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Soybean [*Glycine max* (L.) Merrill] seed yield response to high temperature stress during reproductive growth stages

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Abstract

Seed yield is vulnerable to temperature changes, especially during reproductive growth stage. Field study was conducted in 2009 and 2010, to determine the effects of high temperature stress during reproductive growth stage on soybean seed yield components and yield. The experiment comprised three soybean varieties viz., AGS190 (large seeded), Willis (medium seeded) and Dieng (small seeded) and three levels of temperature viz., T_1 (control, ambient temperature), T_2 (high temperature, around 30 ^{0}C and T_3 (very high temperature, around 35 ^{0}C). The temperature treatments were exposed from R1 to R2 (term as R1-R2) or from R1 to R5 (term as R1-R5) reproductive growth stages. At the beginning of flowering, the entire plants were covered with single and double layers plastic case to create temperature of around 30 and 35 ^{0}C, respectively. The durations of temperature were 5 and 14 days for R1-R2 and R1-R5 growth stages, respectively. Results showed that longer exposure of plants (R1-R5 growth stages) to higher temperature had a more negative effect on seed yield components rather than shorter exposure (R1-R2 growth stages). There was a linear trend of seed yield components decline with increase in temperature in all varieties. At about 30 ^{0}C, yield components were not significantly affected over control (25 ^{0}C), whereas yield components were negatively and significantly affected at 35 ^{0}C at the both growth stages. Small seeded variety (Dieng) was less sensitive to deterioration in yield components to high temperature compared to large seeded genotype (AGS190). The differences in temperature sensitivity identified among varieties imply the possibility of selecting soybean genotypes with tolerance to elevated high temperature condition.

Keywords: High temperature, heat, Malaysia, soybean, abiotic stress, yield components.
Abbreviation: DAS_days after sowing.

Introduction

Climate is an important factor for agricultural production. Agriculture is a sector which is important to consider, in term of climate change. Generally, the global climate related parameters are temperature, precipitation, soil moisture, and sea level (Aydinalp and Cresser, 2008), which expect to alter crop productivity. Many research studies have shown the impacts of climate variability on yield loss or the alteration of physiological mechanisms on cereal crops (Bainy et al., 2008). Increased air temperature is one of the important climate change indicators that cause heat stress on plants. Heat stress is a serious threat to crop production worldwide.

There is a strong scientific consensus (such as IPCC) that global mean surface temperatures will increase from the present by 1 ^{0}C to 3.5 ^{0}C by the year 2100 (Wahid et al., 2007). Hence, the climate change conditions due to global warming are likely to affect future global agricultural production (Mall et al., 2004). Soybeans [*Glycine max* (L.) Merrill] rank as one of the most important agricultural crops in the world. A recent study revealed that unfavourable environmental conditions (temperature and rainfall variability) during the reproductive growth stage can reduce seed yield of soybean (Thanacharoenchanaphas and Rugchati, 2011).

In the tropics, most of the crops are near their maximum temperature tolerance; therefore, crop yield may decrease even with a minimal increase in temperature. Considerable future temperature changes in Malaysia, will be high enough to cause adverse effects on soybean plant and products. However, the possible adverse effects of temperature change on soybean production in the growing season or genetic change has still not been studied in Malaysia. Soybean seed yield components are influenced by temperature. Soybean seed yield is usually increased when temperature increases between 18/12 (day/night) and 26/20°C, but adversely decreases at temperatures greater than 26/20°C (Sionit et al., 1987). Raising temperature from 29/20 to 34/20°C during seed filling stage significantly decreases soybean seed yield (Dornobos and Mullen, 1991). Seeds per pod is the seed yield component which is least affected by temperature (Huxley et al., 1976; Sionit et al., 1987; Baker et al., 1989). Temperatures above 30/25°C (day/night) during flowering and pod development reduce weight per seed, regardless of

Table 1. Effect of temperature, variety, growth stage and season on yield components and seed yield in soybean.

Treatment	Pods plant^{-1} (no)	Aborted pods plant^{-1} (no)	% Aborted pods	Seeds pod^{-1} (no)	Seeds plant^{-1} (no)	100-seed weight (g)	Seed yield (t ha^{-1})
Temperature							
T_1	50.53 a	5.75 c	11.96 c	1.67 a	82.07 a	21.03 a	2.92 a
T_2	47.73 b	9.56 b	18.89 b	1.64 a	76.24 b	20.24 b	2.68 a
T_3	31.75 c	23.12 a	44.54 a	1.43 b	46.34 c	18.90 c	1.93 b
F-test	**	**	**	**	**	**	**
Growth stage							
R1-R2	45.30 a	11.13 b	21.64 b	1.62 a	72.08 a	20.34 a	2.66 a
R1-R5	41.38 b	14.51 a	28.62 a	1.53 b	64.46 b	19.77 b	2.40 b
F-test	**	**	**	*	**	**	**
Variety							
AGS190	16.00 c	7.70 c	32.57 a	1.79 a	29.37 c	43.97 a	2.80 a
Dieng	54.21 b	15.93 a	22.65 b	1.41 b	76.41 b	6.53 c	2.23 c
Willis	59.77 a	14.81 b	20.17 c	1.54 b	94.53 a	9.66 b	2.48 b
F-test	**	**	**	**	**	**	**
Year							
2009	44.05	13.09	25.59	1.58	68.97	20.35	2.65
2010	42.64	12.55	24.68	1.57	67.49	19.75	2.42
F-test	NS	NS	NS	NS	NS	NS	NS
CV (%)	7.00	10.37	9.80	6.56	6.46	4.24	8.66

In a column, either within temperature or growth stage or variety, the figures bearing the same letter (s) do not differ significantly at $P \leq 0.05$ by DMRT; **, indicates significant at 1% level of probability; NS, not significant .

T_1 = Control, ambient temperature, temperature range was 23.2-24.9 ^{0}C, T_2 = High temperature, temperature range was 28.0-29.5 ^{0}C and T_3 = Very high temperature, temperature range was 32.0-34.3 ^{0}C.

temperature during seed filling period (Egli and Wardlaw, 1980). Under humid tropical environments, day temperature reaching up to 33°C is common. Under controlled environments, soybean seed production is significantly reduced at temperatures above 30°C (Lindsey and Thomson, 2012). Reproductive growth periods (R1-R7) of soybean are more sensitive to high temperature than vegetative growth (Reddy and Kakani, 2007). Environmental conditions, particularly daytime temperature have a direct effect on photosynthesis and transpiration, consequently, affecting soybean yield. Therefore, plant reproductive organs will be more vulnerable to changes in short episodes of high temperatures prior to and during early flowering stage.

In order to adapt soybean systems to the increase in daytime temperature, a comprehensive understanding of the impact during reproductive growth stage on soybean yield is required. Controlled environment chambers have proven that moderate increase in daytime temperature (18-26ºC) during seed filling benefit soybean yield (Sionit et al., 1987). It is reported that temperatures during reproductive periods reduce seed yield components of soybean in high temperature of 32-38 ^{0}C (Huxley et al., 1976; Dornbos and Mullen, 1991; Gibson and Mullen, 1996).

In the controlled experiments (growth chamber, green house), daytime temperatures are held constant during seed development. In contrast, daily maximum temperature in the field varies diurnally and it increases gradually from sunrise, with advancement of the day and maximum at mid-day, followed by a decline afterwards. Thus, temperature treatments in controlled environments may be more severe than similar temperature ranges in the field. Therefore, it is very difficult to extrapolate the results of controlled-temperature experiments to the field conditions. Records of the long-term agro systems provide a unique opportunity to evaluate the response of soybean seed yields to daily maximum temperature during seed filling in the fields. The sensitivity of high temperature to reproductive *in vitro* development of soybean is not well understood under tropical agro-climatic conditions. Therefore, the objective of this study was to evaluate the relationship between high air temperature at reproductive growth stages and yield components from plants growing in the field of tropical region.

Results

Air and leaf temperature

Air temperature was measured from the reproductive growth stage of R1 (starting of opening flower) to R5. The leaf temperature of plants increased with increasing air temperature (Fig. 1). In the control plants, the air and leaf temperature ranged from 23-25 and 20-23 ^{0}C, respectively, and temperature difference between air and leaf temperature was nearly 2 ^{0}C. In 30 ^{0}C treated plants, the air and leaf temperature range was 28-30 and 26.0-27.5 ^{0}C, respectively and temperature difference between air and leaf temperature was nearly 1.5 ^{0}C, while in 35 ^{0}C treated plants, the air and leaf temperature range was 33-35 and 31-33 ^{0}C, respectively. The temperature both in air and leaf was very close to each other about 35 ^{0}C in whole reproductive growth period. Considering the daily mean temperature, results showed that both air and leaf temperature was low in the morning, which increased with advancement of the day until 1 pm followed by a decline up to 7 pm (Fig. 1). Air temperature inside the polyhouse was increased with increasing the polythene layers.

Yield components and seed yield

The effect of temperature on yield components and seed yield in soybean was significant (Table 1). Results showed that seed yield components such as number of pods plant^{-1}, seeds pod^{-1}, seeds plant^{-1}, 100-seed weight and seed yield decreased with increasing air temperature whereas reverse trend was observed in number of aborted pods plant^{-1} and percent aborted pods. However, the yield attributes and seed yield were not greatly influenced at T_2 treatment compared to T_1.

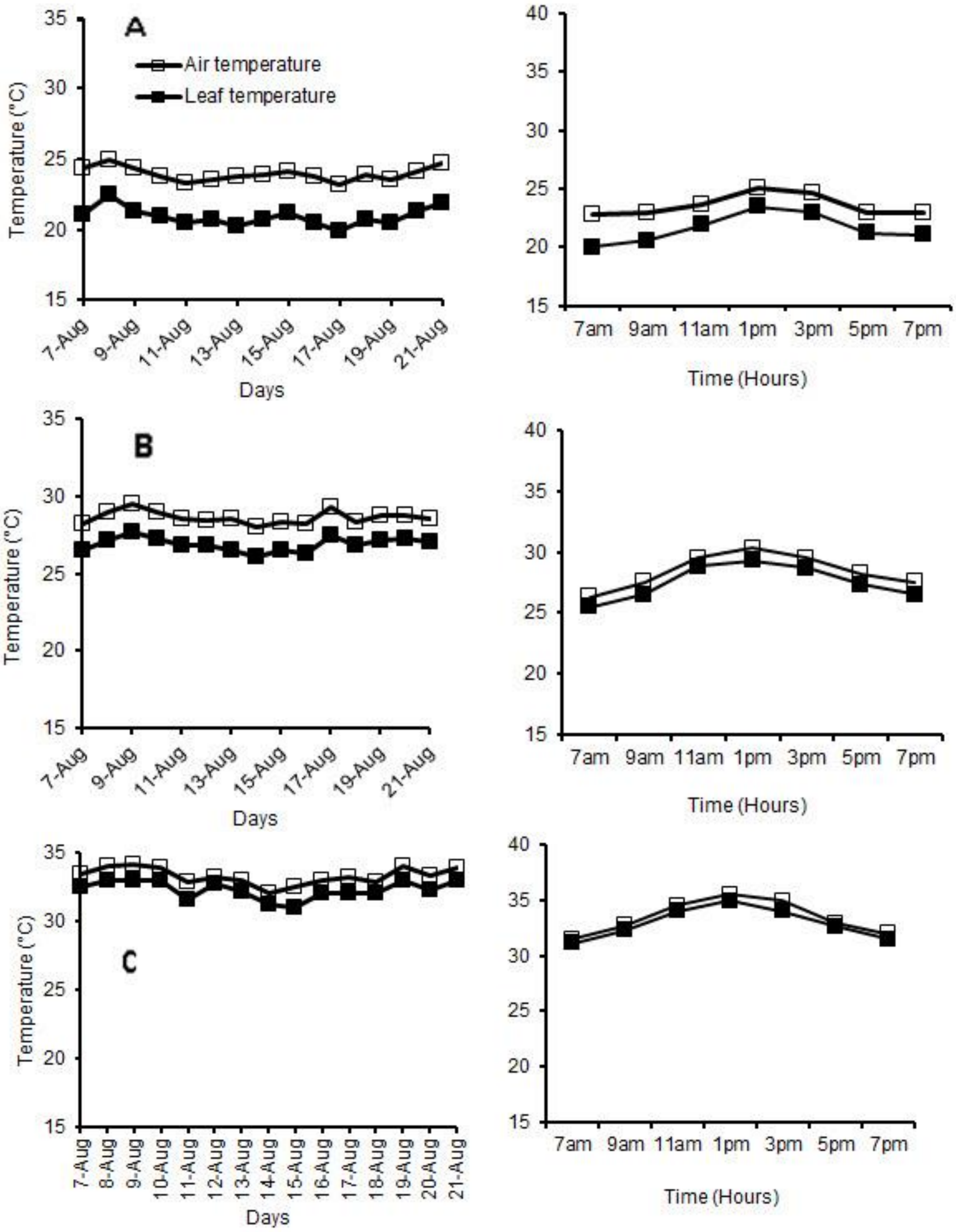

Fig 1. Average mean air and leaf temperature (first column), and daily mean air and leaf temperature (second column) (A) Without cover, (B) Single layer and (C) Double layer plastic sheet cover of variety, AGS190 in 2009. Similar results were also observed in other varieties in both years.

The highest number of pods plant^{-1} (50.53), seeds pod^{-1} (1.67), seeds plant^{-1} (82.07), 100-seed weight (21.03 g) and seed yield (2.92 t ha^{-1}) was recorded in control plants (T_1 treatment) followed by the plants grown in T_1. The lowest yield components were recorded in plants grown under T_3 treatment. The maximum aborted pods (23.12 plant^{-1} and 45.20% of the total) was recorded in plants grown under T_3 treatment and the lowest was recorded in control plants (5.75 plant^{-1} and 11.96% of the total).

Results revealed that reproductive growth stages of R1-R5 in soybean were more sensitive to temperature than the reproductive growth stages of R1-R2 (Table 1). The number of pods plant^{-1}, seeds pod^{-1}, seeds plant^{-1}, 100-seed weight and seed yield were greater in the growth stages of R1-R2 than the growth stages of R1-R5 while the reverse trend was observed in case of number of aborted pods plant^{-1} and percentage in aborted pods. The number of aborted pods plant^{-1} and percentage in aborted pods were higher in the reproductive growth stage of R1-R5 than in growth stage of R1-R2. Among the varieties, AGS190 showed superiority in seed yield (2.80 t ha^{-1}) due to production of bolder seeds (43.97 g/100-seed) and greater number of seeds pod^{-1} (1.79), though it produced lowest number of pods plant^{-1} (16.00)

Table 2. Interaction effect of variety and growth stage on yield components and seed yield in soybean (Mean over two years).

Interaction		Pods plant^{-1} (no)	Aborted pods plant^{-1} (no)	% Aborted pods	Seeds pod^{-1} (no)	Seeds plant^{-1} (no)	100-seed weight (g)	Seed yield (t ha^{-1})
Variety	*Growth stage*							
AGS190	R1-R2	17.50 d	6.62 d	28.22 b	1.80 a	30.98 d	44.34	3.00 a
	R1-R5	14.51 e	8.78 c	36.92 a	1.79 a	27.85 e	43.60	2.60 b
Dieng	R1-R2	56.57 b	13.90 b	19.17 d	1.46 c	82.13 b	6.72	2.31 d
	R1-R5	51.85 c	17.95 a	26.14 b	1.40 c	70.69 c	6.34	2.14 e
Willium	R1-R2	62.48 a	13.35 b	17.53 d	1.66 b	104.1 a	9.94	2.61 c
	R1-R5	57.05 b	16.28 a	22.82 c	1.42 c	84.93 b	9.38	2.36 d
F-test		**	*	*	**	**	NS	*
CV (%)		7.00	10.37	9.80	6.56	6.46	4.24	8.66

In a column, the figures bearing the same letter (s) do not differ significantly at P ≤ 0.05 by DMRT *, ** indicate significant at 5% and 1% levels of probability, respectively; NS, not significant.

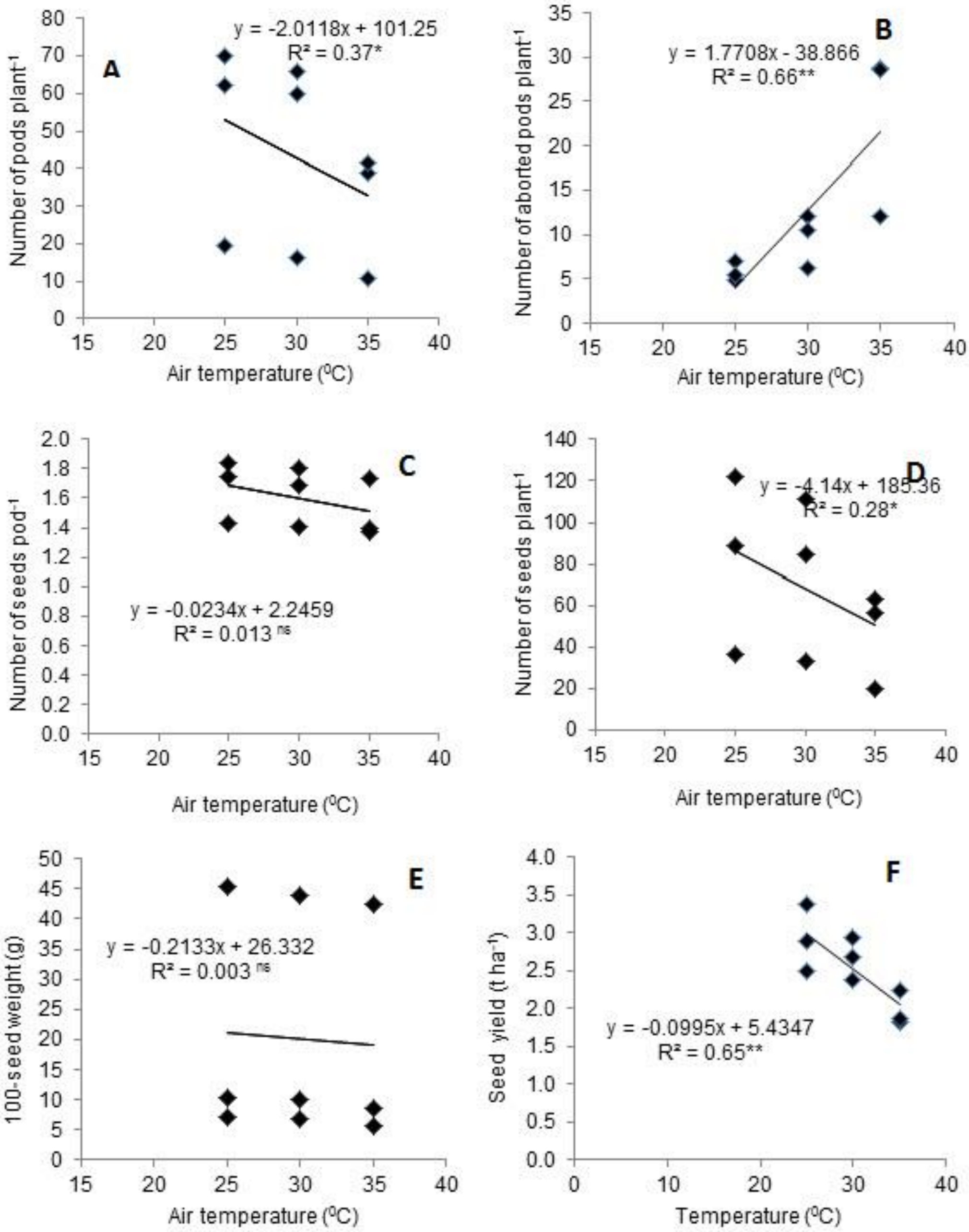

Fig 2. Relationship between temperature and yield components in soybean (values mean over year and growth stages).

(Table 1). The variety, Dieng showed the lowest seed yield (2.23 t ha^{-1}) for its smaller size seeds and less number of seeds pod^{-1}. However, the year had no significant influence on yield attributes and seed yield in soybean (Table 1).

Interaction of variety and growth stage on yield components

The interaction of variety and growth stage on yield components such as number of pods $plant^{-1}$, seeds pod^{-1} and seeds $plant^{-1}$, aborted pods number $plant^{-1}$ and seed yield was significant except 100-seed weight (Table 2). Results showed that yield components and seed yield decreased in the growth stages of R1-R5 as compared to growth stages of R1-R2 in all the varieties but the decrement was not similar among the varieties.

The decrease in number of pods $plant^{-1}$ and seed yield in R1-R5 growth stages over R1-R2 growth stages was the highest in bold seeded plants, AGS190 (17.10 and 13.33% for number of pods $plant^{-1}$ and seed yield, respectively) whereas the lowest decrease in pod number and seed yield was observed in the small seeded variety, Dieng (8.34 and 7.36% for number of pods $plant^{-1}$ and seed yield, respectively). On the other hand, number of aborted pods $plant^{-1}$ and percent aborted pods were increased in the growth stages of R1-R5 as compared to growth stages of R1-R2 in all the varieties but the increment was not similar among the varieties. The highest increase in aborted pods number at R1-R5 growth stages was recorded in the variety of AGS190 (32.63% increased over growth stages of R1-R2) and the lowest was recorded in Willium (21.95% increase over growth stages of R1-R2).

Interaction of growth stage and temperature on yield components

The interaction of growth stage and temperature on yield components and seed yield was significant except 100-seed weight (Table 3). The yield components and seed yield decreased with increasing air temperature in both the growth stages but the decrement was higher in the growth stages of R1-R5 (decrease over control was 41.97 and 39.04% for pod number and seed yield, respectively) than the growth stages of R1-R2 (decrease over control was 32.51 and 29.01% for pod number and seed yield, respectively). On the other hand, number of aborted pods $plant^{-1}$ and percent of aborted pods increased with increasing air temperature in both the growth stages. However, the degree of increment was higher in the growth stages of R1-R5 (increase over control in aborted pod number was 316.3%) than the growth stages of R1-R2 (increase over control in aborted pod number was 283.5%).

Interaction of variety and temperature on yield components

The interaction of variety and temperature showed that yield components and seed yield were decreased significantly with increasing air temperature from T_1 to T_3 in all the varieties. However, the decrement was not similar among the varieties (Table 4). The sensitivity to increase of air temperature (up to 35 ^{0}C) on yield components and seed yield was less in Dieng (Decreased 33.92 and 28.69% over control for number of pods $plant^{-1}$ and seed yield, respectively) followed by Willium (Decreased 37.58 and 35.29% over control for number of pods $plant^{-1}$ and seed yield, respectively). The variety AGS190 was more sensitive to air temperature on yield components and seed yield (Decreased 46.01 and 39.64% over control for number of pods $plant^{-1}$ and seed yield, respectively) than the other two varieties, Dieng and Willium. Relationship between temperature and yield components revealed that there is a strong negative correlation between air temperature and seed yield components (Fig. 2).

Discussion

Air temperature inside the polyhouse increased with increasing polythene layers. Polyhouse permits easy entrance of short-wave radiation and traps the outgoing long-wave radiation. As a result, the air temperature inside the polyhouse gradually increased with increasing polythene layers due to greenhouse effect (Saikia et al., 2001). Thus, inside of a polyhouse becomes warmer by increasing layers of polythene.

High temperature negatively affects yield and attributes in soybean (Egli et al., 2005). The present experiment showed that soybean plants exposed to higher temperature at reproductive stage showed decrease in seed yield components such as number of pods $plant^{-1}$, number of seeds pod^{-1} and 100-seed weight, indicating that high temperatures during flowering and pod set is critical to soybean seed yield. Reductions in pod number caused by high temperature might decrease the effectiveness of pollination and fertilization, and consequently poor setting pods (Prasad et al., 2001). Similar observations were reported in peanuts (Talwar and Yanagihara, 1999) and in kidney bean (Prasad et al., 2002). Lindsey and Thomson (2012) reported that the optimum temperature range for soybean was 25-29 ^{0}C and pod setting seriously affected at temperatures above 37 ^{0}C. In the present study, seed yield components were slightly affected at 30 ^{0}C and highly affected at 35 ^{0}C that supported the results.

A reduction in seed size under increased temperature during seed fill may be related to shorter seed growth period. Higher temperatures during reproductive growth stage may shorten the time for seed to develop fully before maturity resulting in a decrease in seed size (Duthion and Pigeaire, 1991). Moreover, high temperature stress during reproductive development may negatively affect the cell expansion, cotyledon cell number and; thus, seed filling rate, resulting in reduced seed size (Munier-Jolain and Ney, 1998). Seeds have a highly regulated capacity to achieve a uniform size. However, the high temperature stress imposed during the mid-reproductive stage prevented seeds filling capacity to the full potential size. In the present experiment, similar phenomenon happened and seed size decreased with increasing temperature.

Meanwhile, high temperature increased the percentage of aborted pods and lower seed set pod^{-1} in the present study, possibly owing to the increased number of non-viable pollens, failure of anther dehiscence, reduced pollen tube penetration into the stigma and impaired female performance (Gross and Kigel, 1994).

The plants exposed to higher temperature (around 30-35 ^{0}C) for a longer period of time during R1-R5 growth stages encountered greater reduction in all yield components and yield than shorter period of R1-R2 growth stages for all varieties, indicating longer period temperature stress is more effective than shorter periods at reproductive growth stages. Similar result was also observed by Spears et al. (1997) in soybean. The results of present study shows the negative effect of high temperature on seed yield components in all three varieties of soybean. But the sensitivity on high temperature for yield and yield attributes was not similar among the varieties. The variety differences in seed yield components at different temperature in this study might be due to different adaptive mechanisms of the varieties to temperature. Varietal differences in reduction of yield

Table 3. Interaction effect of growth stage and temperature on yield components and seed yield in soybean (Mean over two years).

Interaction		Pods plant^{-1} (no)	Aborted pods plant^{-1} (no)	% Aborted pods	Seeds pod^{-1} (no)	Seeds plant^{-1} (no)	100-seed weight (g)	Seed yield (t ha^{-1})
Growth stage	Temperature							
R1-R2	T_1	51.27 a	5.35 e	10.00 e	1.67 a	83.92 a	21.33	2.93 a
	T_2	50.02 b	7.51 d	15.00 d	1.69 b	81.82 ab	20.55	2.85 a
	T_3	34.60 d	20.52 b	39.91 b	1.51bc	50.50 d	19.13	2.08 c
R1-R5	T_1	49.80 a	6.18 d	13.92 d	1.66 a	80.22 b	20.73	2.92 a
	T_2	45.45 c	11.61 c	22.78 c	1.59 c	70.66 c	19.93	2.51 b
	T_3	28.9 e	25.73 a	49.17 a	1.35 d	42.50 e	18.67	1.78 d
F-test		**	**	**	*	**	NS	**
CV (%)		7.00	10.37	9.80	6.56	6.46	4.24	8.66

In a column, the figures bearing the same letter (s) do not differ significantly at $P \leq 0.05$ by DMRT*, ** indicate significant at 5% and 1% levels of probability, respectively; NS, not significant. T_1 = Control, ambient temperature, temperature range was 23.2-24.9 ^{0}C, T_2 = High temperature, temperature range was 28.0-29.5 ^{0}C and T_3 = Very high temperature, temperature range was 32.0-34.3 ^{0}C.

Table 4. Interaction effect of variety and temperature on yield components and seed yield in soybean (Mean over two years).

Interaction		Pods plant^{-1} (no)	Aborted pods plant^{-1} (no)	% Aborted pods	Seeds pod^{-1} (no)	Seeds plant^{-1} (no)	100-seed weight (g)	Seed yield (t ha^{-1})
Variety	Temperature							
AGS190	T_1	19.67 e	4.90 e	19.90 d	1.84 a	36.05 g	45.50 a	3.38 a
	T_2	17.72 e	6.19 d	26.22 c	1.80 ab	32.67 g	43.97 b	2.99 b
	T_3	10.62 f	12.00 b	51.58 a	1.73 b	19.38 h	42.43 c	2.04 d
Dieng	T_1	62.00 b	6.93 d	10.04 g	1.43 c	88.45 c	7.12 g	2.50 c
	T_2	59.65 c	12.08 b	16.71 e	1.44 c	84.46 d	6.79 h	2.37 de
	T_3	40.97 d	28.77 a	41.20 b	1.37 c	56.33 e	5.69 i	1.82 e
Willium	T_1	69.93 a	5.42 de	5.94 h	1.74 b	121.7 a	10.47 d	2.89 b
	T_2	65.72 b	10.42 c	13.74 f	1.69 b	111.6 b	9.95 e	2.69 c
	T_3	43.65 d	28.60 a	40.83 b	1.40 c	63.30 f	8.56 f	1.87 e
F-test		**	**	*	*	**	*	*
CV (%)		7.00	10.37	9.80	6.56	6.46	4.24	8.66

In a column, the figures bearing the same letter (s) do not differ significantly at $P \leq 0.05$ by DMRT, ** indicate significant at 5% and 1% levels of probability, respectively T_1 = Control, ambient temperature, temperature range was 23.2-24.9 ^{0}C, T_2 = High temperature, temperature range was 28.0-29.5 ^{0}C and T_3 = Very high temperature, temperature range was 32.0-34.3 ^{0}C.

components under above optimum temperature in the current study represent real genotypic variability which can be used to screen genotypes for high temperature tolerance. The variety Dieng (small size seed) showed more tolerance to maintain seed yield components under high temperature than the other two varieties AGS190 and Willis. The most temperature sensitivity was observed in AGS190 (large size seed). The highest decrease in yield components under high temperature was found in AGS190 as compare to the other varieties due to its larger seed size while the less decrease in yield components under high temperature was found in Dieng due to its smaller seed size. These results suggest that variety with larger seed size is more sensitive to high temperature than small seeded ones.

Materials and methods

Site description

The experiments were conducted at the field Laboratory of the Faculty of Agriculture, Universiti Putra Malaysia (UPM) (101^{0}42' E 102^{0}12' N), Malaysia during July to October, 2009 and 2010. The soil of the experimental area was silty clay.

Planting materials and experimental design

Three soybean varieties *viz*., AGS190 (large seeded), Willis (medium seeded) and Dieng (small seeded) were used as planting materials. Seeds were sown in rows, 4 m long and 50 cm apart. Each plot consisted of six rows. The experiments were arranged in factorial randomized complete block design with three replicates. The factors were three varieties of AGS190, Dieng and Willis, the temperature levels of around 25, 30 or 35 ^{0}C and two reproductive growth stages of from R1 to R2 (Early flowering stage) and from R1 to R5 (early flowering stage to beginning pod stage). Determination of plant growth stages were based on procedures outlined by Fehr and Caviness (1977).

Management practices

Seeds were sown continuously in row and two weeks after germination, the plants were thinned to a density of about 80 plants per 4m row. Cultural practices were similar in both seasons. The nylon netting cover was immediately spread after sowing to prevent damage by the birds. Compound fertilizer (NPK) application was carried out at 21 days after sowing (DAS).

The fertilizer calculated based on 50 kg ha^{-1} for N sources and 150kg ha^{-1} for PK sources. Weed control was carried out manually beginning at 21 DAS until reproductive stage when needed. The plots were irrigated as required to reduce moisture stress especially during the crop vegetative stages.

Treatments

Three levels of temperature treatment were employed at the beginning of flowering stage (at 45 DAS). Normal field condition without plastic cover cage as the control (T_1), around 25 ^{0}C (but practically temperature range was found

23.2-24.9 ^{0}C). The entire plants were covered with single layer transparent plastic cage (1501 micron thick plastic sheet) to create temperature of around 30 ^{0}C (T_2) (but practically temperature range was found 28.0-29.5 ^{0}C) and with double layers transparent plastic cage to create higher temperature of around 35 ^{0}C (T_3) (but practically temperature range was found 32.0-34.3 ^{0}C) above the canopy. The durations of temperatures were 5 and 14 days for R1-R2 and R1-R5 growth stages, respectively. The air temperature within the plastic cage and leaf temperature were monitored daily (Fig. 1). The air temperature was taken by simple thermometer (Model: KT-300, China) which was set into the polythene case. Leaf temperature was taken by leaf temperature sensor (Model: LT-1M, Moldova). The size of the polythene cage was 3 m (length) × 2.5 m (width) × 2.5 m (height).

Parameters measured

At maturity stage (R8), 10 randomly selected plants were taken from each plot for recording yield components. The whole plot was harvested and sun dried for 7 days. Pods were separated from plants by hand picking and then the dry pods placed in jute bags were threshed to separate the seeds from the pod walls. Sieving (round hole) was used to eliminate the small, immature, insect damaged seeds and plant debris. Data on number of pods and seeds plant^{-1} was calculated from the ten plants. Hundred-seed weight was also recorded from each plot. Number of seeds pod^{-1} was calculated as number of seeds plant^{-1} divided by number of pods plant^{-1}. The aborted pods denoted when at least one seed aborted in a pod. A total of 100 pods from the harvested plot at R8 were sampled to determine aborted pod. The plot yield was converted into tons ha^{-1}.

Statistical analyses

All data were analyzed statistically as per the used design following the analysis of variance. The mean differences were adjusted with Duncan's Multiple Range Test using the statistical computer package programme (SAS Institute, 2003, Cary, NC). Microsoft excel was used for graphical presentation.

Conclusion

High temperature stress during reproductive growth stage in soybean reduced yield components and seed yield. The extent of reductions in yield components and seed yield by high temperature was influenced by duration of temperature exposure and plant reproductive growth stages. Longer exposure to high temperatures during flowering until fully expanded pod stage (R1-R5) had a greater impact on soybean seed yield components than at early flowering stage (R1-R2).

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