

Agroclimatological factors in soybean plants



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Introduction

The world today is faced with great challenges to produce adequate food, fiber, feed, industrial products and ecosystem services for the globe's 6.4 billion people. With nearly 80 million people are being added every year, and ecosystem goods and services must be developed to meet 8 billion by the year 2025 and over 12 billion by 2050. About 84% of this growth is expected to occur in the developing countries (Xiaobing et al., 2008). Since there is essentially no new arable land that can be cultivated, the increased food supply must come primarily from more intensive cultivation of existing arable land. Added to these stresses comes a threat - global climate change resulting from increased greenhouse gas concentrations in the atmosphere due to anthropogenic activities (Jaleel et al., 2009). Global surface temperature has increased by more than 0.6°C because of anthropogenic climate-forcing agents since the Industrial Revolution (Sato et al., 2000; Mahmoud et al., 2009). Future increases in greenhouse gases are projected to increase Earth's surface temperature to anywhere between 1.5 to 11°C by the year 2100 (Calviño et al., 2003). It was shown that the changes projected in climate will have profound impacts on crop production as evidenced from studies using field and controlled-environments and modeling exercises (Reddy and Hodges, 2000; Shao et al., 2009). Similarly external factors and environmental stresses affects plant growth and production throughout the world (Jaleel et al. 2006, 2007, 2008). Lobell and Asner (2003) evaluated the relationship between climate variation and crop production on two major crops (corn and soybean) grown in the United States between the years 1982 to 1998 and reported that for every 1°C rise in temperature, there was an average 17% decrease in yield. In addition,

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extreme temperatures during flowering period will have even more severe effects on crop yield than just rise in season-long temperature conditions (Reddy et al., 1999). Therefore, extensive research has been carried out to quantify the effect of increasing temperature on crop production. Fruit set in many agronomic crops is sensitive to supra-optimal temperatures; cotton (Reddy et al., 1992), bell pepper (Erickson et al., 2001), tomato (Sato et al., 2000), bean (Porch and Jahn, 2001), groundnut (Prasad et al., 2003), soybean (Ferris et al., 1998), common bean (Gross and Kigel, 1994), and cowpea (Ahmed et al., 1993).

Soybean (*Glycine max* L. Merrill) is an important legume cash crop grown for its oil and protein with over 74.4 Mha worldwide and 29.3 Mha in the United States (<http://www.fao.org>, September, 2005). For example, during 2003, the United States grew about 29.7 million hectares of soybean and produced 2.41 billion bushels of grain (USDA, 2004). Therefore, soybean crop production is extremely important to the economic structure of the global food network, especially the United States. First domesticated in Northeast parts of China, conventional and genetically modified cultivars of soybean have been adapted and commercially cultivated in all climatic zones of USA and in all populated continents of the world (Zhang et al., 2009). Genotypes have been grouped into 13 maturity groups ranging from 000 to XI distributed from Canada to the southern border of the USA based on latitude (Poehlman and Sleper, 1995). Most US genotypes were derived from a small number of ancestral soybean cultivars brought to the USA in the early 1900s (Carter et al., 1993), indicating a small genetic pool.

Soybean is sensitive to the changes in day-length and temperature (Allen and Boote, 2000; Jayakumar et al., 2007; Eunsook et al., 2009). Therefore, soybean breeders and researchers have routinely selected genotypes that are most responsive to a combination of day-length and temperatures for a given niche environment (Mahmoud et al., 2009). Selection for high temperature tolerance has also occurred in crops such as rice (Huang et al., 2009) and soybean (Mahmoud et al., 2009). Vegetative growth was stimulated by increasing temperature, as was leaf and canopy photosynthesis (Boote et al., 1997). However, reproductive growth leading to seed yield was often depressed by the same increases in temperature that enhanced vegetative growth and development (Fang et al., 2008). A temperature between 33 and 40°C reduced soybean growth (Vu et al., 1997). When plants were exposed to temperatures of 35°C for 10 h during the day, soybean yield reductions of about 27% were observed (Gibson and Mullen, 1996). Flower initiation was reduced by temperatures more than 32°C and delayed seed formation at 40°C (Thomas et al., 2003).

Pollen grains are developed within the anther and at maturity contain the products of both sporophytic and gametophytic gene expression (Taylor and Hepler, 1997). They act as independent functional units once released from anthers and are exposed to multiple environmental stresses (Kent and Carter, 2009). Under humid conditions in the southern USA, soybean anther dehiscence occurs between 0800 and 1000 h. Therefore, high temperatures during flowering or short episodes of high temperature during pollen release and germination may more severely affect male reproductive processes than the deeply seated ovules (Matsuyama et al., 2009).

High temperatures during flowering have been shown to affect pollen germination, tube growth, and fertilization in numerous crops (Monterroso and Wein, 1990; Porch and Jahn, 2001; Adriana et al., 2007). Pod yield, the number of flowers produced, and proportion of flowers that were fertilized and retained, were reduced by high temperatures in groundnut (Prasad et al., 2003). Pollen abnormalities were observed in soybean (Koti et al., 2004), snap bean (Suzuki et al., 2001), and common bean grown in high temperatures (Porch and Jahn, 2001). With high temperatures, early degeneration of the tapetal layer occurred in the anthers of snap bean (Suzuki et al., 2001). Recent studies have shown that microsporogenesis was more sensitive to high temperature than megasporogenesis, leading to lowered fruit set (Young et al., 2004). Lower pod and seed set were related to nonviable pollen, unsuccessful anther dehiscence, and pollen shed in (Sato et al., 2000) resulting in reduced pollen tube penetration into the stigma and weakened female performance (Gross and Kigel, 1994). In vitro pollen studies for both pollen germination and pollen tube length in groundnut and cotton genotypes were varied in their responses to base (T_{base}), optimum (T_{opt}), and maximum (T_{max}) temperatures (Kakani et al., 2005). Differences in these cardinal temperatures have been used as screening techniques for tolerance or sensitivity of cotton and groundnut genotypes to high temperature (Kakani et al., 2005; Craufurd et al., 2003; Jegor et al., 2006). To date, there have been no studies conducted to specifically document in vitro pollen germination and pollen tube growth technique for screening soybean genotypes to high temperatures. Also, studies describing the variation in cardinal temperatures for reproductive parameters in any soybean genotype or whether genotypic variation exists

in pollen responses to temperature are lacking. Therefore, identifying cardinal temperatures for pollen germination and pollen tube growth and developing temperature dependent functional responses for these processes will be useful for understanding mechanisms of temperature-tolerance in soybean and to provide a much needed database for modeling soybean growth and yield. Finally, this information will aid in cultivar selection based on niche environments. As Earth's surface temperatures are projected to rise, a global search for genetic material that is more tolerant to abiotic stresses, especially higher temperatures, is needed for soybean.

Physiological parameters that have been widely used to study plant tolerance to high temperature include photosynthesis rates, stomatal conductance, chlorophyll fluorescence (Vu et al., 1997), and cell membrane thermostability (CMT) (ur Rahman et al., 2004). Photosynthetic rates were considered as good indicators of thermo-tolerance in maize at the seedling stage under heat and salt stresses (Karim et al., 2000; Hiroyuki et al., 2009). CMT has been used as a measure of heat-tolerance in several crops including rice (Tripathy et al., 2000), soybean (Tang et al., 2009). CMT in rice has been used as a major selection index for drought tolerance in cereals (Tripathy et al., 2000). Furthermore, CMT was found to be positively and significantly correlated with biomass and yield under stress conditions but not with biomass or yield under non-stress conditions (ur Rehaman et al., 2004). Also, cultivars showing higher CMT yielded better than the cultivars with lower CMT in crops such as wheat (Fokar et al., 1998) and cotton (ur Rahman et al., 2004). However, recent studies showed that CMT was not correlated with pollen germination under high temperature in groundnut and cotton

(Craufurd et al., 2003; Kakani et al., 2005). Thus, it would be helpful to understand the relationships between pollen parameters such as pollen germination and tube length and physiological parameters such as photosynthesis, stomatal conductance, pigments and CMT in different crops and in particular, soybean genotypes (Sinclair et al. 2007). Therefore, the objectives of this research were to (i) quantify the responses of in vitro pollen germination and pollen tube growth to temperature, (ii) determine cardinal temperatures of each genotype and classify genotypes based on their tolerance to temperature, (iii) understand the morphological disturbances of pollen when plants are exposed to high temperature, (iv) determine whether the observed genotypic variation in reproductive parameters is correlated with vegetative parameters such as photosynthetic rates, photosynthetic pigments and cell membrane thermostability, and (v) classify genotypes as tolerant, intermediate or sensitive to high temperature. An additional objective of this study was to determine the basis of tolerance or sensitivity of the genotypes to high temperature.

Origin and Distribution of Soybean

Soybeans cultivation has spread widely from its center of origin in the north and northeastern areas of China, where it has been grown since 2500 B. C. In the late 1700s, soybean was introduced sporadically into the United States. The soybean growing region is part of the temperate climate of northern China and was formally called the Chinese soybean or Manchurian bean (Morse, 1950). Though it has been referred by numerous botanical names, in 1948, Ricker and Morse coined the botanical name to the domesticated soybean wild types as *Glycine max* (L.) Merrill, which originated from *G. soja*.

The crop is adapted to latitudes of 0° to 50° and altitudes of less than 1000 m. Soybean is an annual crop and produces more protein and oil per unit of land than any other crop. The average composition of today's soybean is 40% protein, 21% oil, 34% carbohydrate, and 5% ash. Soybean cultivation has been on the increase and with worldwide production increasing by approximately 400% over the last forty years; in 2003, about 37% of world production was from the United States (FAO, 2005).

Climate Change and Temperature Effects

The world today is faced with great challenges to produce adequate food, fiber, feed, industrial products, and ecosystem services for the globe's 6.4 billion people (<http://www.usaid.gov/pubs/apr96/ch1.pdf>). Future projections indicate that if the human population continues to rise, and the earth will be inhabited by anywhere between 7.4 to 10.6 billion people by the year 2050 (United Nations, 2003). It has been estimated that pressure from global population will cause the demand for cereals and grains to escalate additional 40% by 2020 (Duvick and Cassman, 1999), or an annual-average increase of 1.3%. Furthermore, per capita food consumption rates are also steadily increasing around the world, particularly in developing countries with increasing incomes. Since there is essentially no new arable land that can be cultivated, the increased food supply must come primarily from more intensive cultivation of existing arable land. Kendall and Pimentel (1994) points out that when population and food consumption rate increases are accounted, then the food production will need to triple by the 2050. In addition, gaseous emissions from human activities are substantially increasing the concentrations of atmospheric greenhouse gases, which have

increased and will increase average world temperature. The increase in CO₂ and other greenhouse gas concentrations since the Industrial Revolution has resulted in 0.6°C increase of the earth mean temperature (Sato et al., 2000). Recent model projections suggest that the global mean surface air temperatures will increase by 1.4 to 5.8°C by 2100 (Houghton et al., 2001). A recent study indicated that the projected temperatures may range from 1.5 to 11°C by the year 2100 (Calviño et al., 2003). The current model simulations indicate more intense, more frequent and a longer lasting summer heat-waves over North America and Europe (Meehl and Tebaldi, 2004) in the coming years.

Increasing temperatures will result in a substantial reduction in crop yields, especially if they coincide with the flowering stage of crops. In 2003, Europe experienced a 6 °C increase over the long-term mean temperature and a 50% decrease in precipitation, resulting in crop yield losses of up to 36% (Ciais et al., 2005). It was shown that changes projected in climate will have profound impacts on crop production as evidenced from studies using field and controlled-environmental studies and modeling exercises (Reddy and Hodges, 2000). Therefore, it is essential to protect crop yields both in the present as well as in the future climates.

Maturity Groups and Plant Types of Soybeans

Soybean is a short day plant and was the first species in which photoperiod sensitivity was discovered with cultivars differing in critical day length (Garner and Allard, 1920) and temperature (Carlson and Lersten, 1987).

Soybean is classified by maturity groups based on differences in day length conditions. Thirteen maturity groups have been established for soybean

cultivars grown in the United States and the Canada (Poehlman and Sleper, 1995). Soybean cultivars range from Group 000, adapted to the longer day lengths of the northern United States and southern Canada to Group VIII grown in the southern part of the United States (Kenji et al., 2009). Recently, those that flower after Group VIII were identified as Group IX. Figure 1 shows the geographical distribution of the 13 maturity groups of soybean according to their attitude (Poehlman and Sleper, 1995). Most soybean cultivars respond to photoperiod as quantitative short-day plants and are adapted for production in a narrow band of latitudes. The soybean plant has a juvenile stage after emergence when it is especially sensitive to temperature and insensitive to day length (Cheng et al., 2009).

Soybean cultivars are classified as determinate and indeterminate types according to their reproductive stage and differences due to genetic variation. Groups 000 to IV represent the indeterminate growth habit: flowering starts before stem elongation ceases, in the oldest and lowest nodes, and moves up to the youngest nodes over several weeks. Indeterminate flowering cultivars tend to be more clustered. Varieties within Groups V to IX are mostly of the determinate growth habit and all nodes flower at the same time repeatedly. Most determinate cultivars grown in the United States have long racemes with two to thirty-five flowers each (Cheng et al., 2009). The determinate type is adapted to a long growing season, in which the soybean plant completes vegetative growth before or shortly after flowering is initiated.

Temperature Effects on Soybean Growth

Plant growth is a concert of numerous processes that differ in temperature optima and temperature range. Growth results in an increased volume and size. Yield depends on the amount of assimilate that is transported to the harvested organ. The increase in agricultural yields is mainly attributed to the improvement of the harvest index, or the harvested yield to shoot ratio mass known through breeding programs. Breeding efforts to increase the partition of assimilates to storage organs of interest have been very successful. However, when exposed to environmental stresses, several physiological processes that contribute to crop yield are affected by resulting in lower yield.

Photosynthesis

One of the causes for yield improvement in soybean seems to be enhanced leaf photosynthesis through increased leaf area and duration. High temperature and other abiotic constraints like chemical stresses, modifies soybean photosynthesis as it regulates the photosynthetic biochemistry (Qian and Zhou, 2009). The measurement of leaf photosynthetic rates of soybean grown in field has been reported between 30 and 40 $\mu\text{mol m}^{-2} \text{s}^{-1}$ (Carla et al., 2008). Hofstra and Hesketh (1969) reported that photosynthesis of soybean leaves increase with temperatures $> 35^{\circ}\text{C}$ and declines above 40°C . Soybean normally produces more flowers than pods, and yield is relatively unaffected by which flowers become pods. The number of pods that successfully mature will mainly be a result of the amount of photosynthate available during pod-set. During the seed-fill period, less photosynthate supply results in pod abortion. In contrast, more photosynthate supply will prolong flowering up to three weeks.

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Photosynthesis is extremely sensitive to high temperature stress, especially during the reproductive stage. Ashley and Boerma (1989) and Ferris et al. (1998) found reductions in seed production which coincided with photosynthesis during flowering and seed filling. Photosynthesis was considered an indicator of thermotolerance in maize at the seedling stage during heat stress conditions (Karim et al., 2000).

Dry Matter Accumulation

Dry matter is the culmination of several plant growth and developmental processes. The amount of dry matter accumulated in soybean per unit input (light, water and nutrients) determines the efficiency of the production system. Temperature above or below an optimum value reduces dry weight or biomass accumulation. With air temperatures above 30°C, dry matter accumulations in whole plants begin to decline in soybean (Raper et al., 1977). Increasing temperature affects dry matter accumulation due to direct effects on leaf initiation (Thomas and Raper, 1976) and indirect effects of increased leaf water deficits on leaf expansion, as well as the metabolic level of photosynthesis and respiration. Temperatures above 38°C during the day reduced dry matter production (Prasad et al., 2003) and decreased biomass by 25% at 35°C to 50% at 45°C in groundnut.

Partitioning to Pod Growth

The fluctuation in air temperature that we witness today affects plant growth through altered partitioning of photosynthate between organs (Thomas and Raper, 1976; Pinheiro et al., 2009). Pod yield is usually positively correlated with total dry matter accumulation and therefore any effect of temperature on total dry matter accumulation affects pod yield (Cox, 1979). High

temperature has been reported to reduce partitioning of dry matter between roots and shoots and between vegetative and reproductive structures (Nigam et al., 1994). Partitioning has been identified as the main cause for yield reductions in controlled environments and in field studies. Wheeler et al. (1997) found that a daytime temperature of 45°C reduced the harvest index by 50% compared to a control temperature of 30°C. Nigam et al., (1994) reported that soybean cultivars consistently showed maximal accumulation and partitioning of dry matter and suggesting that these physiological traits are associated with agronomic improvement (Ergun et al. 2007).

Temperature Effects on Soybean Development

Development is defined as a sequence of phenological events which are influenced by the environment. Temperature is the most critical factor affecting development. High temperature has major effects on plant development, especially during the reproductive stage. Miransari and Smith (2009) found that differences in date of flowering of soybean genotypes were due mainly to differences in growth temperature during growth.

Time to Set Flowering

The reproductive stages, from initiation of flower to anthesis, are considered to be the most sensitive to any supra-optimal temperatures compared with any other crop stages. The timing of flowering and pollination are important determinants of seed number. Flowering occurs gradually toward the top of the main stem so that flowering, pod development, and rapid seed growth may occur simultaneously at different locations within the plants. The reproductive stages during development are critical in determining yield

potential. The number of flowers per plant plays an essential role in determining the yield potential, i. e., sink size and seed filling. However, actual sink size is often limited by environmental stresses. Thomas and Raper (1977) found that temperature controls the number of flowers and pods in soybean. Also, Gross and Kigel (1994) reported a decrease in the flower number and sensitivity of bean to high temperatures. Extreme temperatures during the flowering period can have even more severe effects on fruit set in many agronomic crops such as in cotton compared to plants grown at optimum temperature conditions (Reddy et al., 1999), tomato (Sato et al., 2000), soybean (Ferris et al., 1998), and cowpea (Ahmed et al., 1993). Extensive research has been conducted on the chronology of flower and ovule development in soybeans (Prakash and Chan, 1976; Salem et al., 2007). Soybean pods are set in 18 to 49 d between the first and last flower (Dybing, 1994). In summary, soybean requires 20-25 d for initiation of floral primordium in axial of bract, and for sepal, petal, stamen and carpel differentiation depending on temperature. Ovule initiation takes place 10 d before flowering and anther initiation starts 7 d before flowering. Pollen grains are normally mature one day before flowering. Soybean genotypes differ in their time to flowering in response to temperature (Piper et al., 1996). Bell and Mullet (1991) found that peanut plants grown at 33/23°C temperatures flowered 2-3 d earlier than those at 33/17°C.

Time to Pod Initiation

From the moment fertilization is complete, the fertilized ovary begins to elongate into fruit, while the style and stigma dry out. Maximum pod length is reached rather early in development, about 25 to 30 days after bloom.

Approximately, 30 days are required for pod maturation. Plants at optimum temperature produce more nodes and axillary branches and more pods per node compared to high or low temperatures (Thomas and Raper, 1977).

Temperature Effect on Flower and Pod Number

Flower Number

Soybean plant produces more flowers than can develop into pods. Genotypes differ in their time to flowering in response to temperature. About 20 to 80% of the flowers were reported to abscise based on various stresses. Flower initiation was reduced by temperatures greater than 32°C and seed formation was delayed at 40°C (Thomas et al., 2003) in soybean. Koti et al. (2004) reported that soybean genotypes grown under high temperatures (38/30°C) produced smaller and shorter flowers with poor pollen germination compared to flowers at grown at a temperature of 30/22°C. Harmful effects of high temperature on flower number have been recorded in sensitive crops and cultivars. For example, Peet et al. (1997) reported a 17% reduction 17% in flowers in tomato when plants were exposed to a mean temperature of 34°C as compared to optimum temperature. In peanut, Talwar et al. (1999) found similar results; however, the increase was correlated with an increase in leaf numbers and plant dry weight.

Pod Number

The yield component of a soybean crop is based on pod development and seed filling, the two most heat-sensitive stages in soybean (Korte et al., 1983). Temperatures have a significant effect during the reproductive stage and seed filling (Gibson and Mullen, 1996). A temperature of 40°C results in adverse effects on growth rate, flower initiation and pod set for soybean

reproduction. Ferris et al. (1998) studied the determinate soybean cultivar, 'Fiskeby V', and reported that the number of pods was increased by 18% under elevated CO₂ concentrations and high temperatures. Prasad et al. (2003) reported pod number was reduced in peanuts by a high temperature of 38/22°C. High temperature at podding time reduced pod number by about 32% whilst high temperature at flowering reduced pod number by only 22%.

Temperature Effect on Pollen, Stigma and Ovary

Pollen Viability

The viability of pollen has been defined as having the ability to live, grow, and germinate. Pollen viability and germination are known as the most heat-sensitive stages among various developmental stages in crops (Stone, 2001). Pollen viability and germination were shown to be the limiting factors during fruit set under high temperatures in tomato (Peet et al., 1998), groundnut (Prasad et al., 2003), and kidney bean (Prasad et al., 2003).

Several tests have been developed for a fast and comparable assessment of pollen viability such as staining rates after incubation with fluorescein diacetate (FCR). Schueler et al. (2005) found that the FCR was the most discriminating test for pollen germination. Pollen viability of other crop plants has been studied using various staining techniques, such as 2-3-5-triphenyle tetrazolium chloride (TTC), propionic carmine and 5-bromo-4-chloro-3-indolye-galactoside. Prasad et al. (2003) assesses pollen viability by staining with TTC and reported that pollen viability was reduced when pollen was exposed to night temperatures of 22 and 28°C with day temperatures increasing from 28 to 48°C. High temperature conditions affected development of pollen grains and reduced germination in the bell pepper; these conditions could also possibly affect sucrose utilization in pollen grains.

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Dane et al. (1991) studied the effect of temperature on tomato pollen. Weaver et al. (1989) reported that flowers that were exposed to temperatures over 35°C have less than 50% of pollen viability and at temperatures over 40°C, the pollen was killed.

Pollen Germination

Even if pollen grains are viable based on a viability test, pollen must germinate, the pollen tube must grow in length, and fertilization must occur for seed production. ElAhmadi and Stevens (1979) found that viability percentages are not necessarily correlated with successful fertilization of the ovary. In artificial in vitro medium, cotton pollen grains started germinating in about 10 min (Kakani et al., 2005). Tolerance of both pollen germination and pollen tube length to temperature could be used for selecting genotypes for greater seed production in high temperature environments. Temperature affects all aspects of plant growth and development. All biological processes have nonlinear functions that have three coefficients of the cardinal temperature: minimum (T_{base}), optimum (T_{opt}), and maximum (T_{max}) temperatures. Cardinal temperatures for pollen and pollen tube growth parameters have been reported for many crops. In groundnut, identifying crops with high/low cardinal temperatures for key reproductive processes that may be anticipated in current and future climate conditions may directly contribute to the seed yield enhancement. That may help in defining cultural solutions and breeding strategies to improve heat stress tolerance and may provide better cultivars for a given production area. Previous studies have not reported cardinal temperatures (minimum, optimum and maximum) for soybean reproductive parameters or determined whether genotypic variation

exists in pollen tolerance to temperatures. Various in vitro pollen germination technique has recently become one of the most important screening methods for screening crop cultivars for heat tolerance. In vitro pollen germination percentages have been reported for several crops: 35% in apricot, 32% in bell pepper (Erickson et al., 2002), 42% in avocado (Sahar and Spiegel-Roy, 1994), 44% in cotton (Kakani et al., 2005) and 64-76% in soybean (Koti et al., 2004).

Pollen Tube Length

The time for pollen germination and subsequent pollen tube extension required to reach the ovary is measured in hours for soybean and groundnut to days in tree species such as apple (Kakani et al., 2005). Unlike pollen germination percentage, length of pollen tube required for fertilization depends on the length of the style. Exposure to abiotic stresses such as temperature may delay the pollen tube growth and length. Cardinal temperatures for reproductive parameters for many crops. Variation in in vitro pollen tube lengths have been reported in several crop species (Kakani et al., 2005).

Stigma Style and Ovule

Although male gametes are very sensitive to high temperature, little information is available on its effect on female reproductive structures (Stigma, style, and ovule) and on flower receptivity. Gross and Kiegal (1994) found lower fruit set due to lower in female receptivity in common bean. Peet et al. (1997) concluded that high viability in pollen grains does not ensure fruit set under high temperatures. Saini and Aspinall (1982) reported that female sterility may have contributed to a decreased grain yield.

Approximately 35% of the heat-stressed ovaries contained abnormal embryos and their stigmas had fewer pollen tubes reaching the ovary, decreasing the chances for successful fertilization.

Screening for Heat Tolerance

Abiotic stresses, particularly higher temperatures and periodic episodes of heat and drought, could exacerbate the effect on many aspects of crop growth and development thereby reducing crop yield (Reddy et al., 1999). Different physiological mechanisms may contribute to heat-tolerance in crops. Heat-tolerance metabolism is indicated by higher photosynthetic rates, stay-green and greater membrane thermostability (Dogan et al., 2007). Heat avoidance is indicated by canopy temperature depression. In any crop improvement programs, the first and foremost requirement is to identify suitable genotypes or lines to be used in breeding after assessing their tolerance to a particular stress. Therefore, it is imperative to use cost effective and reliable techniques to screen available germplasm for various eco-physiological, morphological and reproductive traits to assist their utilization in crop breeding programs. Breeding programs may measure such traits to assist the selection of heat tolerant parents, segregating generations or advanced lines (Reynolds et al., 2001).

Vegetative Parameters

Photosynthesis and Chlorophyll Fluorescence

The impacts of high temperature on photosynthesis and several other vegetative growth parameters have been reviewed by Long (1991). Thomas and Raper (1976) found that duration of the vegetative period in soybean was significantly affected by high temperatures. Al-Khatib and Paulsen

(1990) found that high temperature decreased the period of photosynthetic activity in wheat. Extensive studies have been conducted on the short-term and long-term effects of temperature on physiological and cellular processes in plants. Short term effects include change in gene expression, such as heat shock protein synthesis, are expected to occur in soybean (Mathilde et al., 2008). Longer-term include modification in the rate of carbon dioxide assimilation and electron transport per unit leaf area, weakened cell carbon metabolism, and finally, a reduced carbon and nitrogen partitioning within and between organs. Thus, crops that are able to maintain cellular stability and crop production despite heat stress may possess a high level of heat tolerance. High temperature has been reported to damage photosynthesis before other processes in sensitive species (Zhang et al., 2007). Ph