Reprint ISSN 1923-7766 (Web Version)

International Journal of Experimental Agriculture

(Int. J. Expt. Agric.)

Volume: 12 Issue: 1 July 2022

Int. J. Expt. Agric. 12(1): 5-13 (July 2022)

PHOTOPERIOD AND TEMPERATURE RESPONSE IN THE FLOWERING OF SOYBEAN (*Glycine max* (L.) Merrill) PLANT: AN OVERVIEW

M.R. ISLAM

An International Scientific Research Publisher
Green Global Foundation©

Web address: http://ggfjournals.com/e-journals archive
E-mails: editor@ggfjournals.com and editor.int.correspondence@ggfjournals.com

ISSN-1923-7766 (Online)
Int. J. Expt. Agric. 12(1):5-13(July 2022)

PHOTOPERIOD AND TEMPERATURE RESPONSE IN THE FLOWERING OF SOYBEAN (*Glycine max* (L.) Merrill) PLANT: AN OVERVIEW

M.R. ISLAM

KWC Trading LLC Dubai, UAE (Agri Unit)

Accepted for publication on 5 June 2022

ABSTRACT

Islam MR (2022) Photoperiod and temperature response in the flowering of soybean (*Glycine max* (L.) Merrill) plant: an overview. *Int. J. Expt. Agric.* 12(1), 5-13.

Soybean (*Glycine max* (L.) Merrill) is a high-value commercial crop. The demand for soybean has been increasing day by day all over the world. Therefore, it is essential to increase soybean production area and yield for keeping pace with growing demand. Better knowledge about the responses to photoperiod (day length) and temperature on soybean flowering is a key breakthrough to increase production of soybean. Soybean is a photo-sensitive short-day plant that flowers initiate when days are shorter than the maximum critical value and this period varies from genotype to genotype. Earlier findings reported that the sowing time and adaption of soybean to wider ranges of latitude depend on photoperiods. The period from emergence to the flowering of soybean may be divided into three phases: 1) the pre-inductive phase or juvenile growth phase (JGP); 2) the inductive phase; and 3) the post-inductive phase. The photo-sensitivity and JGP give guidance to choose an adaptable genotype for a specific latitude belt. Night break is also responsible for delaying the flowering time of soybean. Alternately, the temperature is also another important factor for soybean production all over the world. Flowering time of soybean is generally affected by temperature regarding days from emergence to first flower open. However, considering accumulated temperatures during emergence to first flower, it could be stated that temperature might affect quantitatively in soybean flowering i.e., the temperature may not have a triggering effect on flowering initiation in soybean. There is a great problem to separate the photoperiod and temperature effect in the field experiment because these two factors changed daily and interact with each other. It is essential to conduct experiments in the control environment to clarify the effect of photoperiod and temperature independently on soybean flowering. The current study made clear the effect of photoperiod and temperature independently on the flowering of soybean.

Key words: *photo-sensitivity, accumulated temperature, juvenile growth phase, genotypes, short day*

INTRODUCTION

Photoperiod and temperature affect many aspects of soybean plants. This review will provide information about the effect of photoperiod and temperature on the flowering of the soybean plant. This study has paramount importance due to the adaptation of soybean plants throughout tropical, subtropical, and temperate zone is determined by the response of flowering to photoperiod and temperature. Photo-sensitivity decides to select suitable genotypes for specific areas, determine the best planting date, and predict seed yield. Besides, the temperature is another crucial key factor that controls flowering time in soybean. The suitable temperature for soybean flowering is 20–22°C (Liu *et al.* 2008). It is also stated that high temperature stimulates flowering in soybean (Setiyono *et al.* 2007; Rahman *et al.* 2006; Kantolic and Slafer, 2007; Gaynor *et al*. 2011) and increases the rate of crop development (Craufurd and Wheeler, 2009). Early maturing genotypes are more responses to temperature compared with photoperiod (Champman 1986). Hence, the effect of photoperiod and temperature on soybean flowering is extremely important to explore productivity.

The effect of photoperiod on flowering in soybean has been examined since long decade ago (Garner and Allard, 1923 and 1930). To date, it is demandable tropic to increase seed yield and areas of adaptability in soybean. Consequently, it has been reported that there is a notable variation of sensitivity to photoperiod in soybean (Islam *et al.* 2019a). Furthermore, the effect of temperature on soybean flowering is another sound tropic, which has been investigated since introductory work (Garner and Allard, 1930). The days from emergence to flowering in soybean genotypes control plant size and seed yield potentiality (Patterson *et al.* 1977; Thomas and Raper, 1977; Jones and Laing, 1978). Therefore, a better understanding of the effect of photoperiod and temperature on soybean flowering would be a value to provide an indication of genotypes adaptability and yield potentiality for specific areas.

For soybean production areas, information about the sensitivities of photoperiod and temperature is necessary for the selection of adaptable genotypes. However, photoperiod and temperature sensitivity determination in soybean is very complex in the natural environment because of the interaction between photoperiod and temperature. Jonson *et al.* (1960) also reported that the estimation of photo-sensitivity may have limitations due to the fluctuation of temperature in field experiments. In this review, we will be introduced a few techniques to separate the effect of photoperiod and temperature from the natural environment. In control environmental conditions, there is a limitation about photoperiod selection because photo-sensitivity would be changed by different photoperiods.

Corresponding author & address: Md. Rasadul Islam, E-mail: rasadulexim@gmail.com

Thomas and Raper (1977) reported that day and night temperatures may have separate effects on flowering in soybean, and high night temperatures stimulate flower initiation. Other experiments showed that a high night temperature brought the flowering time earlier and reduced the seed yield in soybean (Zheng *et al.* 2003). Thus, there is a major impact on the pattern of responses to temperature in soybean flowering.

From above mentioned background, there is a major impact on the pattern of responses to photoperiod and temperature in soybean flowering. Thus, a clear report is needed for better understanding of the effect of photoperiod and temperature in the flowering of soybean. The aim of this revision is to clarify the effect of photoperiod and temperature in the flowering of soybean. The information from the overview will also be useful to increase soybean production which ultimately leads to meet the food and nutritional security.

History of the photoperiodic research in soybean

Hitherto 1893, the light-dependent system by which plants reduce co_2 to organic matter was called assimilation (Beatty *et al.* 2004). This phenomenon was found in both plants and animals. In 1893, Charles Barnes seemed that the use of the same name for plant and animal was ill-advised and confusing. As a result, Barnes proposed two new names for the green plant biosynthetic process, namely, photosyntax and photosynthesis. From that time plant physiologists believed that plant flowering was a consequence of the accumulation of photosynthetic products synthesized during long days. However, in 1920 Garner and Henry Allard were shown this hypothesis to be incorrect.

Garner and Allard found that a mutant genotype of tobacco (Maryland Mammoth) grew excessively to about 5 m in height but did not initiate flower in the prevailing condition of summer. However, the plants initiate flower in the greenhouse during winter under natural light conditions. These results led Garner and Allard to examine the effect of artificially shortened days by covering plants grown during the long day of summer with a light-tighten from late the afternoon until the following morning. These artificial short days also caused the plants to initiate flower. Garner and Allard revealed that day length, rather than the accumulation of photosynthate, was the controlling factor in flowering. They could confirm their hypothesis in many other plant species including soybean. This work laid the foundations for the extensive consequent research on photoperiodic responses in soybean (Taiz and Zeiger, 2010), although few previous research suggested that day length was important to plant development. Indeed, the Frenchman and Tournois 1914 wrote that flowering in a short-day plant was stimulated by the length of the dark period. However, they did not provide any other information. Therefore, the research of Garner and Allard in 1920 was considered an actual discovery of photoperiod.

Photoreaction during photoinduction

The soybean leaf pigment that receives radiation is the photochromatic type and it is marked by PH_2. It works with a hydrogen receptor (R component) to transform into a p pigment under red light in below equation. However, the opposite reaction occurs in the equation under distant red radiation (Destro *et al.* 2001).

$$\mathbf{PH_2 + R \rightleftharpoons P + RH2}$$

This phenomenon indicating the ultimate result of a clear day, a great portion of the pigment is associated with active p form. thermal reaction occurred and active p form turn back to pigment PH_2 at night time. Since short time distant red radiation at the end of the day raises stem and petiole elongation. It has been reported that the main stem and internode elongation was notably larger when the soybean genotype was exposed to incandescent lighting (distance red component) compared to when plants were exposed to fluorescent lighting (red radiation) (Thomas and Raper, 1985).

Soybean is a short-day plant

Soybean is a photo-sensitive crop. Long-day treatment can hinder or noticeably delay its flowering. Soybean genotypes show a wide range of variations in sensitivity to photoperiod. Islam *et al.* (2019a) used the world mini-core collection including 82 genotypes and reported that the range of variation (0 to 0.47) in those degrees of sensitivity to photoperiod based on accumulated temperature from emergence to flowering. Fatichine *et al.* (2009) worked with 15 genotypes and reported that those sensitivity ranges from 0.12−0.38 based on days to flowering. Fig. 1 shows the variation of response is among the cultivars from very sensitive to insensitive.

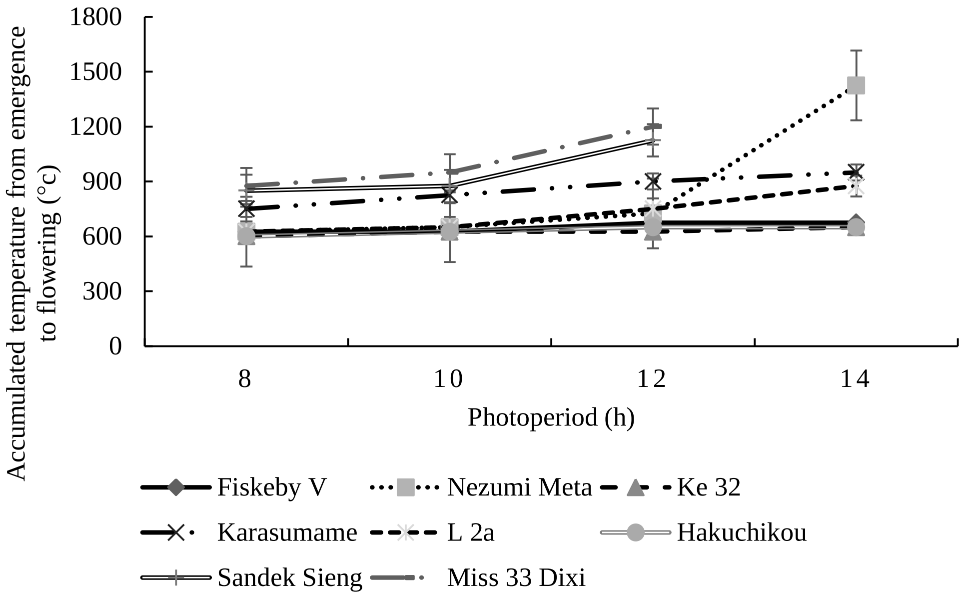

Fig. 1. Response curves of different types of soybean genotypes (Islam 2019)

Several researchers have been reported that genotypes, whose flowering is delayed by short-day treatments and hence are considered short-day plants (Abeyratne 1952; Gangulee 1954; Tiwary *and* Sarkar, 1963). Li *et al.* (1996) tested 10 soybean genotypes under 5 photoperiods (10,11,12,13,14 h) showed all genotypes shorten days to flowering under short photoperiodic conditions. Since soybean is a short-day plant. Khaliliaqdam (2014) studied the determination of sensitive growth stages of soybean to photoperiod. The author reported that days from emergence to flowering are sensitive to photoperiod and flowering does not take place at photoperiod longer than a critical value. Finally, the author revealed that the soybean can be considered as a qualitative short-day plant.

Furthermore, photoperiod response differs noticeably among soybean genotypes, this also exhibits the variation in the photoperiodism of the soybean plant. However, Islam (2019) critically tested the world mini-core collection (*GmWMC*) including more than 80 genotypes, and no one has exhibited a long-day response. Therefore, it is clear that soybean is a short-day plant.

Phases between emergence to flowering

The period from emergence to flowering may be divided into three phases for most of the species including soybean: 1) the pre-inductive phase or juvenile growth phase (insensitive to the photoperiod); 2) the inductive phase (sensitive to the photoperiod); and 3) the post-inductive phase (insensitive to the photoperiod) (Roberts and Summerfield, 1987; Ellis *et al.* 1992).

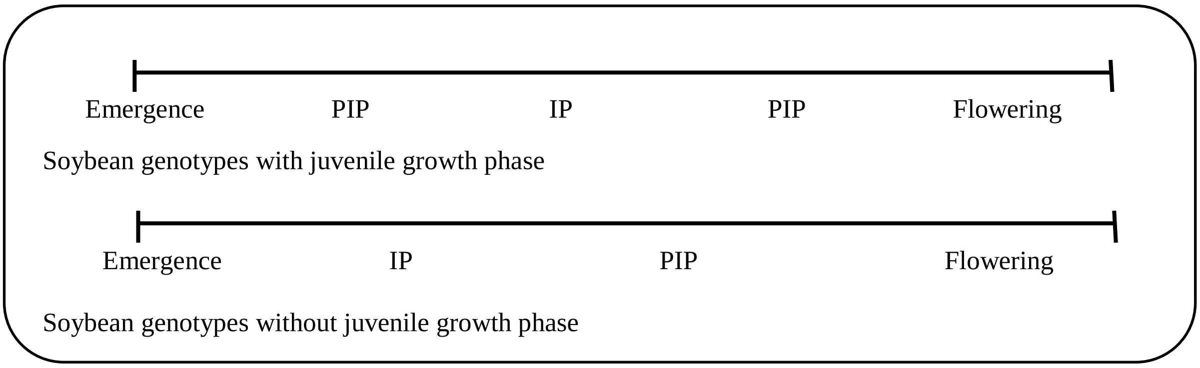

Fig. 2. Growth phases from emergence to first flower open of a soybean genotype with juvenile growth phase and without juvenile growth phase (Denotes: PIP = pre-inductive phase, IP = inductive phase and PIP = post inductive phase).

On the other hand, Wilkerson *et al.* 1989 reported that the interval between emergence and first flower can be divided into four phases: (1) a purely vegetative phase or juvenile growth phase; (2) a photo-sensitive inductive phase; (3) a photo-sensitive post-inductive phase; and (4) a photo-insensitive post-inductive phase.

Pre-inductive phase (PIP) or juvenile growth phase (JGP)

The soybean plant is insensitive to photoperiod at the early growth stages is known as PIP or JGP. There are different kinds of genotypes in soybean ranging from no JGP genotypes to high JGP genotypes. Knowledge about JGP is extremely important in soybean. Because JGP gives guidance to choose an adaptable genotype for a specific latitudinal area. Incorporation of the long juvenile trait into soybean germplasm adapted to one place may help the transfer of advantageous traits to genotypes adapted to the new place. Moreover, JGP supports the soybean grower with more management adjustability in response to climatic conditions and crop rotation schemes.

The long juvenile trait was first identified in Brazil and subsequently expand soybean production in regions of low latitude (Destro *et al.* 2001). The genotypes PI 159925 when sown in May (long photoperiod) at a latitude near 33^{o} N flowered as a maturity group VIII; however, in August (short photoperiod) sowing, it flowered like a maturity group IX or X. This delayed flowering under short-day conditions used as long juvenile trait (Hartwing and Kiihl, 1979). Although the 40% soybean production area of Brazil is located below 24^{o}S, it has become the second-largest soybean production in the world depending on the long JGP invention (Spehar 1995; Destro *et al.* 2001).

Wilkerson *et al.* (1989) developed a method by moving the plants from short (9 h)- to long (22 h)-photoperiod (inductive to noninductive), or the reverse with a constant temperature 26°C to determine the JGP of soybean. They tested six genotypes i.e. Dawson, Williams, Ransom, Forrest, Davis, and Jupiter revealed that the JGP of these genotypes from 0 to 11 days. Collinson *et al.* (1993) used a similar method transferred four genotypes at various times after sowing from short (11.5 h d^{-1}) to long (13·5 h d^{-1}) days and vice versa at day/night temperatures of 30/20°C and identified the JGP: UFV-1 (11.2 d), G2120 (32.7 d), Biloxi (11.9 d) and CPI 104521 (18.6 d).

Islam *et al.* (2019a) established a method that 10 h photoperiod with 28°C (constant) temperature to determine the JGP. They tested world mini-core collection genotypes including 82 genotypes and reported that relative JGP among the genotypes 0 to 308°C (the accumulated temperature from emergence to flowering) in Fig 3.

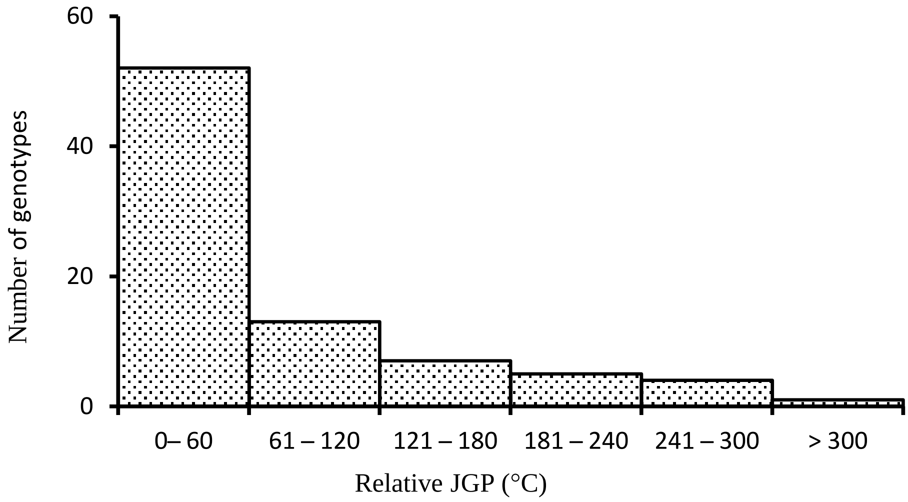

Fig. 3. Distribution of relative JGP among the GmWMC genotypes (Islam 2019)

Inductive phase (IP)

It has been reported that the duration of the IP could be genotyped dependent (Islam *et al.* 2019a). IP decides the plant's sensitivity to photo-sensitive genotypes. This phase is eliminable in some cases. Islam *et al.* (2019a) deleted IP by adjusting photoperiod and temperature.

Post inductive phase (PIP)

It has been reported that the PIP phase is a photoperiod insensitive phase (Roberts and Summerfield, 1987; Ellis *et al.* 1992). This phase is considered from flower bud to flower initiation in soybean. The marked observation of the duration of this stage is around 20 days. Saitoh *et al.* (1999) reported that from auxiliary bud enlarge to flower initiation needed around 20 days in soybean. Islam *et al.* 2019b reported that the duration of this stage is 20 days or 560°C accumulated temperature from emergence to first flowering in soybean.

Sensitivity of flowering to photoperiod

Generally, the sensitivity of flowering to photoperiod is determined by subtracting days to flowering under the short photoperiodic condition from the days to flowering under the long photoperiodic condition. Several methods of measuring photoperiod sensitivity have been established. Fatichine *et al.* (2009) used an equation to calculate the photoperiod sensitivity in soybean. The equation is following: photoperiod sensitivity = $1-(D_{R1}$-SD) / D_{R1}-LD, where D_{R1}-SD and D_{R1}-LD are the days to flowering (R1) under short and long day length conditions, respectively. Additionally, Islam *et al.* (2019a) used the accumulated temperature from emergence to flowering instead of days to flowering using the difference in the accumulated temperature from emergence to first flower open (ATEF) between long- (13 h) and short- (10 h) photoperiods at 28°C using the following equation:

$$IPF = 1 - ATEF10h / ATEF13h$$

where ATEF10h and ATEF13h are the accumulated temperatures from emergence to first flower open under short- and long- photoperiods. To exact determination of photo-sensitivity is very hard because it depends on optimum and critical photoperiod. Therefore, if we want to determine the exact photo-sensitivity of a genotype, we need to determine the optimum and critical photoperiod for that genotype. Optimum photoperiod is the day length at which the time from emergence to flowering is at a minimum. Critical photoperiod is the longest day length at which the plant initiate flower or the day length above, which could not initiate a flower. Optimum and critical photoperiod differ with genotypes. To exact determination of photo-sensitivity using a large number of genotypes is laborious and time consuming.

Effect of sowing period in soybean

Day length changes based on circadian rhythms within a year even differ with latitude. In the equator, day length and night length are 12 h throughout the years. As one goes away from the equator towards the poles, the day length becomes longer in summer and shorter in winter (Fig. 4).

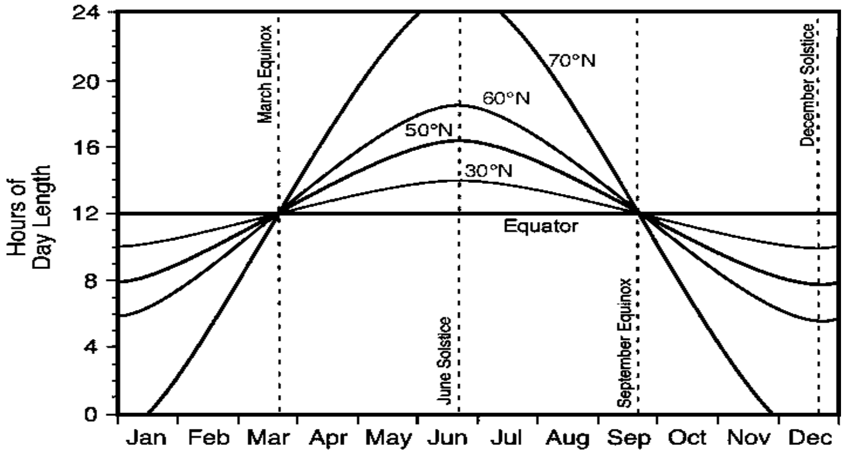

Fig. 4. Effect of latitude on day length at different time of the year in the northern hemisphere

Source: https://www.bing.com/images/search?view=detailV2&ccid=AtJbV4Wp&id=2B5D9F64743846FB060F045AEAA360A45F41FA44&thid (browsed on March 2, 2022).

Plants are submitted to different sowing periods with different day lengths due to the seasonal variations in every location. Therefore, the sowing period is the most crucial agronomic practice in soybean production. Islam *et al.* (2019b) worked on more than 80 genotypes over three years in the field with different sowing dates and concluded that all genotypes initiate flower earlier under late sowing (short photoperiodic condition). Moreover, the sensitivity of flowering to sowing time exhibited a wide range of variation among the genotypes. These diverse genotypes are very advantageous for the sustainable production of soybean.

The sowing period may work as a safety mechanism when optimal sowing dates face adverse weather. For instance, soybean is a very familiar crop in southwestern Japan, which is commonly grown early to mid-July. However, this time is the rainy season in this area and the emergence and seedling standing are harmed by excessive soil moisture cause of flooding (Zheng and Watabe, 2000; Nakayama *et al.* 2004; Hamada *et al.* 2007; Yamashita *et al.* 2008). Early or late sowing is a preference to avoid the harm of flooding in the rainy season. Thus, the sowing period plays a vital in soybean production.

The latitudinal effect on soybean

Soybean genotypes have been categorized in the USA into thirteen maturity groups ranging from 000 to X. The classification of maturity group is not valid when region latitude is not mentioned. Because, when a genotype is planted in Northern Hemisphere, to the South of its adaption area, it flowers and matures earlier. But, when planted in the North flowers and matures are delayed, however, the opposite occurred in the Southern

Hemisphere. Whigham (1976) planted 20 soybean genotypes in twelve areas including four latitude zones and revealed that the number of days to flowering and maturation increases while yield decreases.

Photo-sensitivity of genotypes is the key factor for determining latitudinal adaption and choosing sowing time for example photo-insensitive genotypes could be sown in a wide range of seasons to fit with multiple cropping systems in tropical areas. The genotypes in the lower latitudes are mostly late maturing. It has been reported that late-maturing genotypes are more sensitive to photoperiod than the early ones (Major *et al.* 1975). It is also recognized that soybean insensitive genotypes can be successfully grown at a wider range of latitudes.

On the other hand, knowledge about JGP of genotypes is another parameter to the latitudinal adaption of soybean. Long juvenile genotypes have potential genotypic importance to grow a wider range of adaption, especially low latitude areas. Similarly, short juvenile genotypes would be adapted in high latitude areas.

Soybean is grown over a wide range of environmental conditions (low to high latitude). This wide adaptability depends on diversity in photo-sensitivity in soybean that the soybean cultivars predominantly cultivated in each area have been selected based on local adaptability i.e., adaptability to the photoperiod and temperature of the growing season to assure the full development of the plant and the best possible balance between vegetative and reproductive growth. Intensive studies in different latitudes have established that photo-insensitive genotypes have wide adaptability.

Interruption of the dark period in soybean flowering

It is recognized since a long day ago that soybean is a very sensitive crop that responds to a light interruption. Nanda and Hamner (1958) reported that an interruption of the dark period by high-intensity light for 30 minutes significantly affected the flower initiation of soybean. Murray *et al.* 1964 reported 72-hour or tridiurnal, cycle using high-intensity light breaks and differential photoperiods. Light breaks were given during the 64-hour experimental dark period of a tridiurnal cycle (each cycle initiated with an eight-hour high-intensity light period) flower initiation may be stimulatory, innocuous, or inhibitory depending on the time at which the interruption is applied. The findings show that the flowering response of the plant is affected by the dark period.

General statement about the effect of temperature on the flowering response in soybean

Temperature is a key factor affecting the growth and development of plants (Hatfield and Prueger, 2015). The relative growth rate (increase in dry weight per unit biomass present with per unit of time) of crops is low under unfavorable temperature conditions, whereas high under favorable temperature conditions (Craufurd and Wheeler, 2009). The favorable temperature for the entire growing season in soybean is 16–28°C (McBlain *et al.* 1987), and the optimum temperature for flowering is 20–22°C (Liu *et al.* 2008). High temperature decreases the time to complete development phases in soybean (Setiyono *et al.* 2007). Soybean plants could not open flowers under night temperatures below 14°C (Parker and Borthwick, 1950). Early maturation cultivars respond better to temperature changes than to daylight length. This was confirmed by Major *et al.* (1975).

Different temperature regime on soybean flowering

Islam (2019) used three temperature conditions (25/18°C, 28/22°C, and 33/28°C) high temperature shortened the days from emergence to first flower open, but it had less effect on the accumulated temperatures during emergence to first flower open; however, there was almost no effect on the effective accumulated temperature from emergence to the first flower open regardless of the temperature conditions. This implied that there were no differences in the effective accumulated temperature from emergence to first flower open in most genotypes among the three temperature conditions tested. Thus, it could be considered that temperature affects soybean flowering.

Fluctuated day/night temperature on soybean flowering

Islam 2019 used three temperature regimes (26/26, 28/24, 30/22, 34/18°C, day/night) at 10 h photoperiod and showed that days from emergence to first flower open differ greatly, but it had less effect on the accumulated temperatures during emergence to first flower open did not differ notably with the fluctuated day/night temperature, indicating soybean flowering was almost unaffected by fluctuated day/night temperature. This result also supports that temperature affect quantitatively in soybean flowering.

Problem in the study in photoperiodism and temperature of the soybean

Mainly two reasons are responsible for the failure to get sufficient information on photoperiodism of the soybean plant: 1) The natural photoperiod and temperature is used in most of the experiments whose are not control treatment at all, since temperature and photoperiod regularly changed and interact each other; and 2) There is no standard distinction between photoperiodic and photosynthetic action of light. It is supported by many researchers that the involvement of a photoperiod and temperature interaction in the soybean flowering (Garner and Allard, 1930; Lawn and Byth, 1973).

In many experiments, poor cultural conditions were used to grow the plant, which is compared with the control, and therefore the results of the experiments may not accurate. Besides, different genotypes are used in the experiments on photoperiod and temperature that make generalization hazardous. The proper term(s) selection may vary for describing the response to photoperiod or classifying the plant according to its response. To get the exact results such terms should be standardized.

CONCLUSION

During the pioneering work, two scientists Garner and Allard in 1020 first stated that photoperiod rather than the accumulation of photosynthate was the controlling factor in the flowering of plants. Ever since soybean is a short-day plant and the time from emergence to flowering may be divided into three phases: 1) JGP; 2) IP; and 3) PIP. Almost all genotypes open flower earlier under a short photoperiod compared with long photoperiod, but the degree of sensitivity varies greatly among genotypes. The JGP is insensitive to the photoperiod; JGP could be estimated by using different photoperiods and there is a big variation among the genotypes in soybean and some genotypes might not have JGP. Long JGP characteristics can help in the development of soybean genotypes for low latitudes areas with greater adaptation. JGP estimation in natural conditions is very difficult because photoperiod and temperature changed daily and interact with each other. Critical photoperiod and optimum photoperiod differ among the cultivars and the variation of these two components is greatly responsible for the inter-varietal variation in flowering response to photoperiod. Furthermore, sowing time is a vital factor to increase the soybean production and soybean can be grown over a wide range of latitudes. This wide adaptability depends on diversity in photo-sensitivity of soybean genotypes. This study also showed that late-maturing genotypes are more sensitive to photoperiod than the early ones and insensitive genotypes can be successfully grown at a wider range of latitudes. The dark period may markedly affect the time of flowering in the soybean plants. In the case of temperature, it may affect quantitatively in soybean plant development and the accumulated temperatures during emergence to the first flower are more appropriate to measure the effect of temperature on soybean flowering compared with days from emergence to the first flower. Determination of the effect of photoperiod and temperature in the natural condition is hard because temperature and photoperiod changed regularly and interact with each other. To solve this problem, it is essential to conduct experiments in the control environment. Ultimately, this study will increase soybean production all over the world and help to crop physiologists for future research by providing enough information related to photoperiod and temperature response in the flowering of soybean.

REFERENCES

Abeyratne E (1952) A preliminary note on an unrecorded group of paddy varieties occurring in Ceylon. *Trop. Agric.* 108:21–28.

Beatty JT, Gest H, Allen JF (2004) Advance in photosynthesis and respiration Discoveries of photosynthesis: History of the world photosynthesis and evaluation of its definition. Springer, P.O. Box 17, 3300 AA Dordrecht, The Netherlands. 20: 38–39.

Champman J (1986) The influence of photoperiod and temperature on the pre-flowering phase length of eleven soybean cultivars in northern Natal. *S. Afr. J. Plant Soil.* 3: 61–65.

Collinson ST, Summerfield RJ, Ellis RH, Roberts EH (1993) Durations of the photoperiod-sensitive and photoperiod insensitive phases of development to flowering in four cultivars of soybean (*Glycine max* (L.) Merril). *Annals of Bot.* 71:389–394.

Craufurd PQ, Wheeler TR (2009) Climate change and the flowering time of annual crops. *J. Exp. Bot.* 60: 2529–2539.

Destro DV, Carpentieri-Pípolo RA, Souza Kiihl DE, Almeida LA (2001) Photoperiodism and genetic control of the long juvenile period in soybean: A review. *Crop Breed. Appl. Biotechnol.* 1:72–92.

Ellis RH, Collinson ST, Hudson D (1992) The analyses of reciprocal transfer experiments to estimate the duration of the photoperiod sensitive and photoperiod insensitive phases of plant development: an example in soybean. *Annals of Bot.*70:87–92.

Ellis RH, Collinson ST, Hudson D, Patefield WM (1992) The analysis of reciprocal transfer experiments to estimate the duration of photo-period sensitive and photoperiod insensitive phases of plant development: An example of soybean. *Annal. Bot.* 70: 87–92.

Fatichine, Zheng S-H, Arima S (2009) Varietal difference in responses to flowering time and plant growth to short day length in soybean. Coastal Bioenvironment. 2009:65–70.

Frenchman, Tournois (1914) Plant Photoperiodism, 1st Edition, Standford university press, Standford, California. P. 413.

Gangulee HC (1954) Types of flowering behaviour in rice *Oryza sativa* Linn. and the distinctiveness of the Aman type. *Curr. Sci.* 23:80–81.

Garner WW, Allard HA (1920) Effect of the relative length of day and night and other factors of environment on growth and reproduction in plant. *Journal of Agricultural Research*. 18: 553–606.

Garner WW, Allard HA (1923) Further studies in photoperiodism, the response of the plant to relative length of day and night. *1. Agric. Res.* 23: 871–920.

Garner WW, Allard HA (1930) Photoperiodic response of soybeans in relation to temperature and other environmental factors. *1. Agric. Res.* 41: 719 –734.

Gaynor LG, Lawn RJ, James AT (2011) Agronomic studies on irrigated soybean in southern New South Wales. I. Phenological adaptation of genotypes to sowing date. *Crop and Pasture Sci.* 62: 1056–1066.

Hamada Y, Shaku I, Sawada Y, Kojima H (2007) Factors causing submergence damage on soybean seedling emergence under no-till culture conditions. *Jpn. J. Crop Sci*.76: 212.

Hartwig EE, Kiihl RAS (1979) Identification and utilization of delayed flowering character in soybeans for short-day conditions. Field Crops Research. 2:45–151.

Hatfield JL, Prueger JH (2015) Temperature extremes: Effect on plant growth and development. Weather and Climate Extremes 10:4–10.

Islam MR (2019) Analysis of Genotypic Variation in Photo- and Thermo-sensitivities in Soybean (*Glycine max* (L.) Merrill) Adaptable to Tropical Areas. Thesis published to the Kagoshima University, Repository. 616.

Islam MR, Fujita D, Wataneba S, Zheng, S-H (2019a) Variation in photosensitivity of flowering in the world soybean mini-core collections (GmWMC). *Plant Prod. Sci.* 19(4), 1-7.

Islam MR, Fujita D, Zheng, S-H (2019b). Genotypic variation of sensitivities to photoperiod and temperature in different growth stages in soybean world mini-core collections (GmWMC). *Trop. Agr. and Develop.* 6(3), 69–78.

Jones PG, Laing DR (1978) The effects of phenological and meteorological factors on soybean yield. *Agric. Met.* 19: 485–495.

Jonson HW, Borthwick HA, Leffel RC (1960) Effects of photoperiod and time of planting on rates of development of the soybean in various stages of the life cycle. *Int. J. Plant Sci.* 122: 77–95.

Kantolic AG, Slafer GA (2007) Development and seed number in indeterminate soybean as affected by timing and duration of exposure to long photoperiods after flowering. *Ann. Bot.* 99: 925–933.

Khaliliaqdam N (2014) Determination of sensitive growth stages of soybean to photoperiod. *Agri. Sci. Dev.* 3: 140–145.

Lawn RJ, Byth, DE (1973) Response of soybeans to planting date in south-eastern Queensland. I. Influence of photoperiod and temperature on' phasic developmental patterns. *Aust. Agric. Res.* 24: 67–80.

Li J, Masaru N, Yoshie S (1996) Photoperiod response of indonesian soybean (*Glycine max* (L.) MERRILL) cultivars. Jpn. J. Trop. Agr. 40(1), 7-14.

Liu XB, Jin J, Wang GH, Herbert SJ (2008) Soybean yield physiology and development of high-yielding practices in Northeast China. Field Crops Res. 105: 157-171.

Major DJ, Johnson DR, Tanner JW, Anderson IC (1975) Effects of daylength and temperature on soybean development. *Crop Sci.* 15:174–179.

McBlain, BA, Hesketh JD, Bernard RL (1987) Genetic effects on reproductive phenology in soybean isolines differing in maturity genes. *Cana. J. Plant Sci.* 67: 105–115.

Murray DB (1964) Photoperiodism in rice in Thailand with reference to a second crop. *Emp. J. Exp. Agric.* 18:271–275.

Nakayama NS, Hashimoto S, Shimada M, Takahashi Y-H, Kim T, Oya Arihara J (2004) The effect of flooding stress at the germination stage on the growth of soybean in relation to initial seed moisture content. *Jpn. J. Crop Sci.* 73: 323–329.

Nanda KK, Hamner KC (1958) Studies on the Nature of the Endogenous Rhythm Affecting Photoperiodic Response of Biloxi Soybean, Botanical Gazette. 120(1), 1-9.

Parker MW, Borthwick HA (1950) Influence of light on plant growth. Annual Review of Plant Physiology. 1:43–58.

Patterson DT, Peet, Mary M, Bunce JA (1977) Effect of photoperiod and size at flowering on vegetative growth and seed yield of soybean. *Agron. 1.* 69: 631–635.

Rahman MM, Hampton JG, Hill MJ (2006) Soybean development under the cool temperate environment of Canterbury. *J. New Seed*. 7: 17–36.

Roberts EH, Summerfield RJ (1987) Measurement and prediction of flowering in annual crops. In J. G. Atherton (Ed.), Manipulation of Flowering. London: Butterworth. pp-17–50.

Saitoh K, Wakui N, Mahmood T, Kuroda T (1999) Differentiation and development of floral organs at each node and raceme order in an indeterminate type of soybean. *Plant Prod. Sci.* 2: 47–50.

Setiyono TD, Weiss A, Specht J, Bastidas AM, Cassman KG, Dobermann A (2007) Understanding and modeling the effect of temperature and daylength on soybean phenology under high-yield conditions. *Field Crops Res.* 100: 257-271.

Spehar CR (1995) Impact of strategic genes in soybean on agricultural development in the Brazilian tropical savannahs. *Field Crops Res.* 41:141–146.

Taiz L, Zeiger E (2010) Plant physiology (5^{th} Edition): The control of flowering. In: Wigge, P.A. (ed) P 732-733. Sinauer Association, inc., 23 Plumtree Road, sunderland, MA 01375 U.S.A. pp:732–733.

Thomas JF, Raper CD (1985) Internode and petiole elongation of soybean in response to photoperiod and end-of-day light quality. Botanical Gazette. 146: 495–500.

Thomas JF, Judith F, Raper CD (1977) Morphological response of soybeans as governed by photoperiod and temperature, and age at treatment. *Bot. Gaz.* 138(3), 321–328.

Tiwary NP, Sarkar DK (1963) The effect of short photoperiods on growth and yield of some aus (autumn) rice varieties. Oryza. 1(2), 35–40.

Whigham DK (1976) Intsoy world-wide variety trials. In: Hill, L.D. (Ed.). World soybean research. Interstate Printers and Publ., Danville. pp: 276–285.

Wilkerson GG, Jones JW, Boote KJ, Buol GS (1989) Photoperiodically sensitive interval in time to flower of soybean. *Crop Sci.* 29:721–726.

Yamashita H, Tsuchiya S, Nakano N, Tasaka K, Sasaki Y (2008) Studies on reducing germination damage from after-seeding irrigation by controlling seed water content, seeding depth and irrigation amount. Rep. Kyushu Br. *Crop Sci. Soc. Jpn.* 74: 49–51.

Zheng S-H, Maeda A, Fukuyama M (2003) Genotypic and environmental variation of lag period of pod growth in soybean. *Plant Prod. Sci.* 6: 243–246.

Zheng S-H, Watabe R (2000) Relationship between sugar exudation from imbibing seeds and seedling emergence in soybean. *Jpn. J. Crop Sci.* 69: 520–524.