CHAPTER 4

Effects of temperature on growth, phenological development, seed yield and quality of mungbean (*Vigna radiata* L. Wilczek)

4.1. INTRODUCTION

In the preliminary experiment, in the presence of optimum rates of nutrition, temperature played an important role determining the grow h and development of mungbean. Mean day temperatures ranging from 25°-30°C and night temperatures from 14°-21°C resulted in excellent growth and yield. Poor plant growth and yield were observed under mean day temperatures ranging from 24°-27°C and night temperatures ranging from 12°-16°C illustrating the need for optimum temperatures during the growing period.

The aims of the present experiment were to compare the growth and yield of different cultivars of mungbean under a range of temperature regimes and also to examine the phenological development as influenced by temperature. A range of cultivars were used; the aim was to assess the potential for variety x temperature interactions which might lead to the possibility of recommending cultivars for cooler regions of northern Australia. Specific emphasis was placed on the effects of temperature on growth, phenological development, yield and seed quality of mungbean.

4.2. MATERIALS AND METHODS

4.2.1. Temperatures

Four treatments were used to cover the range from adequate to cool; these were T1 a glasshouse with daily temperatures ranging from 42°C maximum and 11.8°C minimum, T2 a temperate glasshouse with daily temperatures of 38°C maximum and 5.5°C minimum, T3 outside in pots with 35°C maximum and 6°C minimum, and T4 a field site with 35°C maximum and 5.7°C

minimum at Laureldale Research Station, Armidale.

4.2.2. Cultivars

Six cultivars of mungbean (*Vigna radiata* L.) with different phenotypic characters were compared in each treatment: these were Kiloga (suggested as cold tolerant), Shinsho (cold tolerant), V6-1973A (adapted to a wide range of temperatures), Satin (tall and easy for mechanical harvesting), Emerald (a bushy plant with large seed) and Celera (small seeded), (Table 4.1).

Table 4.1 Description and origin of mungbean cultivars

Cultivars	Line	Origin	Year of pedigree registration
V6-1973A	CPI 98867	AVRDC	D-1986
Emerald	CPI 109900	AVRDC	D-1990
Satin	N 63	unknown	D-1986
Kiloga	Q 10591	Oklahoma	D-1985
Celera	-	unknown	D-1990
Shinsho	-	China	-

CPI = Commonwealth Plant Introduction.
AVRDC = Asian Vegetable Research and Development Centre.
D = Dalby, South East Queensland, the place where the plant was first grown.
N = Breeder designated cultivar name.
Q = Queensland.

4.2.3. Cultural methods

The experiment was conducted at the Department of Agronomy and Soil Science of the University of New England (UNE), Armidale, New South Wales (NSW) using a randomised block design in each temperature with four replications.

Five seeds of each cultivar were sown into 30 cm diameter pots on 19th November 1992, at the depth of 3-4cm. Before sowing all seeds were inoculated with commercial inoculum (Bradyrhizobium spp.) Group-1. Five days after emergence, plants were thinned to two plants per pot. The soil mixture used in the pots had a pH of 6.5 and consisted of sandy loam and peat in a 3:1 ratio. The soil used in the field was a chocolate soil type (dark grey / brown) with a light to medium clay A horizon, overlaying dark brown light clay B horizons. The profile depth was

approximately 1m overlaying soft weathered basalt.

Fertilisers (NPK) in the form of urea, triple superphosphate and muriate of potash were used at the rate of 60 kg ha-1 N, 40 kg ha-1 P and 60 kg ha^{-1} K. All the superphosphate and potash plus half the rate of urea, were mixed thoroughly with the soil at the time of potting. The remaining 50% of urea was applied during the time of flower bud emergence.

Other agronomic practices, such as watering, mulching and fungicide (mancozeb) were applied as required. During the experimental period, photoperiod was maintained at 13 hours photoperiod using additional 1000W mercury vapour lamps. The light spectrum was predominantly blue (the spectrum range was from 254 to 546 nm) with a light intensity of 55 Wm^{-2} at the pot levels. Meteorological data was collected for the field site 50m from the field experimental area.

4.2.4. Sampling procedure

Data was collected on hypocotyl length, plant height, leaf area index (LAI), flower number, pod number, yield and yield contributing characters and total dry matter from all the varieties in each treatment. Plant height was measured from the soil surface to the apex of the inflorescence 4 times at 15 day intervals from seedling emergence and at final harvest. Total area of leaves, including senescent leaves, were measured by planimeter (Paton Electronic Planimeter). Plant components were separated and dried at 80°C for 72 hours; the samples were weighed for dry weight and used for the determination of plant nitrogen.

Total numbers of nodes and reproductive nodes per plant were recorded to calculate a reproductive index (RI); this is the ratio between flower bearing nodes and the total number of nodes. The number of mature pods was counted at harvest and the number of open flowers was also recorded every day from the beginning until the end of flowering in all the treatments (except T4) for the determination of percentage of pod set.

The stages of phenological development were recorded as in Chapter 3. The end of grain filling or physiological maturity was recorded as the time when the first pod in every treatment turned from

green to yellow. Harvest maturity of mungbean was recorded when more than 50% of pods on plants turned black.

4.2.5. Post harvest measurements

The nitrogen content of different vegetative parts was determined following grinding by the Kjeldahl sulphuric acid digestion of ground samples and indophenol blue colorimetric measurement. The percentage of protein was calculated using a correction factor of N x 6.25 (Norton et al., 1985).

Seed used in germination tests was dried in natural sunlight to approximately 12% of moisture content. A germination test was conducted in a growth cabinet on seed from the four temperature treatments to assess their seed viability, vigour and seed quality. The paper towel method (ISTA, 1976; Ellis et al., 1985a, 1985b) was used with twenty seeds from each treatment placed between three layers of paper towels and sprayed with water until the paper towels were wet. All the paper towels were then rolled and placed inside plastic bags and watered again to maintain a uniform distribution of water. Four replicates of each treatment were placed in a growth cabinet at a temperature of 25°C with a relative humidity of 80% and a 13 hour photoperiod.

After seven days, the seedlings were assessed for germination percentage, hypocotyl length (cm) and root length (cm). Seedlings were then placed inside a drier at 80°C for 72 hours to determine their dry weight.

4.2.6. Degree days or thermal heat units

From the daily recorded maximum and minimum temperatures degree days or thermal units (TU) were calculated for each phase of development. During the period of the experiments, minimum and maximum air temperatures were recorded at the four treatment sites. Soil temperatures were also recorded at two soil depths (5 cm and 10 cm) in the T3 and T4 treatments. To calculate degree days, the recorded temperatures combined with a base temperature of 10.8°C (Angus, et al., 1981) were used in the following equation (Arnold, 1959);

$$\text{Degree Days} = \sum_{i=1}^{t} (Ti - Tb)$$

where Ti is the mean daily temperature and Tb is the base temperature for mungbean growth and development, and t is the number of days.

4.2.7. Statistical methods

The experimental data was analysed by analysis of variance to determine significant treatment effects ($P<0.05$, 0.01, 0.001 %) using the Genstat statistical package. Statistical differences within the cultivars and treatments was determined using the Duncan's Multiple Range Test (DMRT). Experimental data was transformed into Square Root (SQ) and Log transformations where necessary.

4.3. RESULTS

4.3.1. Temperatures

Maximum, minimum and average maximum and minimum air temperatures for the four experimental sites are shown in Figures 4.1a-d.

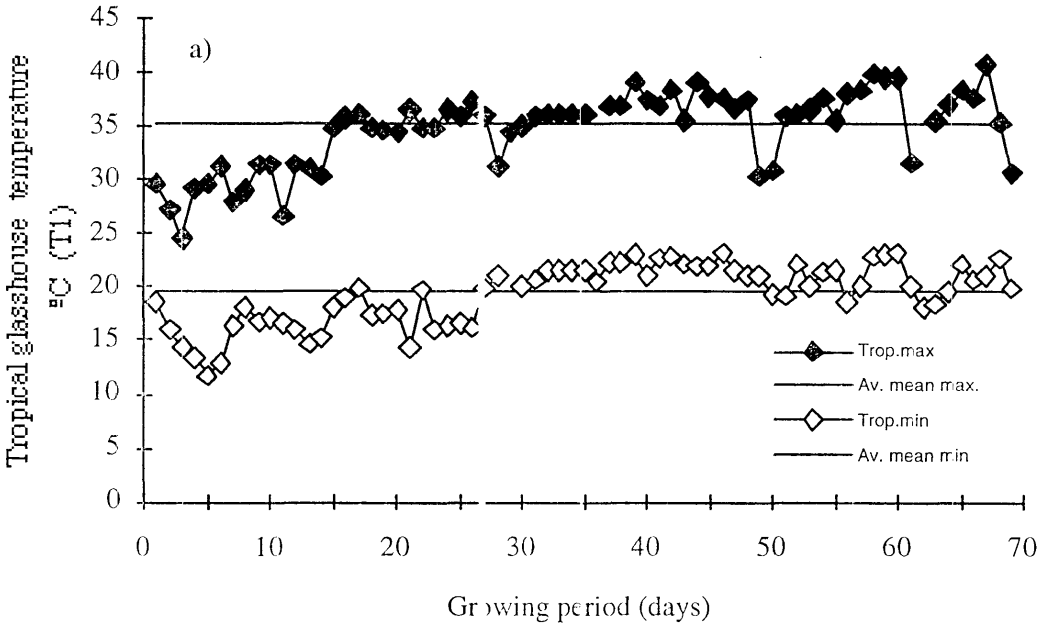

Figure 4.1a Daily maximum, minimum and average maximim and minimum air temperatures for the tropical glasshouse during the growing period (16th November to January 22, 1992 - 1993).

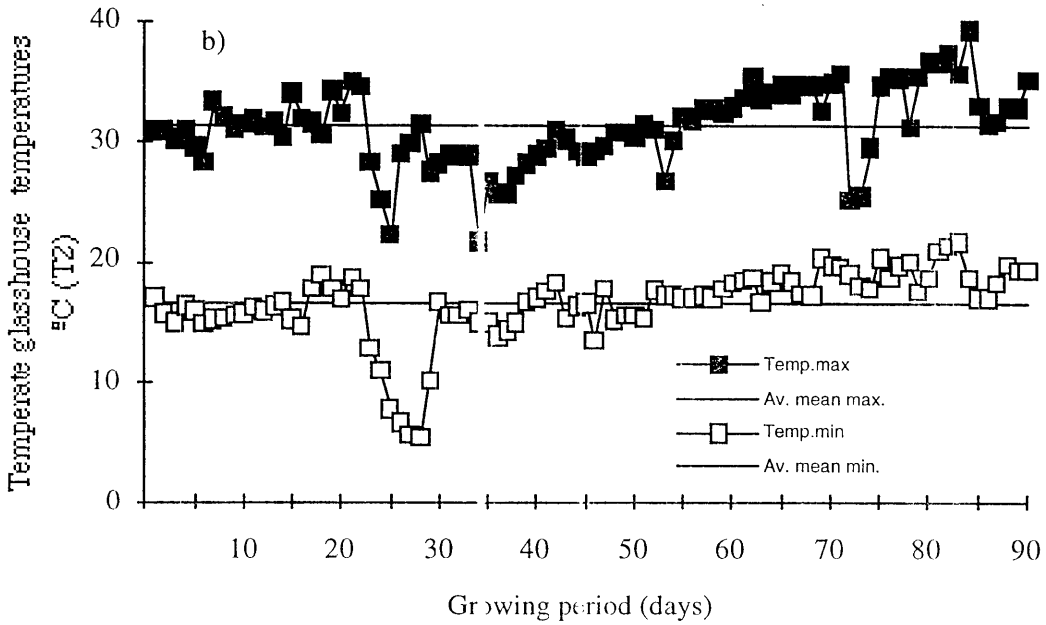

Figure 4.1b Daily maximum, minimum and average maximum and minimum air temperatures for the temperate glasshouse during the growing period (16th November to February 9, 1992 - 1993).

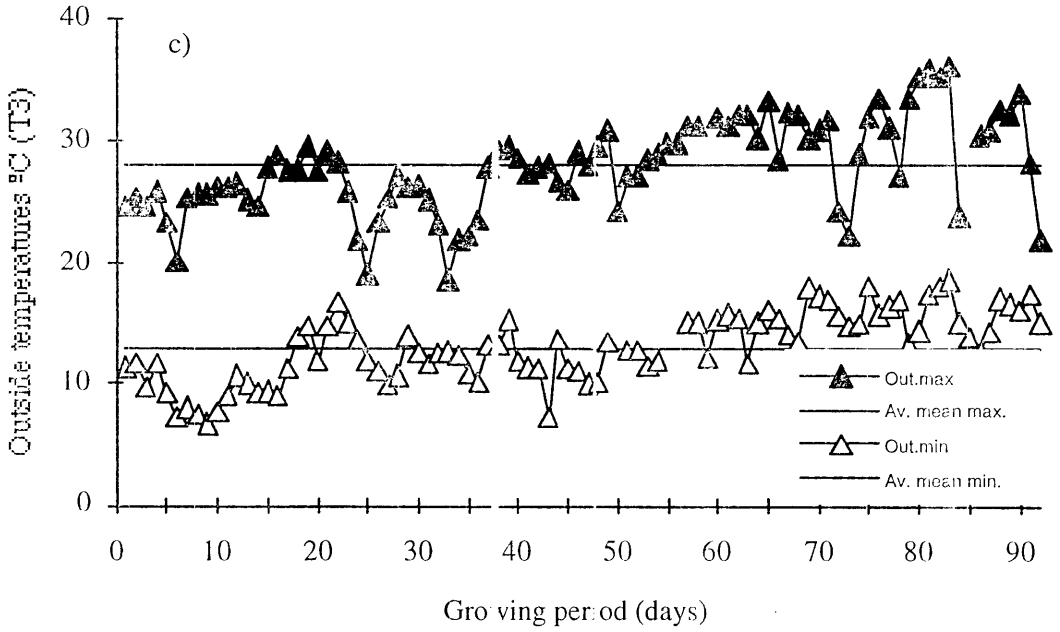

Figure 4.1c Daily maximum, minimum and average maximum and minimum air temperatures outside the glasshouse during the growing period (16th November to March 3, 1992 - 1993).

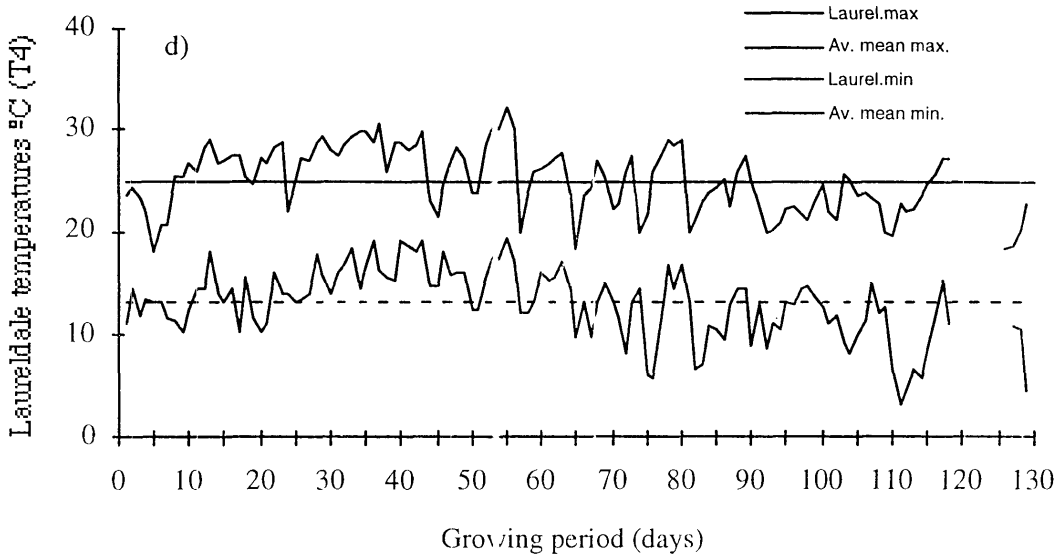

Figure 4.1d Daily maximum, minimum and average maximum and minimum air temperatures at Laureldale during the growing period (14th December to April 20, 1992 - 1993).

4.3.2. Soil temperatures

Recording of soil temperature for outside pot (T3) treatment was started 15 days after seedling emergence. The soil temperatures taken at depths of 5 cm and 10 cm from T3 and T4 treatments are shown in Figures 4.2a-d.. Soil temperatures for tropical (T1) and temperate (T2) treatments were not recorded because it was assumed that both the air and soil temperatures inside each glasshouse were similar.

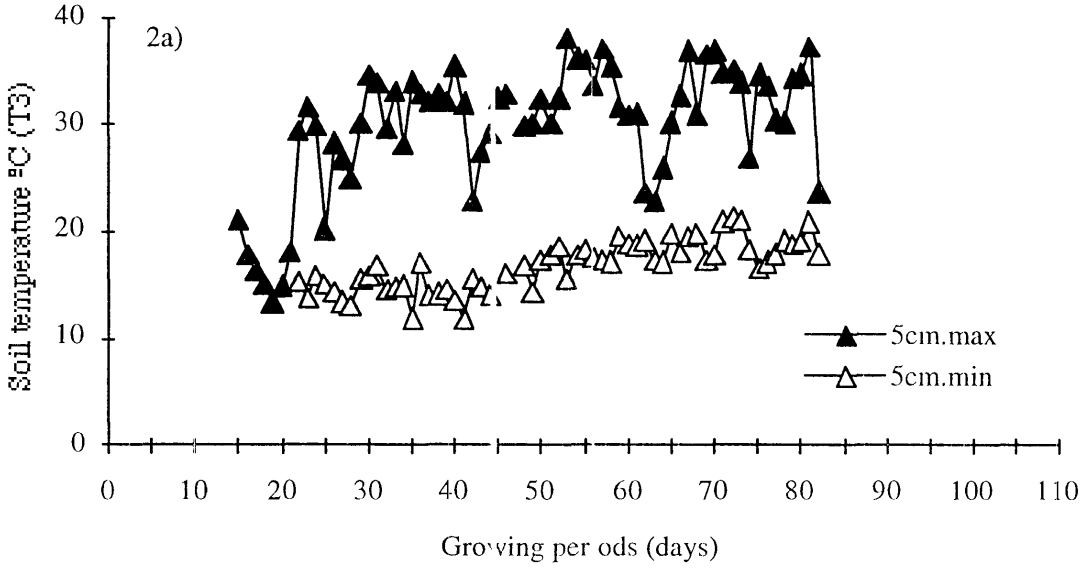

Figure 4.2a Daily maximum and minimum soil temperatures at the depth of 5cm recorded outside the glasshouse in pot (T3) from 30th November to March 3, 1992-1993.

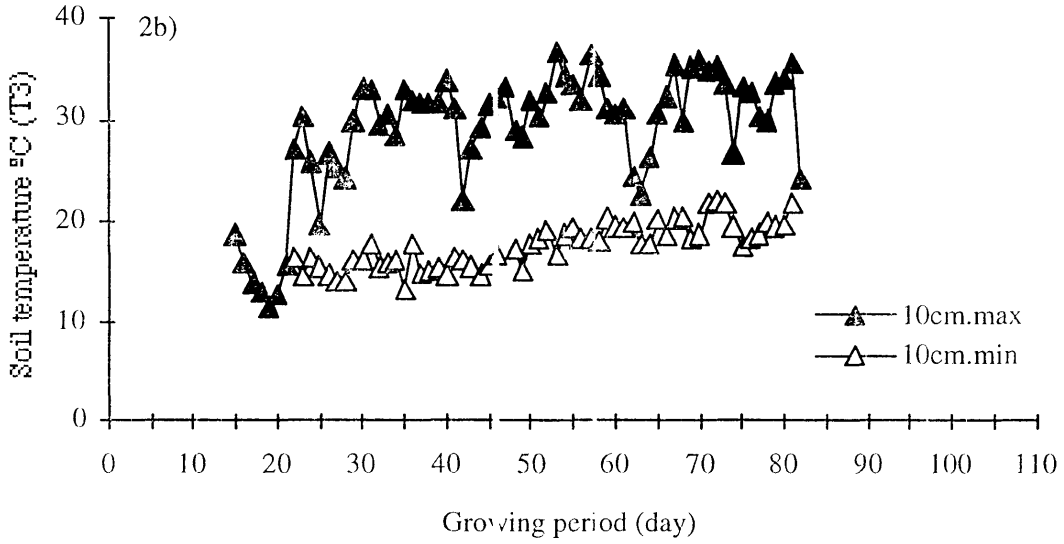

Figure 4.2b Daily maximum and minimum soil temperatures at the depth of 10 cm outside the glasshouse in pot (T3) from 16th November to March 3, 1992-1993.

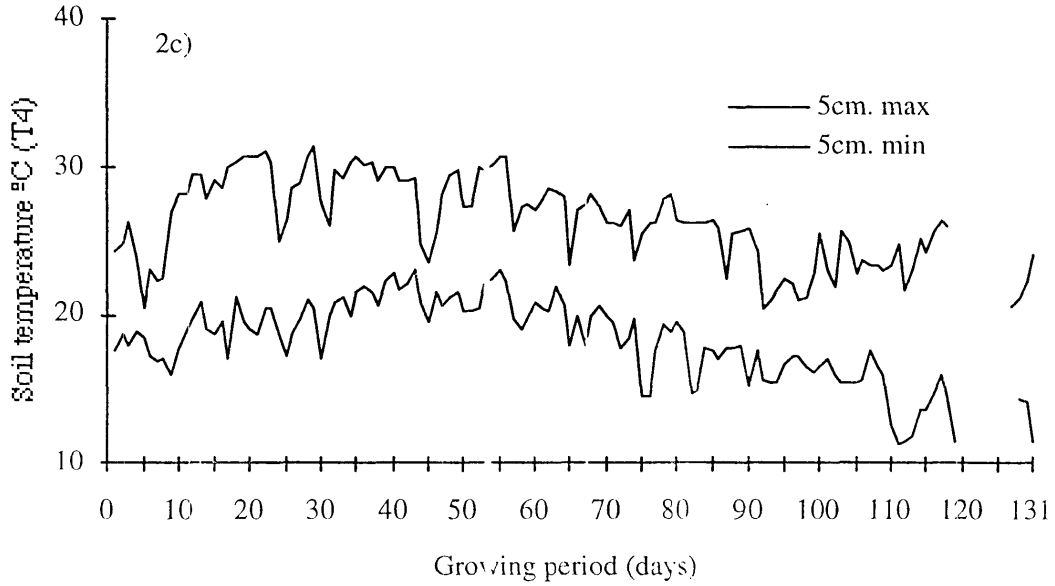

Figure 4.2c Daily maximum and minimum soil temperatures at the depth of 5cm recorded at field (T4) from 14th December to April 20, 1992 - 1993.

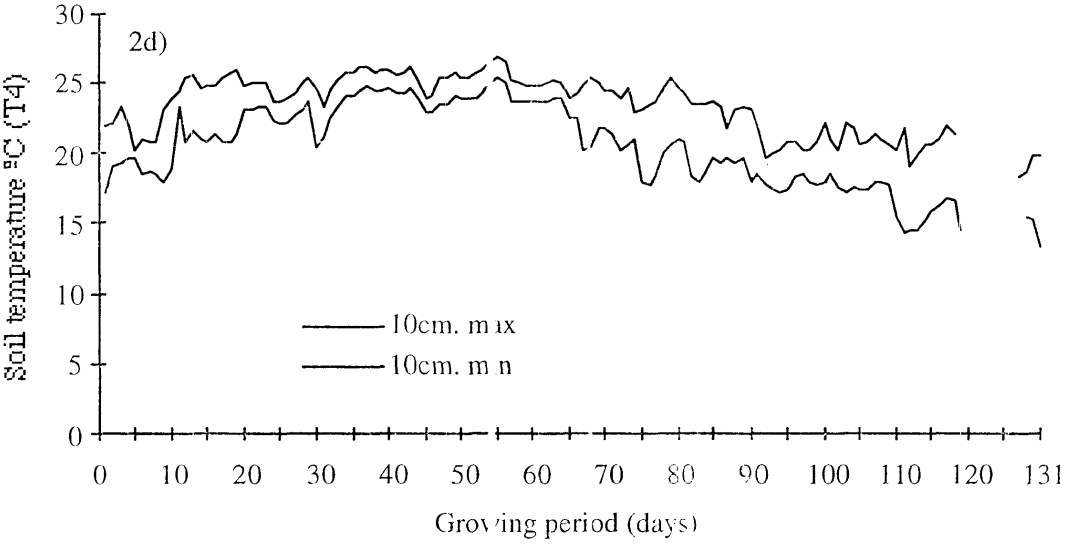

Figure 4.2d Daily maximum and minimum soil temperatures at the depth of 10 cm recorded at field (T4) from 14th December to April 20, 1992 - 1993.

4.3.3. Phenological development

Vegetative stage (seedling emergence to bud emergence)

The mean length of vegetative phase increased in the order T1> T2> T3 but decreased in T4 so that the treatment T2 became similar to T4. Within a treatment, the range in the duration of the vegetative phase across cultivars varied from 8 days under T1 to only 5 days under T2. The order of the cultivars, with increasing length of the growing period is presented in Table 4.2.

Table 4. 2 The response patterns of cultivars to temperature treatments. Values in the parenthesis indicating the days to complete the vegetative phase.

Tropical (T1)	Temperate (T2)	Outside in pot (T3)	Field (T4)
Shinsho (26)	Kiloga (37)	Shinsho (47)	Shinsho (38)
Kiloga (26)	Shinsho (38)	Kiloga (50)	Kiloga (40)
V6-1973A (28)	V6-1973A (38)	Celera (50)	V6-1973A (40)
Celera (32)	Celera (39)	V6-1973A (52)	Celera (41)
Satin (33)	Emerald (42)	Satin (52)	Satin (41)
Emerald (34)	Satin (42)	Emerald (54)	Emerald (41)

Flowering stage (days from flower bud appearance to opening)

Compared to the other stages, temperature differences had the least affect on the length of the flowering phase. The duration of the flowering phase was shortest (6 days) in the T1 treatment but similar in the remaining treatments (T3, 7.8 days; T2, 8.2 days; and T4 8.8 days respectively). The cultivar responses were similar; the shortest in Kiloga (7 days), Celera (7 days), Shinsho (7 days) while longest duration in Emerald (8 days), V6-1973A (8 days) and Satin (9 days). There was no interaction (P>0.05) between cultivar x temperature treatments.

Grain filling stage

There were large variations in the length of the grain filling stage (days from first pod set to changing of first pod colour from green to yellow) due to temperature differences and interactions between cultivar x temperature. There were no differences between the cultivars. The duration of the grain filling stage was longer under field (T4) conditions (32 days) and shortest in T1 (18

days). Emerald had the shortest (17 days) grain filling period at T1 while in the T4 treatment this cultivar took the longest (27 days) time to complete grain filling. Cultivar V6-1973A responded in the reverse way.

Total growing period

Total growing period was shortest in the T1 treatment (56 days) and longest in T3 and T4 (100 and 102 days). However, the proportion of time for each stage varied with temperature treatment (Figure 4.3).

Under the T3 and T4 treatments, where the total period was similar, a shorter vegetative phase under field conditions was balanced by a longer maturation phase (T4) and visa versa for T3.

There were also important interactions between temperature x cultivar. The longest total growing period (87.4 days) was in the cultivar Emerald and the shortest (79.5 days) in Shinsho. But the pattern of cultivar response for total growing period was similar under all the treatments with Shinsho, Kiloga, V6-1973A developing faster than Emerald, Satin, V6-1973A and Celera. In T4 conditions, there was no difference between the cultivar responses (Table 4.3).

Table 4.3 Total days from seedling emergence to harvest for *Vigna radiata* L. under four different temperatures.

Cultivar Treatment	V6-1973A	Emerald	Satin	Kiloga	Celera	Shinsho	Mean
T1	56.4 c	58.0 d	58.3 d	54.9 c	57.4 d	53.0 c	56.3
T2	75.5 b	76.7 c	76.0 c	73.0 b	76.5 c	72.0 b	75.0
T3	103.4 a	104.6 b	98.0 b	98.5 a	96.5 b	98.0 a	99.8
T4	104.5 a	110.3 a	109.0 a	96.4 a	101.8 a	94.9 a	102.8

Within the cultivars, means followed by the same letter are not different at 5% (DMRT).

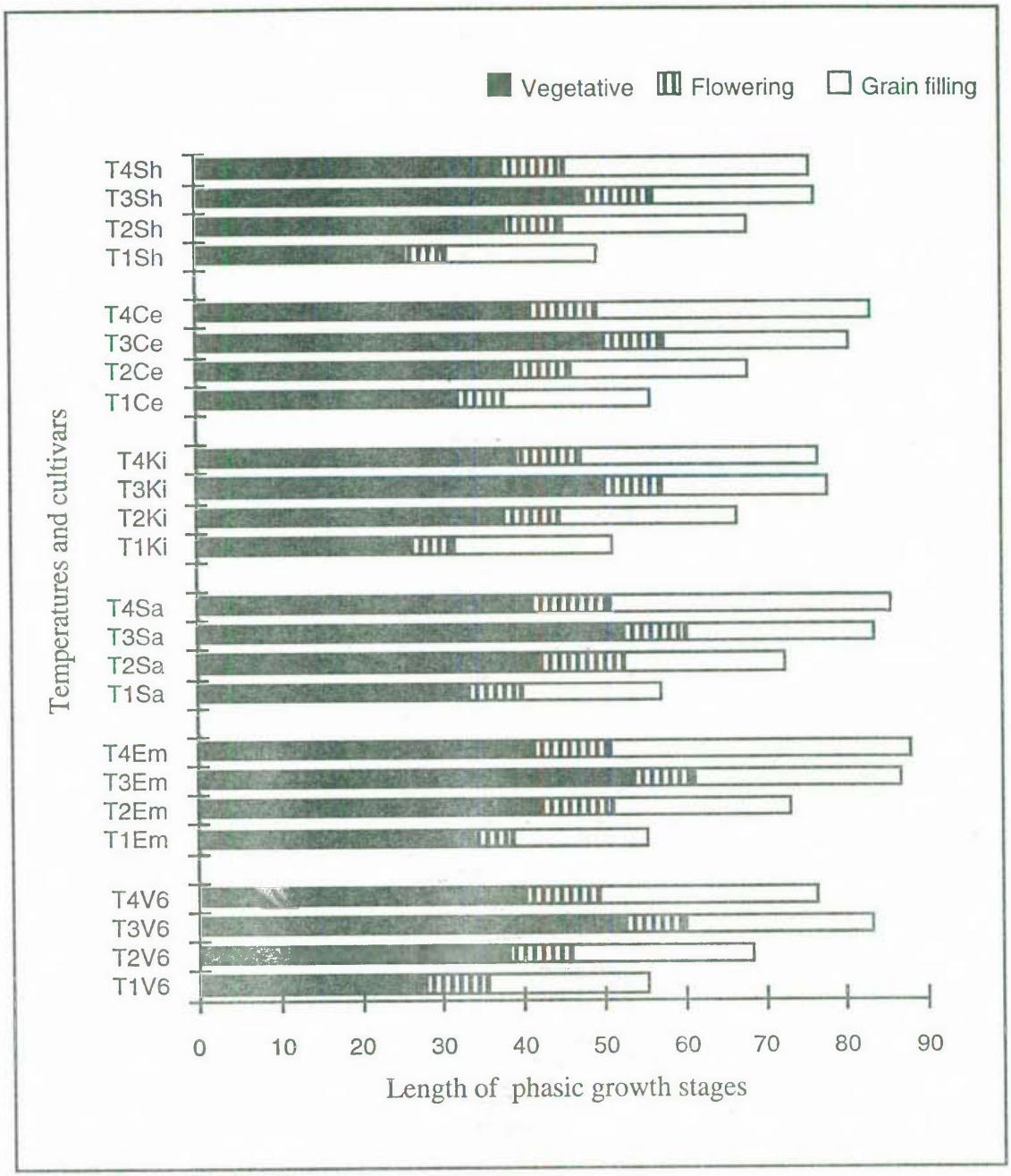

Figure 4.3. Length of phenological stages of Vigna radiata L. at four different temperatures (T1, T2, T3 and T4). The abbreviations used for cultivars are V6=V6-1973A, Em=Emerald, Sa=Satin, Ki=Kiloga, Ce=Celera and Sh=Shinsho.

The significant levels for length of phasic growth stages.

Phases	Vegetative	Flowering	Grain filling
Treatments	*** (0.92)	*** (1.15)	*** (1.48)
Cultivars	*** (0.99)	* (1.1)	ns
Interactions	*** (2.0)	ns	*** (3.63)

Levels of significant difference between means; *P<0.05; *** P<0.001; ns, not significant.

Values within parenthesis are the lsd at P=0.05

4.3.3. Degree days for each growth stage

Degree days to flowering

There were differences in degree day accumulation in the time to flowering between cultivars, treatments and in interactions between cultivar x temperature (Figure 4.4). Most of the cultivars required a similar degree day accumulation between seedling emergence and flowering except in the cultivars Emerald and Satin. These cultivars required significantly more degree days under T1 and T2 conditions to reach flowering than when grown under lower temperatures. The differing temperature treatments did not induce any major changes in day degree requirements for the remaining cultivars.

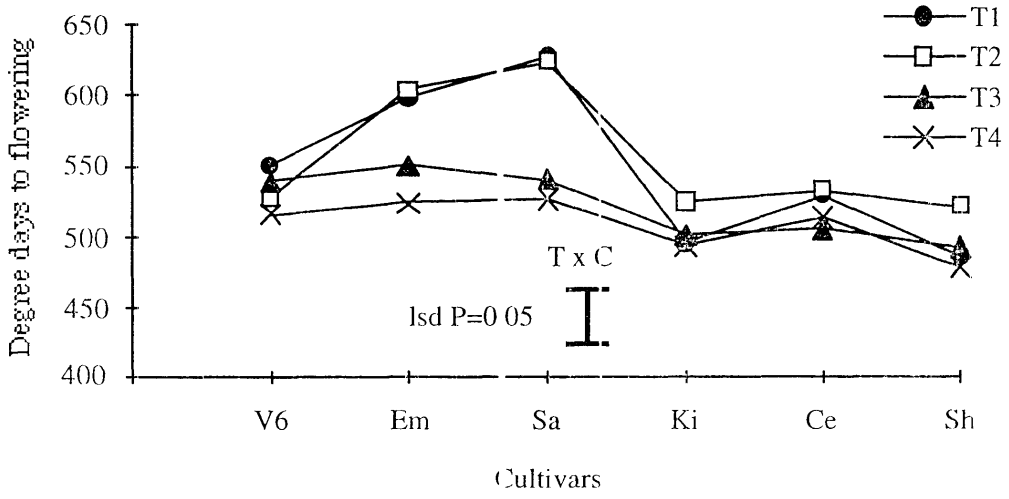

Figure 4.4 Degree days from seedling emergence to flowering at four different temperatures. The lsd value for T= treatment, C= cultivar and TxC= interaction between the treatment and cultivar.

Degree days from flowering to end of grain filling

The number of degree days from flowering to the end of grain filling were similar between the cultivars with the exceptions in cultivar V6-1973A (Figure 4.5). Fewer degree days were accumulated by the plants generally under T3 and T4 conditions. Within the T4 treatment,

maturation occurred in cultivar V6-1973A in half the degree days compared to the remaining cultivars, whereas the same cultivar required the highest degree days total under T1 conditions.

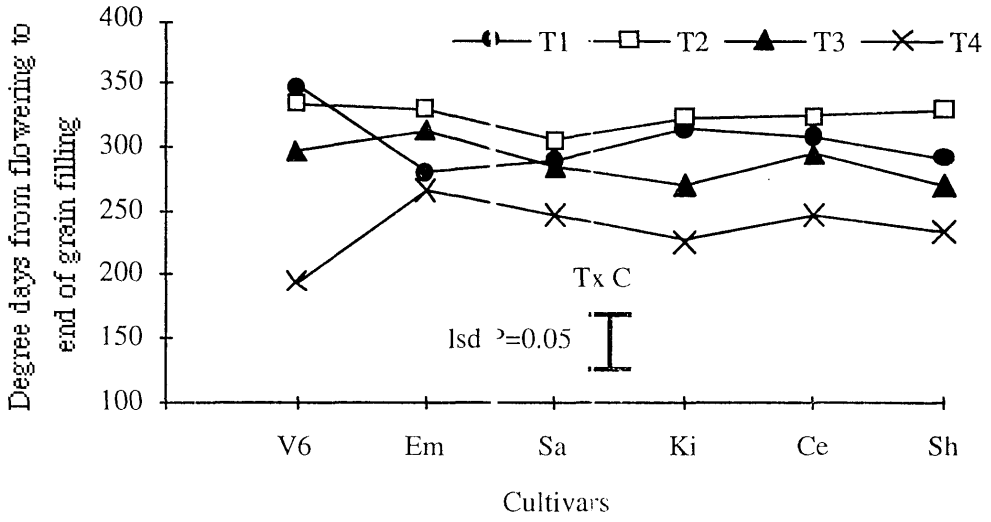

Figure 4.5 Degree days for grain filling of *Vigna radiata* L. at four different temperatures.

Degree days from seedling emergence to harvest

The lowest number of degree days were accumulated by the plants under the T4 (876) and T1 (900) treatments compared to T2 (970) and T3 (968) treatments. Smaller differences between maximum and minimum temperatures lengthened the period of total accumulation of degree days under T4 conditions compared to T2 and T3 conditions.

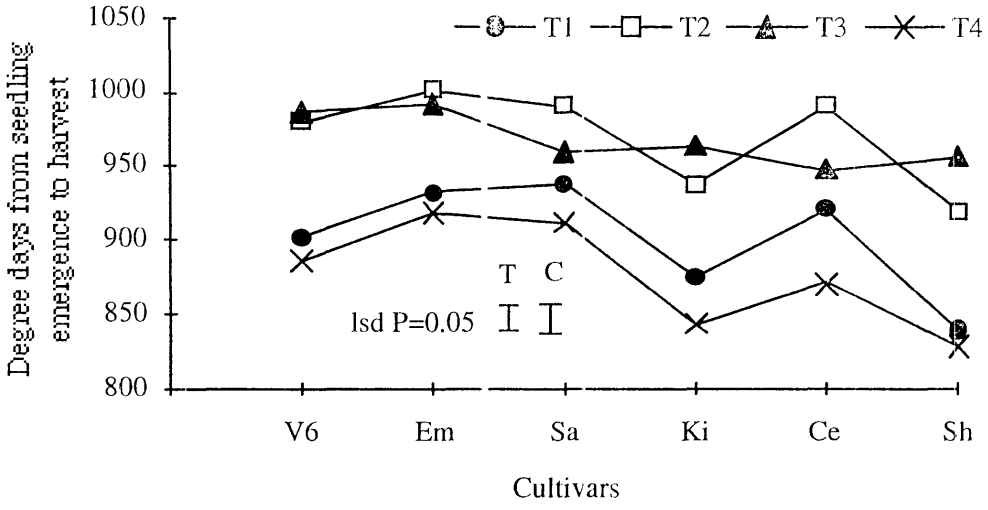

Figure 4.6 Degree days from seedling emergence to harvest of *Vigna radiata* L. at four different temperatures. The lsd value in the figure, T= treatment and C=cultivar.

4.3.4. Growth parameters

Seed germination

From seed sowing to seedling emergence it took an average of 6 days for all the cultivars under all pot conditions but this was extented to 12 days under T4 (field) conditions. There were no differences between the cultivars in seedling emergence rate.

Hypocotyl length

Both temperature and cultivar treatments had major effects on hypocotyl length in mungbean (Figure 4.7). The pattern of response to the treatments was similar for all cultivars with hypocotyl length approximately double for the T1 (tropical) treatment compared to T2 and T4. Hypocotyl lengths of all cultivars were significantly shorter in T3 treatment. The greatest hypocotyl length was produced in the cultivar Shinsho and the shortest in Emerald while the remaining cultivars were similar. There were no interactions between temperature and cultivars.

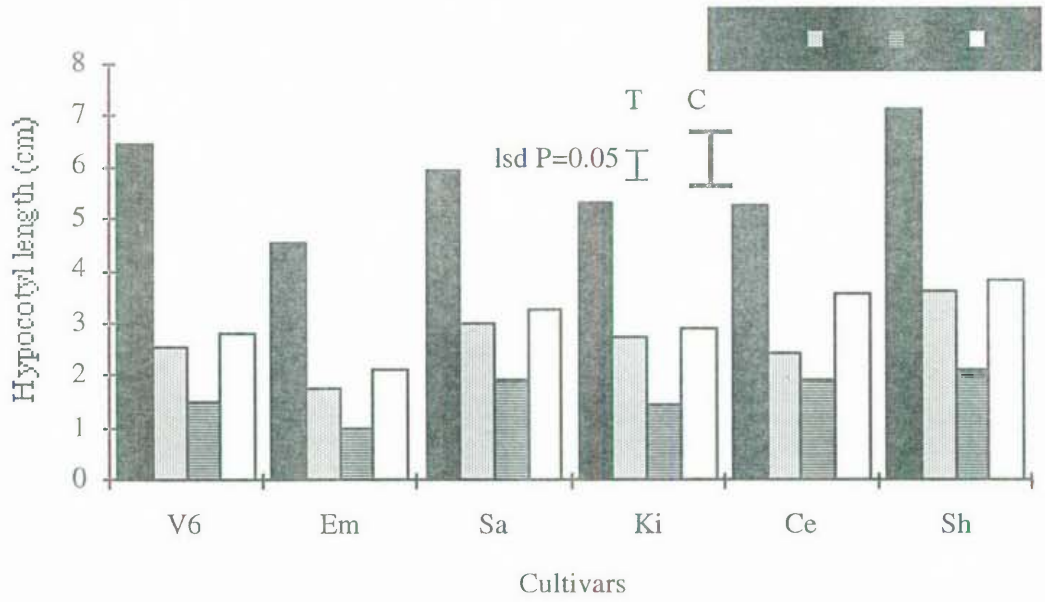

Figure 4.7 Mean hypocotyl length of six different cultivars of *Vigna radiata* L. under four temperatures.

Plant height

The heights were measured at four dates starting from 15 days after seedling emergence and continued up to harvest (Figure 4.9). The tallest plants 15 days after seedling emergence were recorded under T1 and the shortest under the T3 treatments; 30 days after seedling emergence the tallest plants were in the T4 treatment.

Plants were generally tallest under field (T4) conditions (Figure 4.8); this was associated with longer growing period. The cultivars' response to temperature treatments was similar except for Celera in the field, which was short with any temperature (Figure 4.9). The cultivar Celera almost ceased growth after day 45 (Figure 4.9).

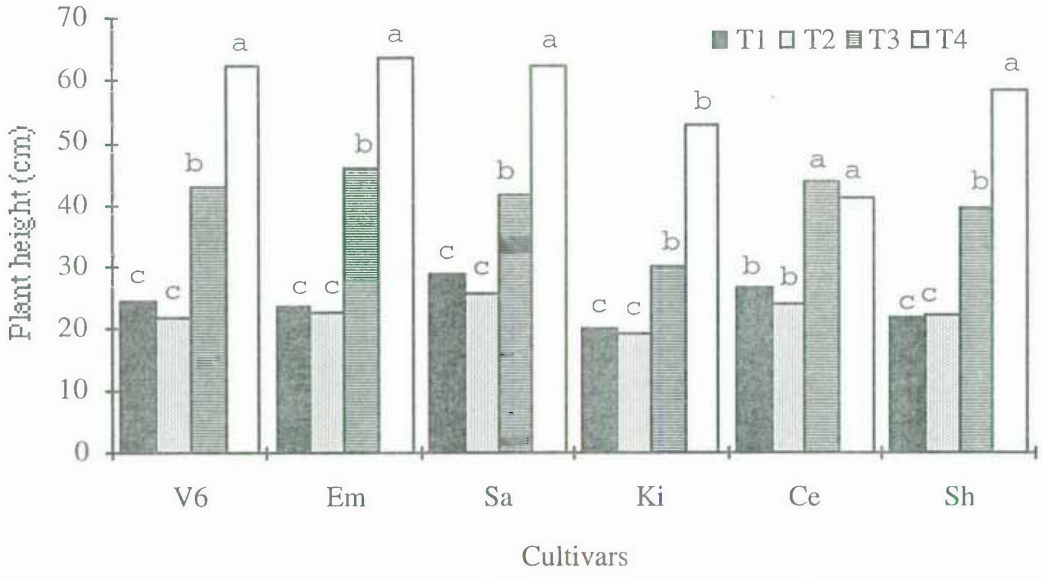

Figure 4.8 Plant height attained at harvest by the six different cultivars of *Vigna radiata* L. grown under four different temperatures. Within the treatment means and those followed by the same letter are not significant at lsd 5%, Duncan's Multiple Range Test.

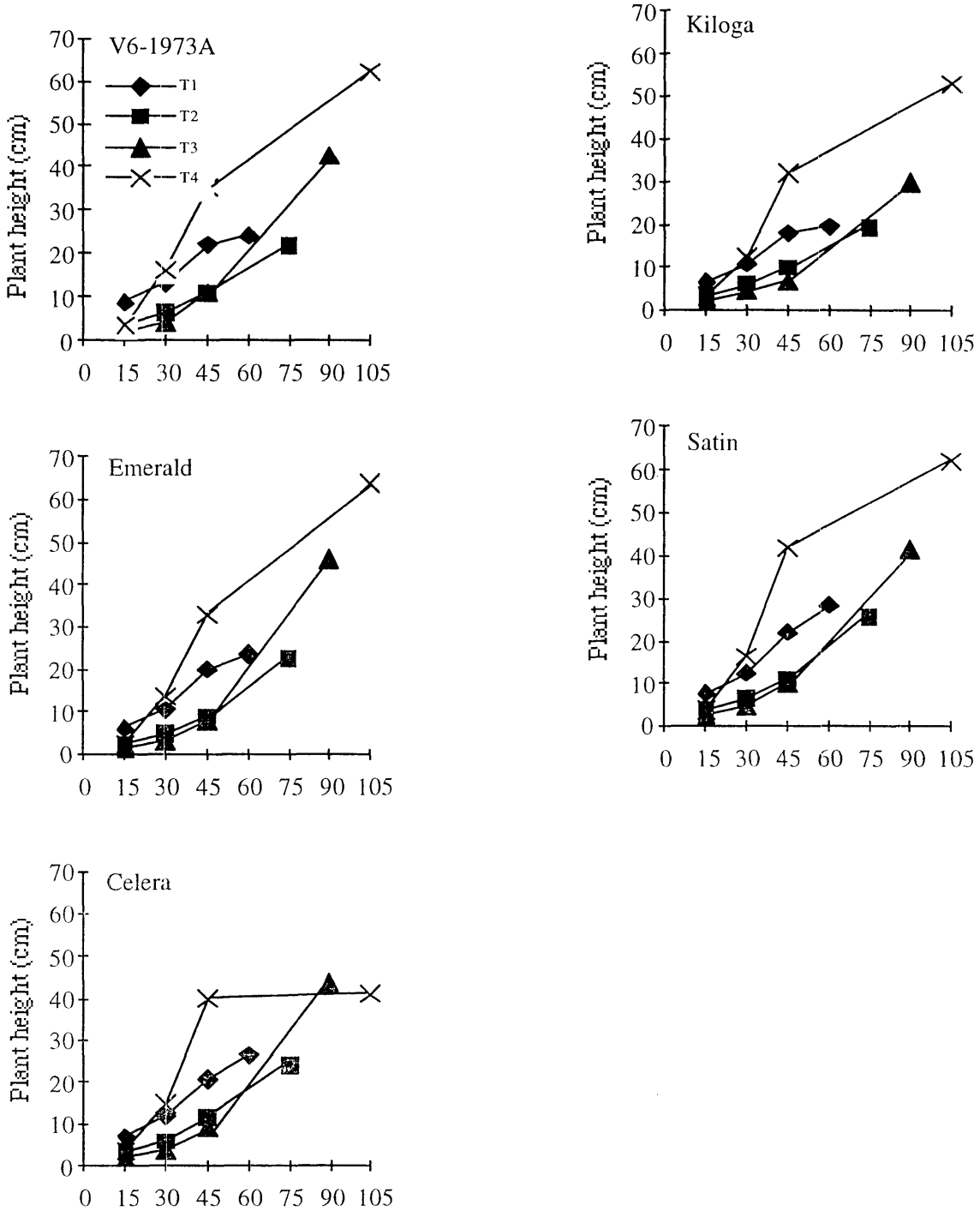

Figure 4.9 Plant heights during the growing period of six different cultivars of *Vigna radiata* L. under four levels of temperature treatments.

Significance levels in plant heights at different times and at harvest.

	15 days	30 days	45 days	Harvest
Treatments	***(0.39)	***(0.63)	ns	***(4.97)
Cultivars	***(0.42)	***(1.1)	ns	***(3.8)
Interactions	**(1.83)	ns	ns	**(8.3)

Levels of significant difference between means; ***P=0.001; **P=0.01; ns=not significant. Values within the parenthesis are the lsd values at 5% (DMRT).

Node number

The number of nodes per plant at harvest was strongly influenced by the temperature treatments (Figure 4.10). The highest number of nodes were produced in the T4 treatment with progressive decreases in the T3, T2 and the T1 treatments. The response patterns in node number were similar between cultivars. The interactions between cultivar x treatments were significant and the cultivar Celera produced the highest number of nodes under T1 treatment compared to remaining cultivars, while under T3 treatment it produced the lowest.

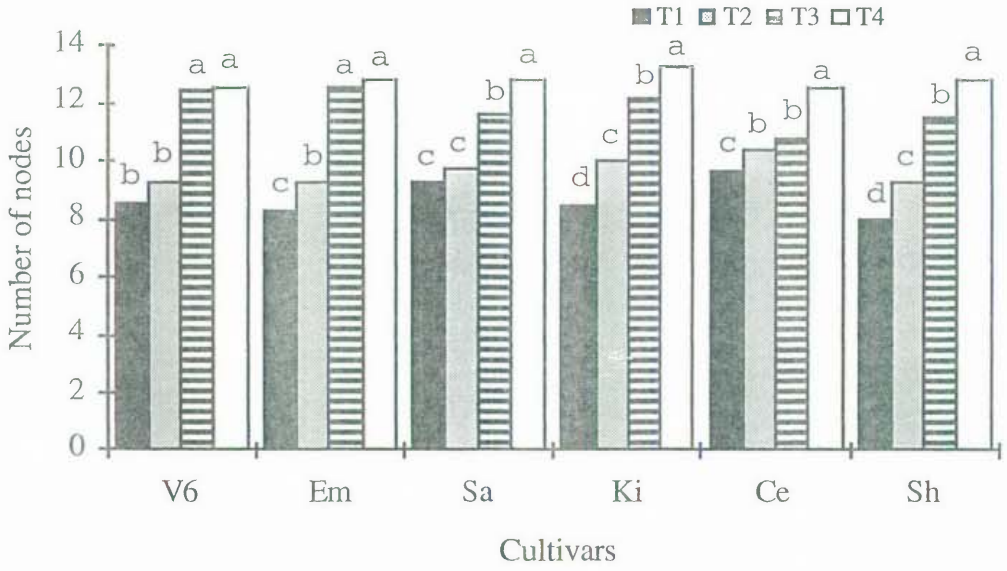

Figure 4.10 Number of nodes in six different cultivars of *Vigna radiata* L. at four temperature treatments. Within cultivars, figures with the same letter are not different (P=0.05), Duncan's Multiple Range Test.

Branch number

The highest branch number was produced by the plants under the T4 treatment (with a longer growing period) while the short growing period in T1 reduced the branch number drastically (Table 4.4). The branch number was highest with the cultivars V6-1973A and Kiloga and the lowest in Emerald. There were no interactions (P>0.05) between cultivar x treatments.

Table 4.4 Branch number of six different cultivars under four temperature conditions.

Cultivars Treatments	V6-1973A	Emerald	Satin	Kiloga	Celera	Shinsho	Mean
T1	3.9 b	1.3 c	2.2 c	4.5 c	3.0 c	2.5 c	2.9
T2	3.8 b	2.5 c	2.5 c	4.3 c	3.5 c	2.8 c	3.2
T3	7.0 a	4.3 b	5.3 b	6.0 b	5.0 b	6.3 a	5.8
T4	7.3 a	6.1 a	5.9 a	6.8 a	5.5 a	5.9 b	6.4

Within cultivars, figures followed by the same letter are not different at 5% (DMRT).

Leaf area

There were progressive increases (P<0.001) in leaf area under the pot growing conditions T1> T2>T3 with the highest leaf area being produced under T4 conditions (associated with the longer growing period). All the cultivars produced similar leaf area under each temperature treatment (Table 4.5).

Table 4.5 Leaf area (cm2) per plant of different cultivars under four temperature conditions.

Cultivars Treatments	V6-1973A	Emerald	Satin	Kiloga	Celera	Shinsho
T1	36016 b	35604 b	36498 c	27766 c	28416 b	31408 c
T2	36794 b	45059 b	41719 bc	46230 bc	38806 b	42805 c
T3	132906 b	114520 b	141875 b	138713 b	130596 b	157093 b
T4	582962 a	406529 a	514427 a	325472 a	338356 a	383671 a

Within cultivars, treatments followed by the same letter are not statistically different at 5% lsd, Duncan's Multiple Range Test.

Vegetative dry matter

Total vegetative dry matter (Figure 4.11) at maturity reflected differences in the total growing period and in growing conditions. The vegetative dry matter was much higher in T4 in all cultivars and showed progressive increases from T1> T2> T3 treatments. The pattern of response between cultivars was similar while the interactions between cultivar x treatment were significant ($P<0.05$). Under T4 treatment cultivar V6 and Satin produced more vegetative dry matter (VDM) than the remaining cultivars.

Vegetative dry matter partitioning

There were major differences in pod, leaf and stem dry weights between the temperature and cultivar treatments (Figures 4.11). As a proportion of total dry matter the greatest dry matter was in pods.

The highest pod dry weight occurred in field (T4) conditions and decreased with the increasing temperatures T3> T2> T1 (Figure 4.11 . V6-1976A produced the highest pod dry weights under field (T4) conditions and Celera the lowest compared to the remaining cultivars.

Leaf dry weight production was highest in T4 treatment and progressively increased with decreasing temperatures from T1< T2< T3 (Figure 4.11). Cultivar response patterns varied significantly under the T4 treatment and was similar under remaining temperatures. Emerald produced the highest leaf dry weight and Kiloga the lowest in the T4 treatments compared to the remaining treatments.

The highest stem dry weight occurred under field conditions (T4) and it gradually decreased with increasing temperatures from T3> T2> T1 (Figure 4.11). V6-1973A produced the highest dry weight under the T4 conditions; there were no consistent relationship between dry weight production in plant fractions and temperature treatments.

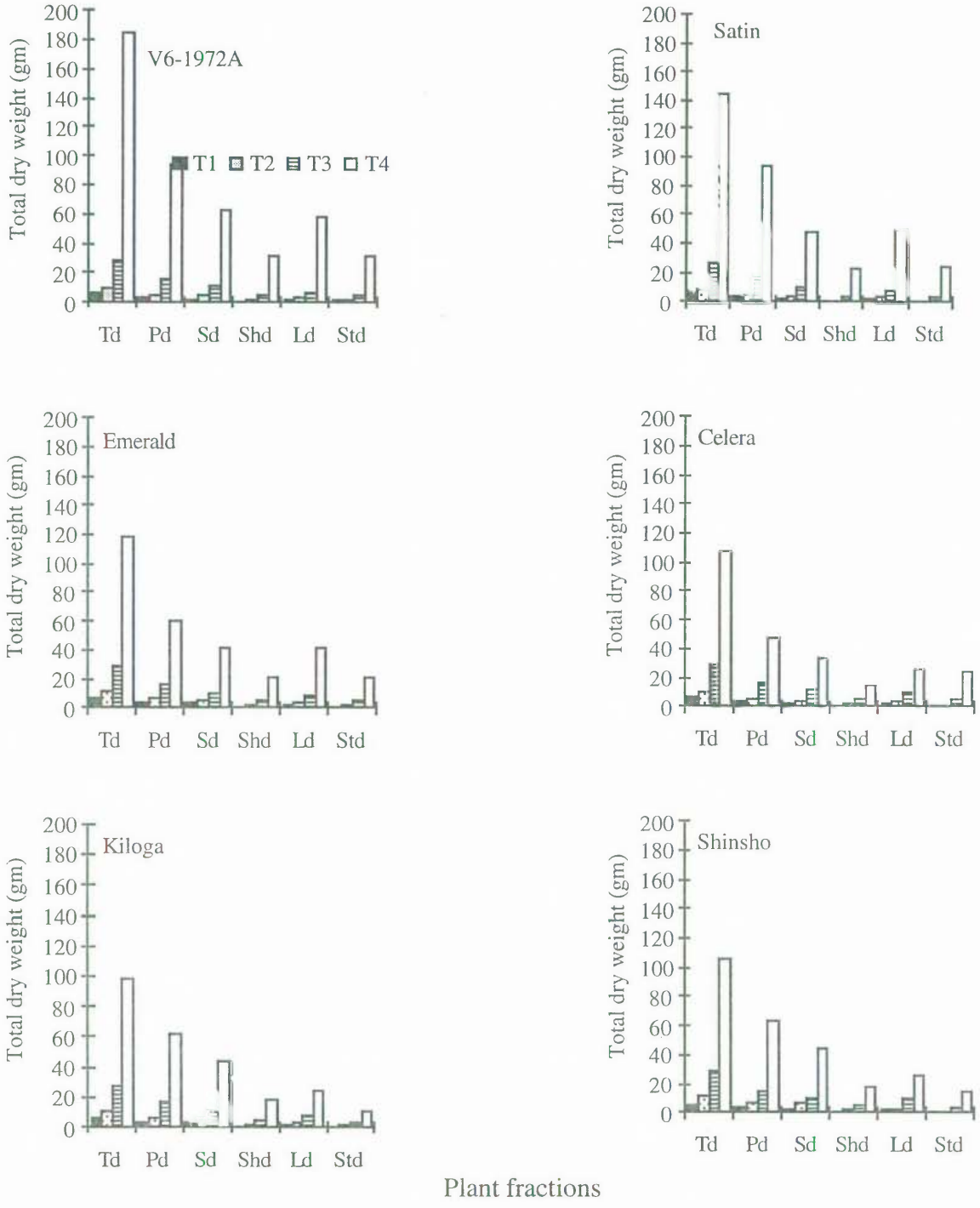

Figure 4.11 Total vegetative dry weight and its partitioning into plant fractions at harvest in six cultivars of *Vigna radiata* L. under four temperatures. The abbreviations in graphs are, Td= Total, Pd= Pod, Sd= Seed, Shd= Pod wall, Ld= Leaf and Std=Stem dry weight respectively.

Significance levels in plant fraction dry weights after harvest.

	Td	Pd	Sd	Shd	Ld	Std
Treatment	***(15.1)	***(7.8)	***(5.6)	***(2.2)	***(4.2)	***(2.5)
Cultivars	*(14.3)	*(6.7)	ns	**(2.0)	**(5.6)	***(2.2)
Interactio ns	***(45.3)	**(14.2)	*(10.1)	***(4.3)	***(10.2)	***(4.7)

Values within the parenthesis are lsd at 5%. Significant difference between means ***P=0.001; **P=0.01; *P=0.05; ns= not significant at P=0.05.

4.3.5. Yield and yield contributing characters

Seed Yield

The greatest seed yield was in the T4 treatment; in the remaining treatments yield increased with decreasing temperatures (T1< T2< T3) (Figure 4.12). In the T4 treatment, cultivar V6-1973A produced the highest seed yield and Celera the lowest while there was little difference in remaining cultivars. The variations in seed yield across the temperature treatments reflected the trend of total vegetative dry matter (Figure 4.11).

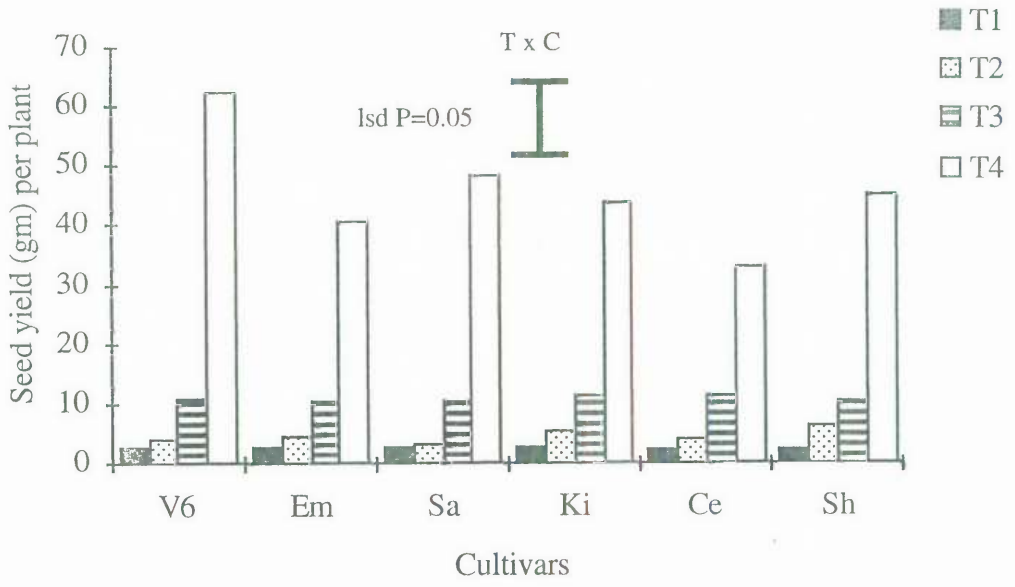

Figure 4.12 Seed yield per plant of *Vigna radiata* L. under four temperature treatments.

There was a strong correlation between seed yield and seed number with different growing conditions (Figure 4.13). The yield of individual cultivars was more strongly related with the seed number and for most of the cultivars the correlation coefficient was very high (Figure 4.15).

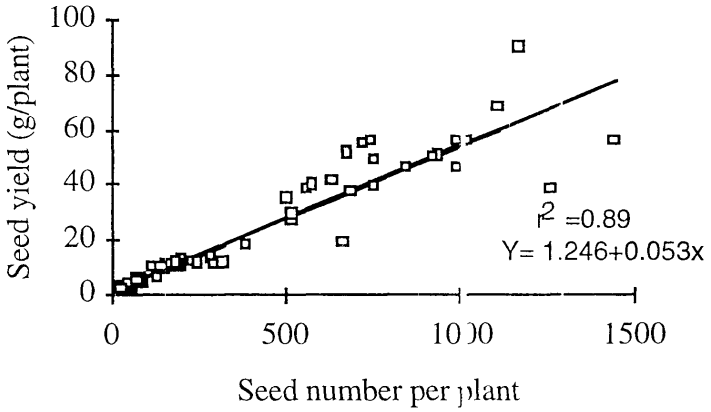

Figure 4.13 The relationship between seed yield and seed number of mungbeans grown under four temperature treatments.

Seed yield was also positively correlated with the number of flowers produced under pot growing (Figure 4.14) conditions.

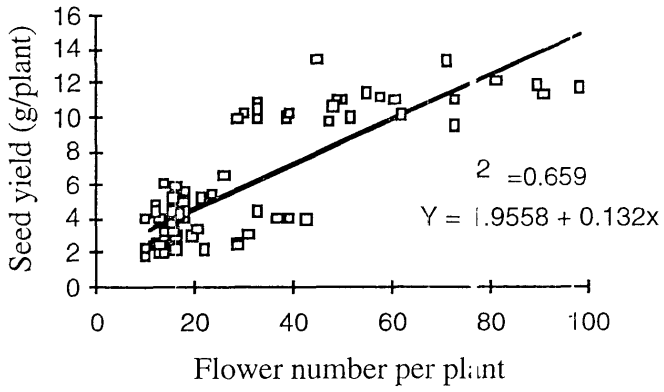

Figure 4.14 Relationship between yield and flower number of mungbean under for temperature treatments.

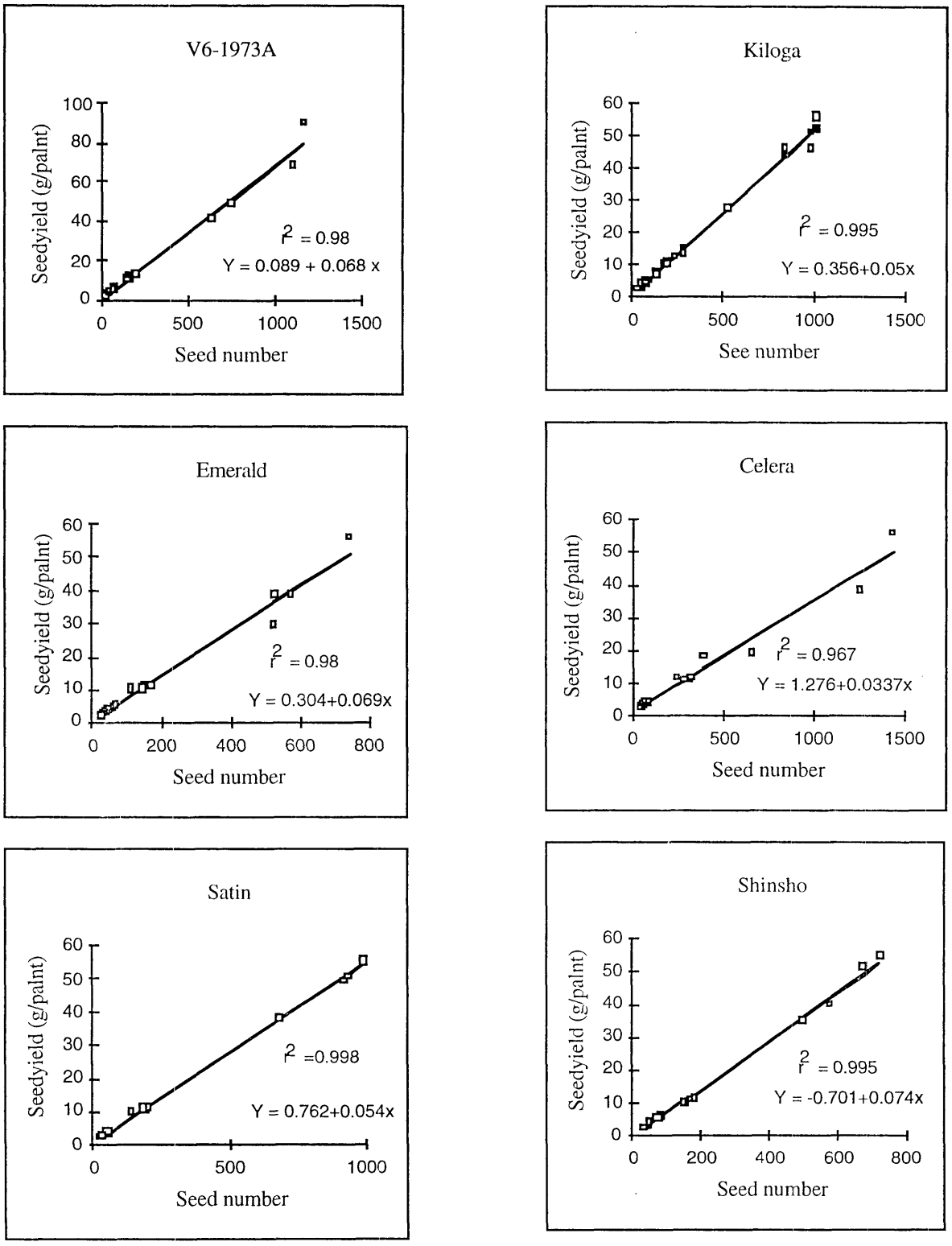

Figure 4.15 The relationshipbetweer yield and seed number of mungbean cultivars under different growing conditions.

Number of flowers per plant

The highest flower number occurred in T3 with similar numbers in T1 and T2; data from the T4 treatment could not be collected due to rainfall (Figure 4.16). There was a positive correlation between flower numbers and pods in pot growing conditions with decreasing temperatures (T1< T2< T3). The regression equation is Y= 0.339 + 1.83x with correlation coefficient r2 = 0.84.

Cooler temperature in T3 treatment increased flower number more in Celera than in other cultivars.

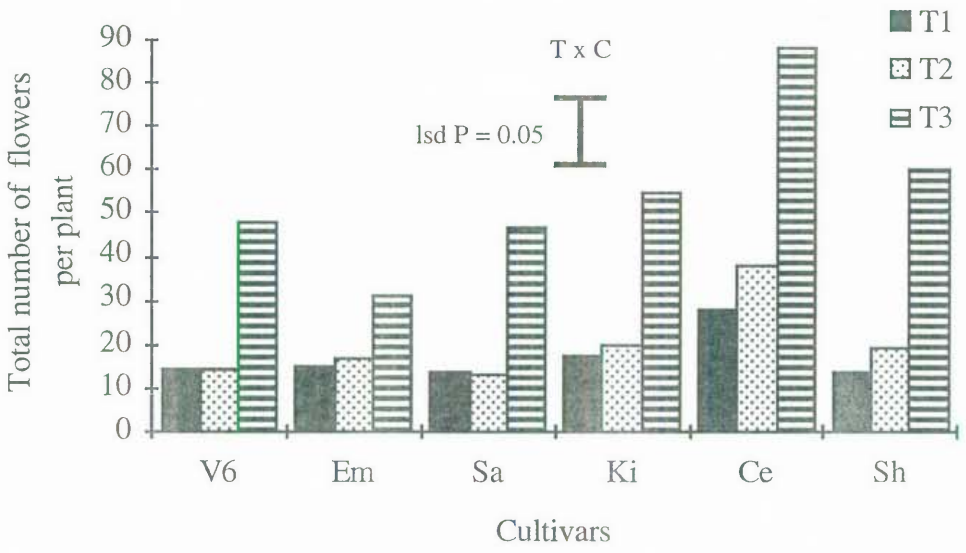

Figure 4.16 Total number of flowers under three different temperatures.

Pod number

Pod number per plant is one of the most important yield contributing factors. Pod number consistently declined as temperature increased from T3, T2 to T1 (Figure 4.17). The cultivars produced similar number of pods except Celera under T3, which had almost twice that of the other cultivars. In the T4 treatment Celera and Emerald produced the highest number of pods and Shinsho the lowest.

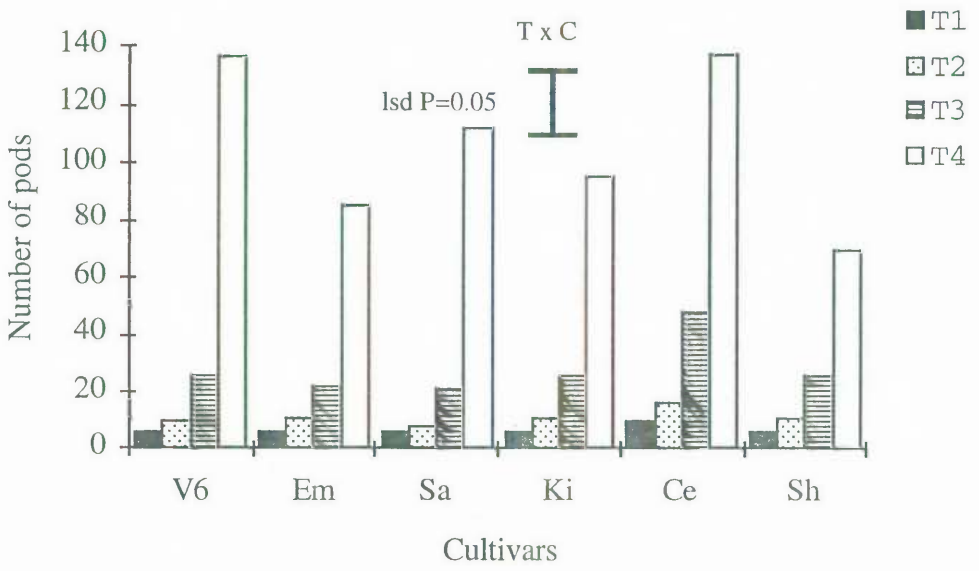

Figure 4.17 Number of pods per plant of *Vigna radiata* L. grown under four different temperature treatments.

Percentage of flowers which set pods

Plants under temperate (T2) conditions showed an increase in the percentage pod set (Figure 4.18). The percentage of pod set under T2 was similar to T3 but different from the T1 treatment. Due to rainfall at the time of flowering, data in T4 treatment could not be collected. There was no cultivar x temperature interaction.

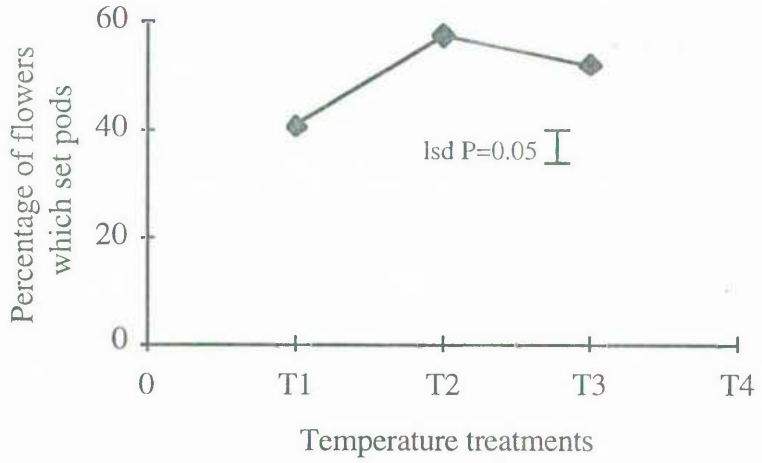

Figure 4.18 Percentage of flowers which set pods in *Vigna radiata* L. grown under three temperature treatments.

Number of pods per node

All the treatments grown in pots (T1, T2 and T3) had similar numbers of pods per node; the field treatment T4 had large increases in all cultivars (Table 4.6). The highest number of pods per node produced by Celera in T4.

Table 4.6 Number of pods per node of six different cultivars of *Vigna radiata* L. grown under four different temperature treatments.

Cultivars Treatments	V6-1973A	Emerald	Satin	Kiloga	Celera	Shinsho	Mean
T1	2.1 b	2.7 b	2.3 b	2.1 b	2.7 b	2.4 b	2.4
T2	2.5 b	3.3 b	2.5 b	2.3 b	2.7 b	2.6 b	2.6
T3	2.7 b	3.2 b	3.0 b	3.1 b	5.2 b	2.8 b	3.3
T4	12.3 a	8.7 a	10.3 a	8.7 a	12.8 a	6.7 a	9.9

Within the cultivars figures followed by the same letter are not different at 5% (lsd), Duncan's Multiple Range Test.

Number of seeds per pod

The greater number of seeds per pod were obtained in the T3 and T4 treatments (Table 4.7). Even with large increases in pods per node at T4, seed number per pod was maintained. Meaned over temperatures, Kiloga had the highest seed number per pod. There were no interactions between cultivar x treatment.

Table 4.7 Seed number per pod of *Vigna radiata* L. grown under four temperatures.

Cultivars Treatments	V6-1973A	Emerald	Satin	Kiloga	Celera	Shinsho	Mean
T1	5.2	6.0	7.1	7.5	5.2	5.9	6.2 b
T2	5.5	5.2	5.2	8.8	4.9	7.2	6.3 b
T3	6.6	6.9	8.9	8.8	6.1	6.5	7.3 a
T4	6.8	7.0	7.9	8.7	6.8	8.9	7.7 a
Means	6.0 d	6.3 cd	7.5 ab	8.5 a	5.8 d	7.1 bc	

For the mean effects of temperature and cultivar, figures with the same letter are not different (P=0.05), Duncan's multiple Range Test.

Number of seeds per plant

The greatest number of seeds per plant was produced in T4; further smaller decreases occurred from T3> T2> T1 (Figure 4.19). Seed numbers in the field treatment (T4) were 3, 12 and 20 fold higher than T3, T2 and T1 respectively. Celera and V6-1973A produced the highest seed number per plant and Emerald the lowest number of seeds per plant under T4 conditions. There were no interactions between cultivar x treatment.

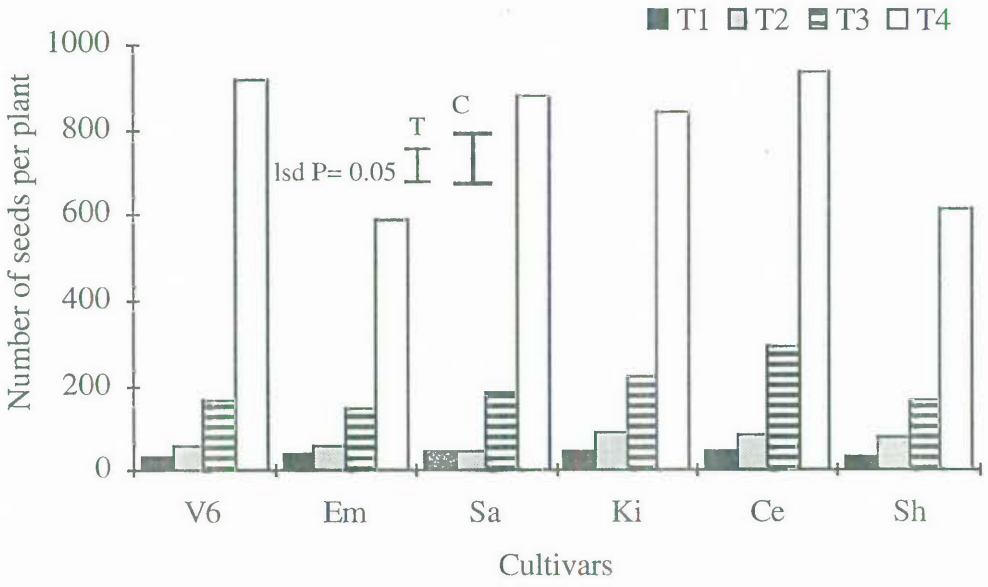

Figure 4.19 Number of seeds per plant produced under different temperature treatments.

Thousand seed weight

The increased seed number per plant reduced the thousand seed weight under T4 and T3 treatments; the reverse occurred in T2 and T1 conditions (Table 4.8). The maximum mean seed weight was produced by the cultivars Emerald, V6-1973A and Shinsho with the lowest in Celera.

Table 4.8 Thousand seed weight (g/plant) of *Vigna radiata* L. grown under four temperature treatments.

Cultivars Treatments	V6-1973A	Emerald	Satin	Kiloga	Celera	Shinsho	Mean
T1	83.57	79.19	71.67	64.06	54.60	73.15	71.0a
T2	78.45	80.93	75.04	66.30	50.58	81.11	72.1a
T3	66.69	72.89	57.71	51.17	39.83	63.09	58.6b
T4	67.30	68.02	56.23	51.94	36.34	72.77	58.8b
Mean	74.0 a	75.26 a	65.16 b	58.37 c	45.34 d	72.53 a	

For the mean effects of temperatures and cultivars, figures with same letter are not statistically different (P=0.05), Duncan's Multiple Range Test.

Reproductive index (RI)

Reproductive index (RI), the ratio between total productive nodes (i.e. those that produce seed) and total number of nodes, is an indicator of seed yield. Temperature and cultivar treatments and their interactions induced major changes in RI (Figure 4.20). In half the cultivars the greatest number of productive nodes were produced under T4 conditions; higher temperatures (T2 and T1) reduced RI in all cultivars.

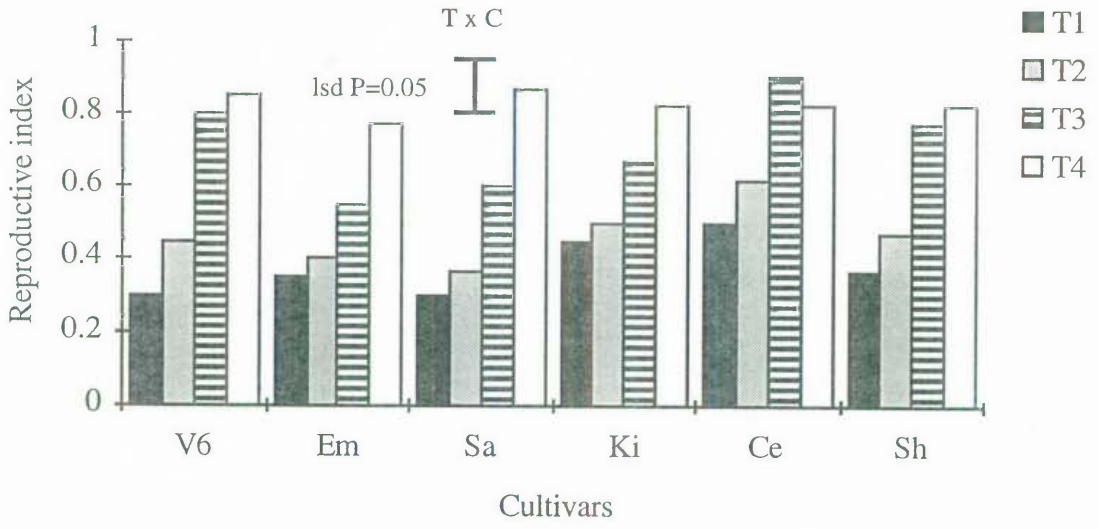

Figure 4.20 Reproductive index of *Vigna radiata* L. grown under four temperature treatments.

Harvest index

Harvest index (HI) is the ratio of seed yield to the total biomass produced, expressed as a percentage; it was lowest in the T3 and T4 treatments (Table 4.9). The highest HI occurred in the cultivars Kiloga and Shinsho. There were no interactions between cultivar x temperature.

Table 4.9 Harvest index of *Vigna radiata* L. grown under four temperature treatments.

Cultivars Treatments	V6-1973A	Emerald	Satin	Kiloga	Celera	Shinsho	Mean
T1	0.52	0.44	0.46	0.48	0.40	0.44	0.46 a
T2	0.43	0.41	0.38	0.54	0.40	0.58	0.46 a
T3	0.39	0.37	0.38	0.42	0.39	0.36	0.39 b
T4	0.33	0.34	0.33	0.44	0.30	0.43	0.37 b
Means	0.42 b	0.39 b	0.39 b	0.47 a	0.38 b	0.45 ab	

For the mean effect of temperatures and cultivars, figures with the same letter are not different (P=0.05), Duncan's Multiple Range Test.

4.3.6 Post harvest parameters

Protein content of different plant fractions of mungbean

Seed protein

The percentage protein in seed was lowest under the T3 treatment compared to remaining treatments (Table 4.10). Under field conditions high soil nutritional status and more root production probably increased the protein content compared to pot conditions in the T3 and T2 treatments. The mean protein concentration in cultivars Satin, Emerald and V6-1973A were similar and higher than Kiloga, Celera and Shinsho. There were no interactions between cultivar x temperature.

Table 4.10 Percentage seed protein of mungbean grown under four different temperature conditions.

Cultivars Treatments	V6-1973A	Emerald	Satin	Kiloga	Celera	Shinsho	Mean
T1	25.8	23.5	26.9	24.4	23.4	24.5	24.8 a
T2	22.9	24.8	24.3	23.2	22.3	23.7	23.5 a
T3	20.4	20.4	22.1	18.4	18.1	18.8	19.7 b
T4	25.5	24.8	26.2	24.5	24.1	22.7	24.6 a
Mean	23.7 abc	23.4 ab	24.9 a	22.6 bc	21.9 c	22.4 bc	

Means followed by the same letters are not significantly different at P=0.05 (DMRT).

Protein content in leaf

Leaf protein levels after harvest were higher in the T1 treatment and declined in all other treatments (Figure 4.21) particularly T3 and T4.

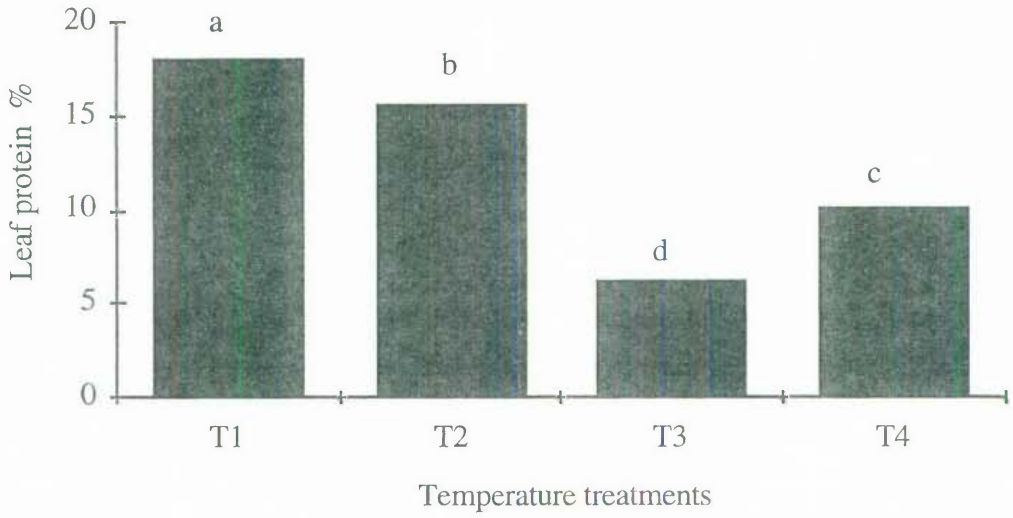

Figure 4.21 The mean percentage protein content in leaf material after harvest from T1, T2, T3 and T4 treatments. The letter indicate differences at P=0.05, DMRT.

Protein content in stem

The stem protein content was highest under T1 and T2 treatments (Figure 4.22). The cultivars Kiloga and Shinsho maintained the highest protein content under the T1 and T2 treatments.

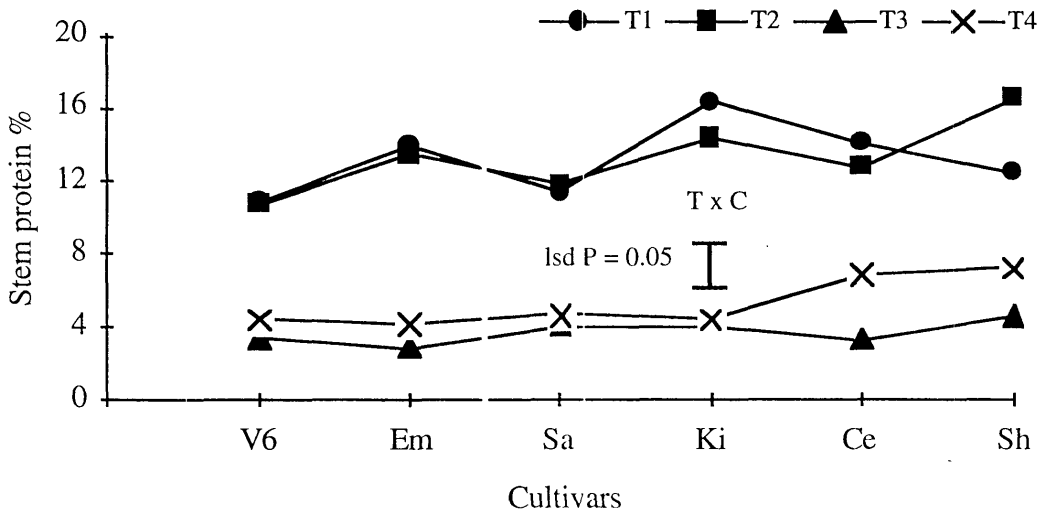

Figure 4.22 Protein content in mu ıgbean stem grown under four different temperature treatments.

4.3.7. Germination tests

Germination percentage

Germination tests of harvested seeds (Figure 4.23) indicated interactions between cultivar and growing temperature. A higher percentage germination occurred under T1, T2 treatments than the T3 and T4. Close to one hundrec percent germination was obtained in Shinsho under all temperature treatments; Celera had the lowest percentage of germination under most treatments. Both Celera and Emerald showed reduced germination % with any reduction in growing temperatures.

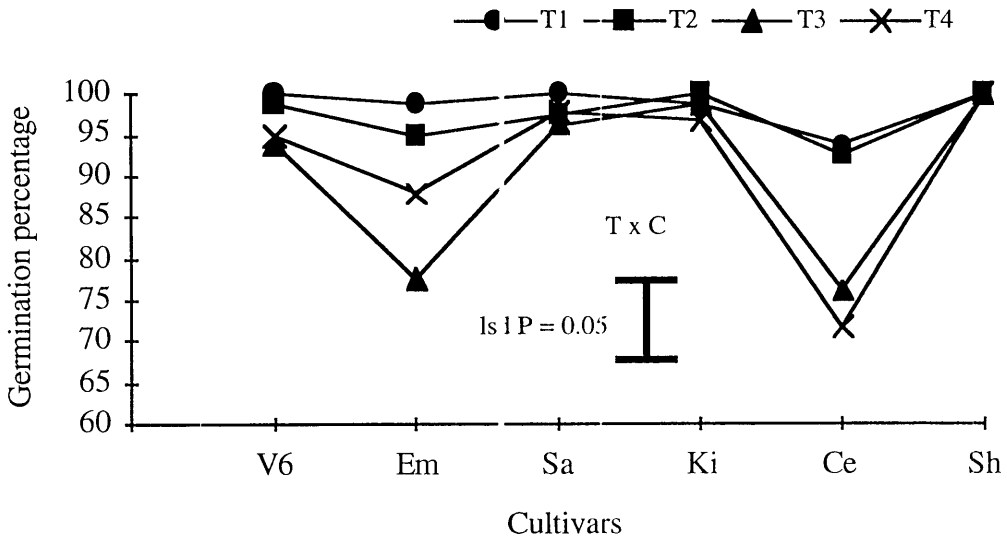

Figure 4.23 Germination percentage of seeds tested in growth cabinet (25°C) after harvest from T1, T2, T3 and T4 treatments.

Hypocotyl length

Seeds produced under the T1 treatment developed significantly longer hypocotyls followed by those under T2, T3 and T4 respectively (Table 4.11). Longer hypocotyl were produced by the cultivars Satin and Celera than the rema ning cultivars.

Table 4.11 Hypocotyl length of mungbean seedlings grown in a growth cabinet (25°C).

Cultivars Treatments	V6-1973A	Emerald	Satin	Kiloga	Celera	Shinsho	Mean
T1	10.30	9.93	11.15	9.23	10.28	9.55	10.71a
T2	10.03	9.43	10.0	9.10	10.13	9.60	9.71b
T3	8.48	9.18	10.3	9.08	9.45	9.23	9.28c
T4	6.13	6.7	7.05	7.30	7.98	6.00	6.86d
Mean	8.73 b	8.81 b	9.63 a	8.68 b	9.46 a	8.59 b	

For the mean temperature and cultivar treatments, those with the same letter are not statistically different at lsd 5%, DMRT.

Root length

Temperatures during growth influenced root length in seedlings in the next generation (Figure 4.24); root length was higher from seed produced in T1, T2 treatments and lowest in T4. Longer

Maximum root length did not appear to be related to seed size.

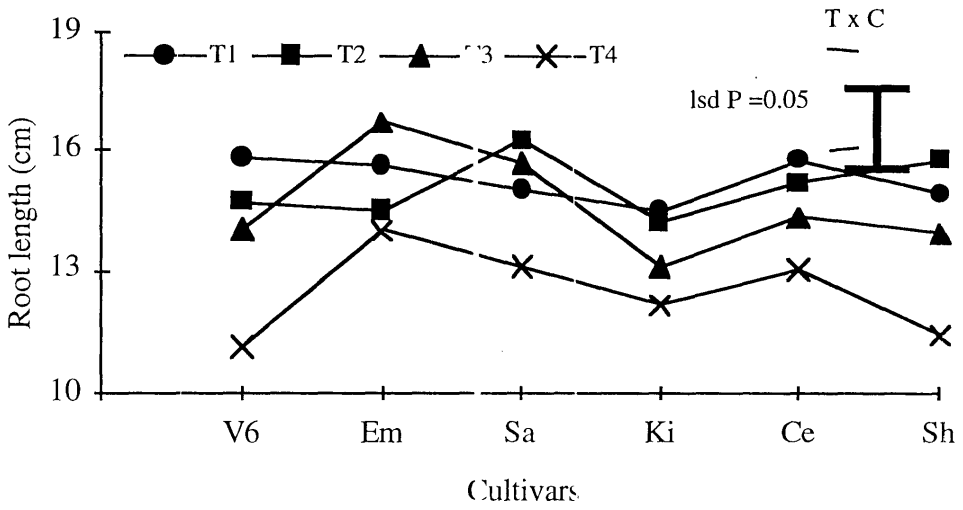

Figure 4.24 Root length of seedlings of mungbean grown in a growth cabinet (25°C).

Seedling dry weight

The seedling dry weight production indicated differences between the growing temperatures, between the cultivars and due to their interactions. Seedling dry weights were higher under T1 and T2 treatments than under T3 and T4 (Figure 4.25). The highest seedling dry weight was obtained from larger seed. The highest seedling dry weight was recorded in Emerald and lowest in Celera reflected a relationship between seed size and seedling dry weight.

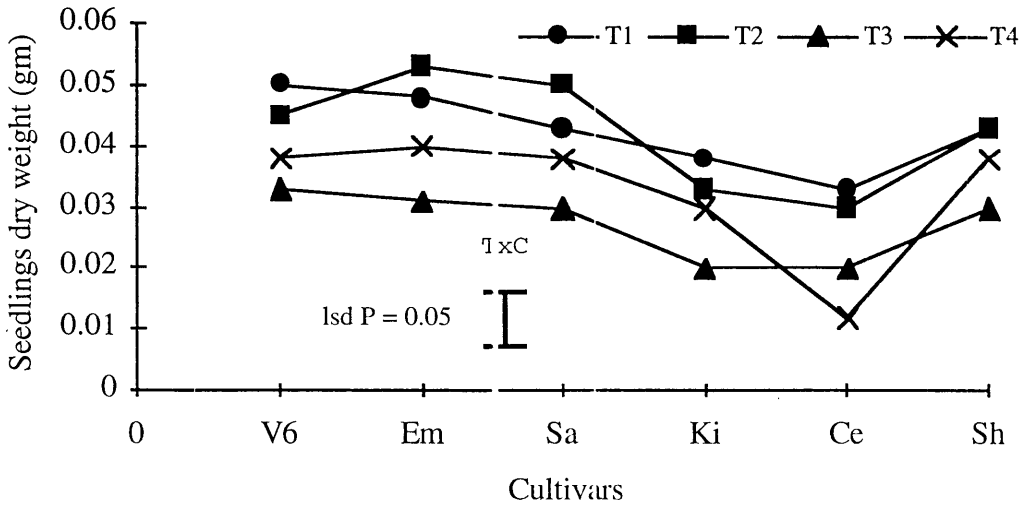

Figure 4.25 Dry weight of six different cultivars of *Vigna radiata* L. seedlings grown in growth cabinet.

4.4. DISCUSSION

The range of growing conditions, with marked differences in temperature between the treatments, induced large differences in phenological development patterns and grain yields. In comparisons of treatments it must be remembered that T4 plants were field grown whilst plants in the remaining treatments were in pots. Nutritional and water status, root growth and root temperatures would have been different in T4 compared to the remaining treatments; direct comparisons of similar growing conditions except for temperature are thus only strictly valid between T1, T2 and T3 conditions. The T4 treatment represents the best growing conditions except for cooler temperatures.

4.4.1. Phenological stages

The rate of germination and the progression through all growth stages was fastest in the tropical (T1) glasshouse (Figure 4.3). Under field conditions with lower temperatures, germination took almost twice as long as under T1 and T2 conditions; similar results were reported by Fyfield and Gregory, (1989), Searle et al., (1980) and Raison and Chapman (1976). Under higher

temperatures water absorption may ɔe greater which may increase the rate of biochemical processes in germination leading to ear y seedling emergence.

The lengths of the growth stages are ʏery sensitive to temperature. The length of the vegetative stage (Figure 4.3) was longer under ɔooler T3 conditions than the remaining T1, T2 and T4 treatments. A longer vegetative phase in the T3 treatment plants may promote greater carbon assimilation; this carbon may be remob lised dᴜring grain development (Bushby and Lawn, 1992), with a resulting increase in total yield. Consequently, it may promote excessively heavy vegetative growth which may reduce yields. In tᴜe T4 tᴜeatment, high yield was associated with a longer length of the grain filling stage. Under high temperature conditions (T1) flowering was relatively earlier than the remaining treatments (Figure 4 3). This finding agrees with the results obtained in mungbean by Aggarwal and Poehlman (1977); Huxley et al. (1976); AVRDC (1978) and Imrie and Lawn (1990).

Growth phase length was related to degree days or heat unit accumulation. Under T4 and T3 treatments the grain growth period was longeᴜ (Table 4.3) than T1 and T2; this was associated with a smaller accumulation of degree ɗays under these conditions (Figure 4.6). The accumulation of degree days varied with temperature differences; some other factor such as daylength response may have been effective in some treatments. The length of time from seedling emergence to maturity was closely correlated with cᴜmulative degree days using a base temperature of 10°C (Figure 4.6); these results were similaᴜ to those obtained with soybeans (Nathalie et al., 1993), but I was unable to find any references ɔn mungbean in relation to day degree requirements.

4.4.2. Growth parameters

The longer growing period in T4 waᴜ associated with greater plant height (Figure 4.8), node number (Figure 4.10), branch number Table 4.4) and leaf area (Table 4.5). The greater growth under T4 treatment was probably not ʍholly ᴜemperature dependent for the reasons mentioned earlier. Vegetative growth of mungbeaɔ plants is known to be susceptible to both high day and low night temperatures (Farlow et al., 1979). Low temperature was found by Lawn (1979b) to

slow the growth and development of mungbean. These findings are similar to the present experimental results where development was slower under T4 and T3 conditions than in the T1 and T2 treatments.

Relatively high temperatures were found to increase the early vegetative growth of the different cultivars of mungbean used in this experiment and these findings contradict the findings of Farlow et al., (1979) who observed that vegetative growth of mungbean was severely reduced at high temperatures of 35°-40C. Other researchers including Huxley et. al. (1976); Seddigh (1983); Sionit et. al.,(1987) and Van Schaik and Probst (1958), however support these findings.

4.4.3. Yield and yield component

Seed yield was found to be greatly influenced by temperature differences and cultivar variations (Figure 4.12). The highest temperature (T1) induced more rapid vegetative growth whilst the highest per plant grain yields (Figure 4.12) were in T4 conditions. The reduction in grain yield from the T1 and T2 treatments was associated with reduced plant growth, increased shedding of flowers and young pods, the largest number of sterile pods and the short grain filling period. The reduced yield at temperatures higher than 28-30C in mungbean has been reported previously (Lawn and Ahn, 1985).

Similar observations were made by Summerfield et al., (1975); Egli and Wardlaw, (1980); Dickson and Boettger, (1984) who reported that seed yield was drastically reduced by high temperatures of 30-32C in soybean due to the reduction of seed size and the shortening of the grain filling period in *Phaseolus vulgaris* (Stobbe et al., 1966).

The highest grain yield in T4 treatment (Figure 4.12) was associated with the longer developmental period which contributed to greater dry matter weight, a greater number of productive nodes (flower and pod bearing nodes) as well as a larger area for root development and better soil nutritional status. From these findings we may conclude that low night temperatures may not be a limiting factor for mungbean production. The higher leaf area also has the potential to improve total yield through increased light interception.

High yields under field conditions were directly associated with the number of pods (Figure 4.17), the number of seeds per plant (Figure 4.19) and thousand seed weight (Table 4.8). There was no consistent relationship between flower and pod number but total flower production was increased with taller plants (Figure 4.8) which had more main stem nodes (Figure 4.10) and branch numbers (Table 4.4). The highest pod number per plant were recorded under T4 whilst the least number were in the T1 and T2 treatments, associated with small plant size.

Flower, pod formation and pod set are highly sensitive to temperature and all these were greatly reduced when grown under high day / night temperatures of 32/27C. The number of seeds per plant (Figure 4.19) was also positively correlated to the flower number with a correlation coefficient of 0.84. The highest number of seeds per plant was produced under field conditions (T4) and the lowest in T1. A larger number of seeds per plant has been related to leaf area and the amount of photosynthetically active radiation intercepted, and the ability of the plants to absorb it for photosynthesis (Muchow and Charles-Edwards, 1982a, 1982b).

The reduced number of seeds per plant (Figure 4.19) under the T1 and T2 treatments gave an increased per seed leaf area (data not presented); this may be reason for the higher thousand seed weight (Table 4.8) in the T1 treatment. It has also been reported that the higher temperatures alter assimilate translocation and distribution to the seed (Williams and Williams, 1978). In T4, it was observed that both vegetative and reproductive buds were growing simultaneously, which might be the reason for the reduction in seed size due to competition as well slow rate of grain filling.

The highest reproductive index (RI, Figure 4.20) in the T4 treatment with a low level in T1 and T2 clearly demonstrated the severe effects of high temperature on the number of productive nodes. With the longer maturity period, the number of productive nodes increased; a shorter growing period drastically reduced the number of productive nodes and they remained confined to the upper few nodes. This observation contradicts those of Lawn (1979) who reported that prolonged vegetative growth in mungbean under field conditions might merely result in the accumulation of lower sterile nodes without an appreciable increase in the yield potential of the

plant.

The highest harvest index (HI, Table 4.9) was recorded in T1 and T2. The warmer conditions were less favourable to vegetative development under T1 conditions whilst the cooler conditions under the T3 and T4 treatments enhanced vegetative growth and produced higher total vegetative dry matter (TVDM). Reasons for the low dry weight under the T2 treatment were not clear but a combination of low day and night temperatures appeared to reduce dry matter production. The lowest TVDM production with T1 and T2 was similar to that of Lawn (1979) who observed improved vegetative dry matter yield with later season cultivars while the HI with a shorter maturity period decreased.

4.4.4. Seed measurements

The percentage protein in seeds varied from 18 to 26 % (Table 4.11) with the highest in T1 and the lowest in T3. These findings agree with those of AVRDC (1973), Lawn and Ahn (1985) and Sarwar (1989) who reported 22 to 28% protein in mungbean seed when grown under a mean temperature of 28-30C. The reasons for higher protein content in T1 and T2 treatments as compared to T3 were probably due to more active remobilisation of protein from the vegetative parts (leaf and stem) which is influenced by the higher temperatures. Under T4 conditions, the protein production per hectare would have been much greater than that in the other treatments.

The percentage protein content in the plant components (leaf, Figure 4.21 and stem, Figure 4.22) were lower in T3 and T4 treatments than T1 and T2. This lower protein in these components under T3 and T4 treatments was associated with a longer maturity period.

Under germination test conditions, the germination percentage of seeds was highest in plants grown under T1 and T2 treatments (Figure 4.23). Results indicated that at high temperatures, a small number of larger seeds per plant were produced, while under cooler temperatures, the seed

size was smaller with a higher number of seeds per plant. During the germination test it was observed that Celera had more hard seeds than all other cultivars; whilst this may be a natural survival mechanism, it could cause problems during germination for bean sprouts.

Differences in hypocotyl length (Table 4.11) from seed produced under the different treatments suggested that high temperatures (T1) during growth increased the subsequent elongation of the hypocotyl whilst cool temperatures combined with other field conditions (T4) reduced its length. Lower seedling dry weights in the cultivars Celera and Kiloga were associated with the smallest seed size (Figure 4.25); protein concentration also lowest in the seeds of these cultivars (Table 4.10).

The highest germination percentage (100%) of seeds was observed in the cultivar Shinsho regardless of growing conditions; this suggests that this cultivar may be best suited to a wide range of growing conditions.

4.5. CONCLUSIONS

Phenological development in mungbean is very sensitive to temperatures, and relatively high temperatures progressively increased the rate of phenological development while low temperatures reduced this rate. Under field conditions (T4), the yield components, including plant height, leaf area, DM and grain yield, increased several fold compared to pot grown treatments.

Current experimental results imply that mungbean phasic development requires either a shorter length of maturity with high temperatures or longer length with low temperatures in order to balance the degree days requirement.

Temperatures during growth had major effects on subsequent seed production, seed germination and seedling growth which were highest under T1 and T2 treatments. Whilst the treatments under this experiment indicated important temperature effects on phasic development and yield, cool temperature did not appear disasterous for high yields. Further experimental work will explore tolerance to lower temperatures.