to the absence of any reproductive structures.

Flower (Table 3.1) and pod number (Table 3.2) increased with a higher rate of fertiliser under both tropical and temperate conditions in experiment 1. But the relative pod set under temperate glasshouse conditions was very small compared to tropical conditions which suggest that flower and pod set are highly dependent on the warmer temperatures. However, in the next experiment the highest number of pods was produced under cooler field conditions (Figure 4.17) which contradicts the previous results. Cooler temperatures over the whole growing period decreased flower (Figure 3.7) and pod number (Table 3.2 and Table 5.13) in experiments 1 and 2, but the critical time appears to be during the flowering stage; cool conditions during the vegetative phase increased yield (Figure 5.11). In experiment 4, low night temperatures did not change flower

production or percentage pod set (Table 6.1).

The increased yield with the higher fertiliser rate under tropical conditions but not under temperate conditions in experiment 1, suggests that higher temperatures may influence the efficient utilisation and translocation of applied nutrients. Since this was a pot experiment, the soil temperature was also low. Low soil temperature reduces root functions and decreases the absorption of nutrients from the soil.

The reduction in grain yield under high temperature conditions (experiment 2 tropical glasshouse) was associated with reduced plant growth, the abscission of flowers and young pods, also the development of empty pods and shortening of the grain filling period. These findings are in agreement with those of Lawn and Ahn (1985) who reported a susceptibility of mungbean to temperatures higher than 28°-30°C. Similar observations were made by Summerfield et al., (1975); Egli and Wardlaw, (1980); Dickson and Boettger, (1984) who reported a drastic reduction of seed yield in soybean by high temperatures of 30°-32°C due to reduction in seed size and the shortening of the grain filling period. There was a strong linear correlation between increased yield and seed number (Figure 4.13 and 4.15), flower number (Figure 4.14) and pod number; increasing temperatures in experiment 2 (from T3 > T2 > T1) appeared to reduce yield mainly through lower seed numbers per plants.

The percentage protein content under tropical conditions was higher (24%) with the higher fertiliser rate suggesting that the higher fertiliser application might increase the amino acid content in the plants. These amino acids may be converted into nitrogen during the latter stages of development. This result supported the findings of Brevedan et al., (1978) and Ashour and Thalooth, (1983) who reported that the protein content in soybean increased from 38 to 42% due to an increased application of nitrogen fertiliser. The optimum rate of fertiliser application will depend on native soil N levels and the degree of biological N fixation. In experiment 2, the highest seed protein content of 22-28% was found in mungbean grown under tropical temperatures and the lowest seed protein content was from plants grown in pots outside the glasshouse (Table 4.10). The lower protein content in the pots outside the glasshouse, even

though there was a regular application of aquasol, suggests that the rate of nutrient supplied was not adequate to adequetly maintain growth, yield and protein content.

In commercial mungbean production, growers emphasise the importance of seed colour, uniformity in seed size and percentage germination but when nutritional value or quality are important we must consider the protein level of seed. The increased protein content is a major concern for the cereal based diets in the developing countries.

High nutrient status and tropical growing conditions appear to produce the highest protein content in seeds; this supports earlier information (AVRDC, 1974; Lawn and Ahn, 1985 and Sarwar, 1989) but the most important aspect in this context will be the degree to which the plants are able to fix N and not to deplete the soil N levels. In these experiments, whilst seeds were inoculated with the rhizobial strain, no measurements of N fixation were undertaken. It would be of interest to know how temperature changes N fixation but this was beyond the scope of this present study. Under field production, whilst seed N levels are important, growers are not paid on protein percentage so the other factors such as colour, size and germination are more important.

The quality of seeds from plants grown under varied temperatures was tested. Yields produced under tropical and temperate glasshouses were small but the seed were bigger and shiny in appearance compared to those grown in pots outside the glasshouse or under the field conditions. The germination of the former group was satisfactory with the percentage of germination above 97% (Figure 4.23). The reduced germination under field conditions was associated with malformed seedlings, increased number of hard seeds and rotten seeds caused by fungal infestations. The length of both hypocotyl and roots of the seedlings were longer where the seeds were produced under tropical conditions. Results from this experiment demonstrated that high temperatures during plant development enhanced the elongation of the hypocotyl. High temperatures during seed production may affect the levels of growth hormones in the seed which subsequently affects the hypocotyl growth. These results confirm the findings of Grabe and Metzer, (1969); Gilman et al., (1975); Hatfield and Egli, (9174) and Chang (1978). Low nutritional status of the seeds produced outside the glasshouse may have caused short hypocotyl

length, even though there was a regular application of aquasol. The rate of applied aquasol may not be enough for the plants in pots, where biphasic pod developments occurred. The dry weight of seedlings was highest from seeds produced under tropical temperature conditions and lowest in seedlings from seeds produced in pots kept outside the glasshouse. Careful assesment of quality aspects are likely to be important if the crop is grown under northern Tableland conditions.

From the results it was observed that the yield performance was best in cultivar V6-1973A under field conditions, but in quality assesment cultivar Shinsho was the best in relation to germination percentage. On the other hand, cultivar Satin had the highest protein content in seed under the same growing conditions.

CONCLUSIONS

Mungbean is reputed for its developmental plasticity over a wide range of temperatures. Cooler field conditions lengthened the growing period and induced larger plants, higher grain yields and increases in many yield components compared to tropical glasshouse conditions. There was no difference in protein content in seeds between the cooler field and tropical glasshouse conditions. In the comparative seed germination study there was no big difference in germination percentage except with cultivar Celera.

Considering the above quantitative and qualitative factors we may successfully grow mungbean (cultivars V6-1973A, Satin and Emerald) in cooler Tableland regions of Australia. Mungbean needs climatic conditions where day and night temperatures are reasonably high and should avoid frost.

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