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The Quantitative Effects of Temperature and Light on Growth, Development and Yield of Faba Bean (*Vicia faba* L.) (II. Development)

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Abstract: In this study, it was aimed to define the relationships between temperature, light intensity and development stages for faba bean namely rate of progress to emergence, flowering rate, rate of progress to pod onset, rate of height, rate of stem diameter increase and leaf appearance rate. Changes in plant development caused by the effects of environmental conditions such as temperature and light intensity were intended to be described by plant development stages models. All equations produced for development stages were derived as affected by light intensity and temperature. As a result of multi-regression analysis, it was found that there were close relationship between actual and predicted development stages. The regression coefficients (R^2) of the produced equations for development stages changed from 0.71 (leaf appearance rate) 0.99 (flowering rate and rate of progress to pod onset).

Key words: Faba bean, temperature, light, modeling, development stages

INTRODUCTION

Faba bean (*Vicia faba* L.) is its high potential to produce grains rich with valuable protein and its symbiotic nitrogen fixation ability. Both the production of *Rhizobium* nodules on roots of leguminous plants and the keeping of their nitrogen fixation ability are processes which demand a high energy output from a host plant (Filek *et al*., 2000).

In recent years, most of the researches have focused on investigation plant developmental periods. Plant development contains stages form seed sowing to reproductive stages and form reproductive stages to harvest (Ellis *et al*., 1990).

The effects of environmental conditions such as temperature and light on dry matter production rate of the plant and the effects of these conditions on plant growth rate should be distinguished. Because different physiological process occurs in different periods of plant growth, their needs for optimum temperature differ (Pearson *et al*., 1993).

The studies have focused on the relations between temperature, plant growth and development. As a result of this, mathematical models have been developed by considering the effects of different milieu temperatures on plant growth and development (Uzun, 1996 unpublished data).

Developmental models are commonly explored using computational or simulation techniques. The simulation software may be general-purpose, intended to capture a variety of developmental processes depending on the input files, or special-purpose, intended to capture a specific phenomenon. Input data range from a few parameters in models capturing a fundamental mechanism to thousands of measurements in calibrated descriptive models of specific plants (species or individuals). Standard numerical outputs (i.e., numbers or plots) may be complemented by computer-generated images and animations (Prusinkiewicz, 2004).

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To date, there have been a few attempts to describe the relationship between faba bean development, temperature and light intensity but with no wide temperature and light ranges. Therefore, this research quantitatively examined the effects of temperature and light on faba bean development, using a wide range of temperature and light intensity.

MATERIALS AND METHODS

Material

The research was conducted as field and greenhouse experiments. The field experimental area was constructed on a land area of 280 m^2 (14×20 m). The cultivar of Lara was used in the study. The soil used in the research was loamy-clay and had a pH value of 5.7.

Temperatures were measured in the greenhouse with a Sato Keiryoki MFG R-704 thermo hydrograph (0°C with 50°C±1) and soil temperature with a soil thermometer Testo 615 (0°C with 50°C±0.4).

Light measurements were performed 1 m high on the plants by Delta-T Sun Scan Canopy Analyser (Cemek, 2002).

Method

The field experiment area was divided into four blocks of 1.5×20 = 30 m^2. A similar arrangement was also applied to the greenhouse. Each block was then divided into three replications. Measurements and observations were carried out for each replication. Each measurement was repeated ten times starting from early plant growth stage to the harvest. In order to obtain a wide variation in the growth trend of faba bean for each replication, October the 15th, January the 15th, April the 15th and July the 15th were determined as sowing times. The seeds were sown by hand in drills. The distance between each sowing line was 50 cm and seeds were sown 20 cm apart in rows. Half of two blocks, in which April and July sowings were conducted, were shaded with a green net file. The shading material had a 50% light transmission. The procedure followed in field experimental area was almost identically repeated in the greenhouse. The development stages were calculated as rate of progress to emergence, flowering rate, rate of progress to pod onset, rate of height, rate of stem diameter increase and leaf appearance rate.

Air temperature, soil temperature and light intensity were used as independent variables during the development period of faba bean. Regression analysis was performed with Microsoft Excel 2003 program. Curve fitting processes were continued until the least sum of square of residuals was obtained. Fitted planes from multiple regression analysis were shown on 3-D graphics using SlideWrite computer package version 2.0.

RESULTS

Rate of Progress to Emergence

A relationship between rate of progress to emergence, temperature was obtained by mean of multi-regression analysis and the equation below (Eq. 1) was produced. Most of the variation (93%) in rate of progress to emergence (RPE) was explained by the selected parameter, namely soil temperature (T).

$$\begin{aligned} RPE &= -0.17253+(0.033139\times T)-(0.00088\times T^2) \\ SE &= 0.032^{**} \quad 0.0041^{**} \quad 0.00012^{**} \\ R^2 &= 0.93 \end{aligned} \qquad (1)$$

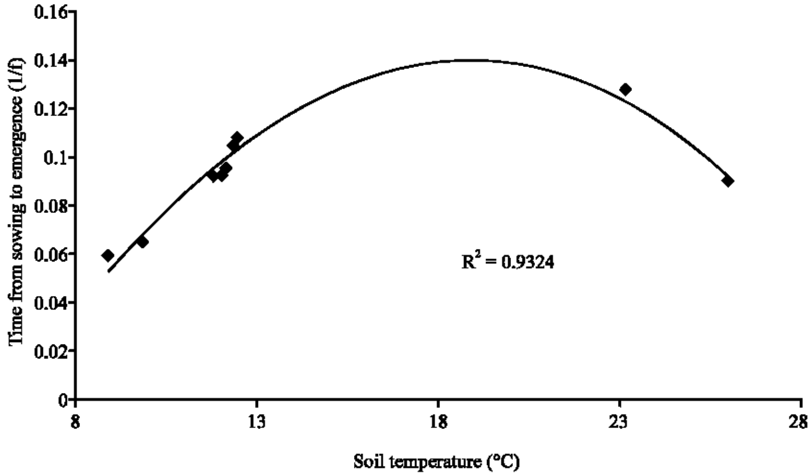

Fig. 1: Changes in rate of progress to emergence of faba bean with daily soil temperature (°C)

When the temperature values in Fig. 1 was considered, the change in rate of progress to emergence was between 8-26°C. The rate of progress to emergence was increased curve linearly depending on increasing soil temperature from 8 to 18.82°C. When the soil temperature was 18.82°C, the rate of progress to emergence has reached the top level. After that value increasing soil temperature was affected the rate of progress to emergence in a negative way. When it was 26°C, the rate of progress to emergence was descended the lowest level and when it was hotter, there was no rate of progress to emergence.

Flowering Rate

The result of multi-regression analysis showed that there was a significant relationship between flowering rate, temperature and light intensity. As a result of this relationship Eq. 2 was obtained. It was found that most of the variation (99%) in flowering rate (FR) was explained by temperature (T) and light intensity (L).

$$\begin{aligned} FR &= (-0.0221) + (1.58E^{-04} \times T) + (0.011 \times L) - \left[6.5E^{-04} \times (T \times L)\right] \\ SE &= \quad 6.16E^{-03}* \quad 3.3E^{-05}** \quad 2.29E^{-03}** \quad 1.54E^{-04}* \\ R^2 &= \quad 0.99 \end{aligned} \qquad (2)$$

As shown in Fig. 2, at low light intensities flowering rate increased curve linearly with temperature while there was not a clear effect of temperature on flowering rate at high light intensities. The highest flowering rate was obtained at low light and higher temperatures. The lowest flowering rate was at the lowest light and temperatures.

However, there was an interactive effect of temperature and light intensity on flowering rate such as flowering rate increased with increasing light intensities at low temperature regimes while it declined with the increase in light intensity at higher temperatures.

Rate of Progress to Pod Onset

According to the results of multi-regression analysis for rate of progress to pod onset in faba bean, it was found that first podded was affected by temperature and light intensity significantly. The following equation was obtained as a result of the analysis (Eq. 3).

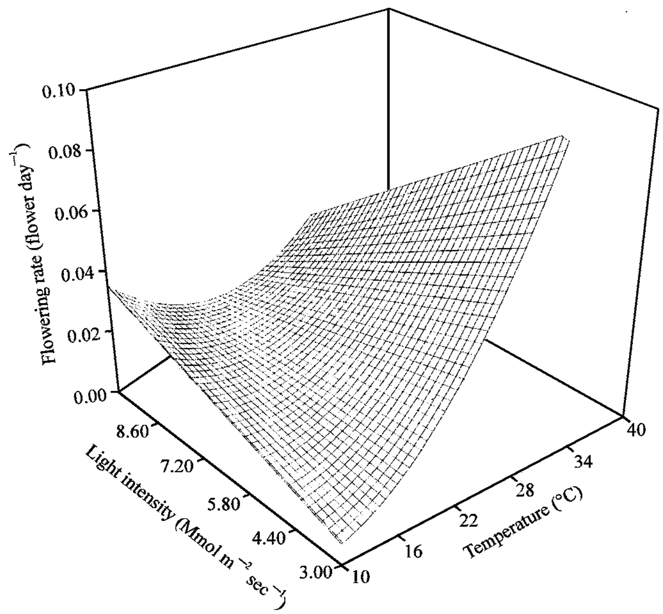

Fig. 2: Changes in Flowering Rate (FR) (flower day^{-1}) of faba bean with daily mean light intensity (μmol m^{-2} sec^{-1}) and temperature (°C)

$$P = (-31.57E^{-03})+(37.09E^{-04}\times T)+[3.13E^{-06}\times(T\times L)]-[2.6E^{-07}\times(T^2\times L)]+[1.31E^{-10}\times(T\times L)^2]-[1.7E^{-09}\times(T\times L^2)]$$

$$SE = 9.97E^{-04}* \quad 1.02E^{-04}* \quad 1.3E^{-07}* \quad 8.6E^{-09}* \quad 4.84E^{-12} \quad 7.79E^{-11}*$$

$$R^2 = 0.99 \qquad (3)$$

It was found that most of the variation (99%) in rate of progress to pod onset was explained by temperature (T) and light intensity (L) (Fig. 3).

As shown in Fig. 3, light did not have significant effect on rate of progress to pod onset at low temperature regimes. However, at high temperatures, rate of progress to pod onset declined curve linearly with increasing light intensity up to around 900 Mmol m^{-1} sec^{-1} and increased thereafter. The highest value in rate of progress to pod onset was obtained at low light and high temperatures.

At all light intensities, rate of progress to pod onset increased curve linearly as temperature increased from 8 to 25°C.

Rate of Plant Height Increase

As a result of multi-regression analysis of rate of plant height increase in faba bean, the effects of light intensity and temperature were found to be significant. The equation below was derived from this relationship (Eq. 4). As seen from the equation, temperature (T) and light intensity (L) explained most of the variation (84%) in rate of Plant Height Increase (PHI).

$$PHI = (-17.93)-(0.118\times T^2)+(5.24\times T)-\left[4.8E^{-06}\times\left(T^2\times L\right)\right]$$

$$SE = 2.53** \quad 1.6E^{-03}* \quad 4.62E^{-05}* \quad 1.64E^{-02}* \qquad (4)$$

$$R^2 = 0.84$$

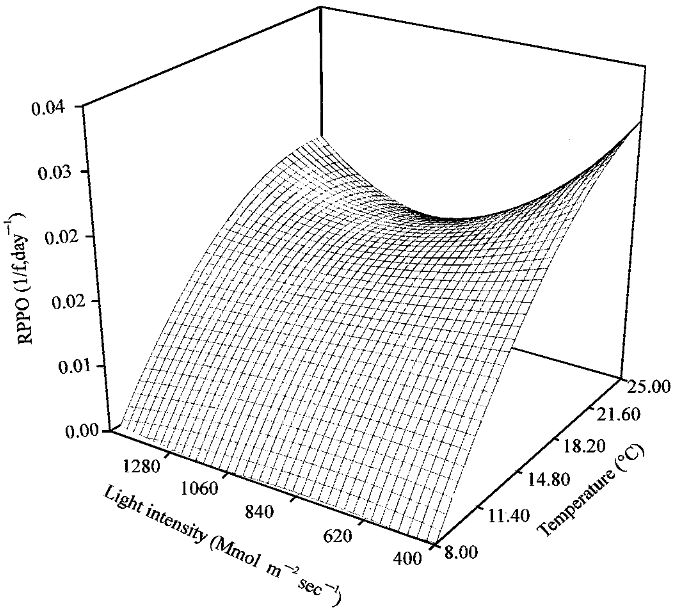

Fig. 3: Changes in Rate of Progress to Pod Onset (RPPO) (1/f, day^{-1}) of faba bean with daily mean light intensity (μmol m^{-2} sec^{-1}) and temperature (°C)

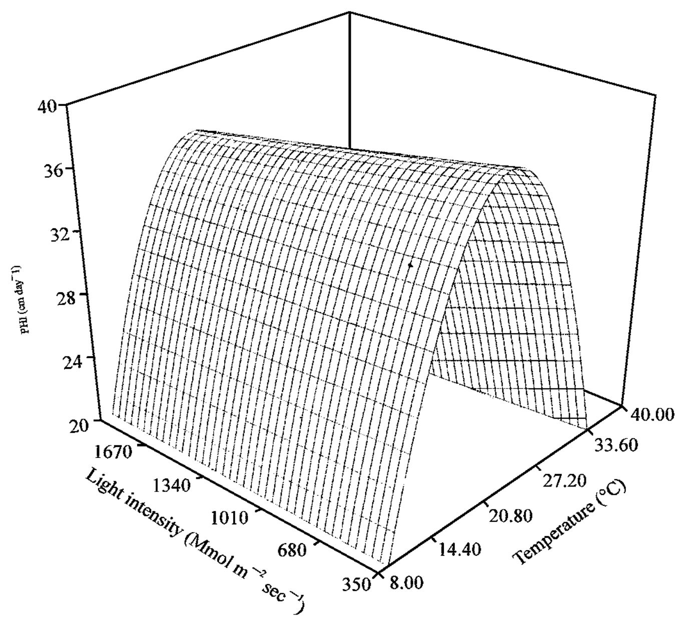

Fig. 4: Changes in Plant Height Increase (PHI) of faba bean with daily mean light intensity (μmol m^{-2} sec^{-1}) and temperature (°C)

When the Fig. 4 was examined, the rise in the temperature form 9°C up to 25°C increased the rate of plant height increase. However, the rate of increase was declined with the rise in temperature. Light

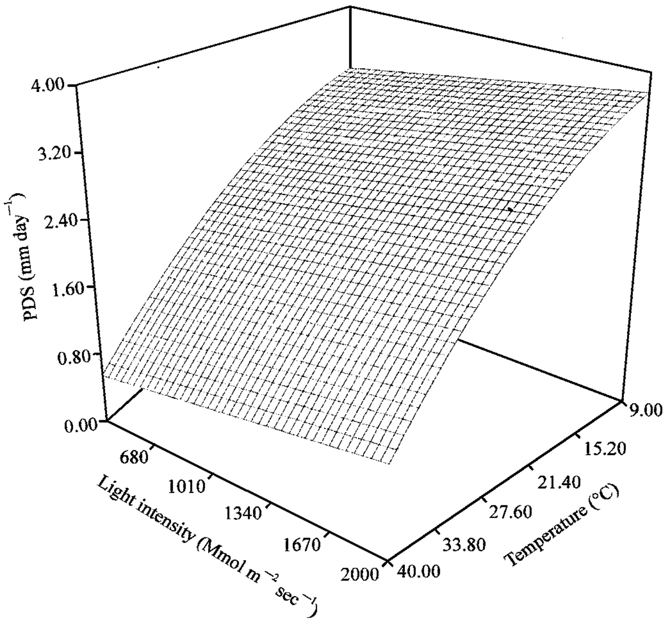

Fig. 5: Changes in rate of stem diameter increase (PDS) (mm day^{-1}) of faba bean with daily mean light intensity (μmol m^{-2} sec^{-1}) and temperature (°C)

intensity had no effect on this change at all temperature. The highest rate of plant height increase was determined at low light intensity (350 Mmol m^{-2} sec^{-1}) and 25°C.

Rate of Stem Diameter Increase

The result of multi-regression analysis showed that there was a significant relationship between rate of stem diameter increase speed, temperature and light intensity. As a result of this relationship Eq. 5 was obtained. Most of the variation (96%) in rate of stem diameter (PDS) increase was explained by temperature (T) and light intensity (L).

$$\begin{aligned} &PSD = (3.246) - (1.74E^{-03} \times T^2) + (3.35E^{-04} \times L) \\ &SE = 0.146{***} \quad 1.32E^{-04}{***} \quad 1.18E^{-04}{***} \\ &R^2 = 0.96 \end{aligned} \qquad (5)$$

At low temperatures, increasing light intensity increased the rate of stem diameter increase. Increasing temperature gave a rise to rate of stem diameter increase more slowly than high light intensities (Fig. 5). Increasing light intensity affected rate of stem diameter increase positively. The highest increase of the stem diameter rate was obtained at high light intensity (2000 Mmol m^{-2} sec^{-1}) and low temperature (9°C). The results showed that increasing temperature and light intensity decreased the rate of stem diameter increase.

Leaf Appearance Rate

A relationship between leaf appearance rate, temperature and light intensity was obtained by means of multi-regression analysis and the equation below (Eq. 6) was produced.

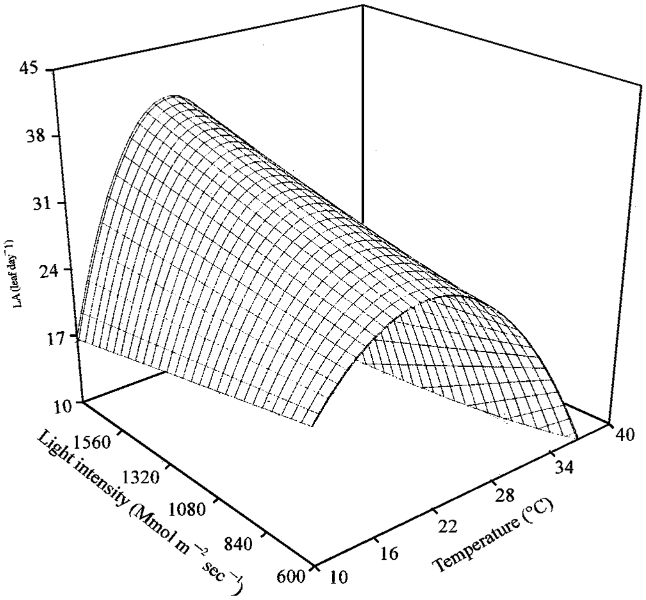

Fig. 6: Changes in Leaf Appearance rate (LA) (leaf day^{-1}) of faba bean with daily mean light intensity (μmol m^{-2} sec^{-1}) and temperature (°C)

Seventy one of variation in leaf appearance rate (LA) was explained by the selected parameters, namely temperature (T) and light intensity (L).

$$\begin{aligned} &LA = (26.99) + \left[5.17E^{-03} \times (T \times L)\right] - \left[1.3E^{-04} \times (T^2 \times L)\right] - \left(4.4E^{-02} \times L\right) \\ &SE = 4.53^{**} \quad 1.6E^{-03}{*} \quad 3.616E^{-05}{*} \quad 1.67E-02{*} \\ &R^2 = 0.71 \end{aligned} \qquad (6)$$

As shown in Fig. 6, in general, leaf appearance rate increased linearly with the increase in light intensity at the temperature regimes between 16-25°C. However, there was a linear decline in leaf appearance rate with light intensity at temperatures below 16°C and above 25°C. At given light intensity, leaf appearance rate increased with the increasing temperatures above 10°C up to maximum depending on light intensity and declined after peak point of temperature.

The highest leaf appearance rate was obtained with the highest light intensity and an optimum temperature of 22°C. However, the optimum leaf appearance rate declined as light intensity increased.

DISCUSSION

According to the results obtained, the emergence in faba bean was at 8-18.82°C soil temperature. According to Şehirali (1998) the average air temperature should be between 18-27°C for appropriate yield. Sepetoğlu (1994) was determined that the lowest germination in faba bean seeds was seen when the soil temperature was 1-2°C, but for the optimum germination soil temperature should be 10-15°C. Akçin (1988) was determined that when the soil temperature was 9°C and the air temperature was between 10-14°C, appropriate faba seeds showed an emergence and germination. Tuli and Yeşilsoy

(1997) were determined that the soil temperature was one of the most important factors affecting the plant growth and yield. It was observed that there was a close relation between the results of this study and literatures. If appropriate conditions and quality seed are provided, emergence speed amount reach to maximum level.

In the light of the data obtained, with the increase at the temperature the flowering rate was affected negatively. That the temperature increased up to 27°C and the light intensity was getting increased affected positively flowering rate of faba bean. In a study carried out by Kar and Uzun (2000) the effect of temperature on development periods and the results of our studies were similar. The ideal rate of progress to pod onset was obtained at 25°C and over 840 Mmol m^{-2} sec^{-1} light intensity. Şehirali (1988) was determined that for the best yield the average temperature should be between 18-27°C and especially high temperature in flowering rating period caused flower to lessen and decrease in rate of progress to pod onset. In another study 112 types of bean were carried out for two years in eight experiment field and at the end it was stated that the time of rate of progress to pod onset showed a wide ranging variations between 44-83 days (Scully and Wallace, 1990). The researchers above were stated that this study made with the bean had similarity in faba bean as well. In present study the similar results was also obtained.

When looking at the studies made on this subject, we can see that there is a linear relation between temperature and rapid gaining length in a great deal of plant in certain limits (Atherton and Harris, 1986; Uzun, 1997). In addition, if the plants after reaching to the maximum growth rate generally are exposed to low temperature, they show higher growth rate than the ones which are exposed to high temperature (Fitter and Hay, 1987; Kürklü, 1994). The results of the rate of plant height increase that we obtained has shown the similarity with the other researcher's results and it has been determined that high temperature (over 40°C) has negative effects on the growing and developing of the plants. In high temperatures, physiological phenomenon such as insufficiency in respiration, closing stomas, difficulty in convection cause the plants to be stressed and stops growth and development.

There are two reasons of the increase stem diameter speed. First, especially in high temperatures as a result of growing in a vegetative state the dry material of the plant accumulates in the root and body. The second one is the increase in the body diameter as a result of the balanced growth among vegetative and generative organs of the plants growing in relatively low temperatures (Atherton and Harris, 1986; Uzun *et al*., 1998). The completion of life cycle in vegetables and certain similar plants was long. Increasing temperature and increasing light intensity depending on it was decreased the stem diameter speed. There were significant differences between the plants which yield late and which was high regarding total yield and the ones which yield early and were grown in high temperature regarding growing speed. In this research similar results were also obtained depending on the number of days following the sowing. The body of faba bean was four-sided and generally its inside was empty. Thickening was appeared in the canals and cambium tissues. Depending on the plant growth transmission were developed and the capacity was increased so the body was thickened.

The reason of increasing of the leaving speed first and then decreasing suddenly in plants leaving fast was that at the beginning as a result of rapid leaving the leaves shade each other and for that reason a decrease was occurred in net assimilation rate of the plant. In a study on this subject Heuveling (1989) determined that increasing temperature ruined nourishment competition between growing point and leaves in growing point's favor. From 115th day leaving speed decreased rapidly at 15°C and 335.35 Mmol m^{-2} sec^{-1} light intensity in which vegetation was long. As a result of this, it was stated that this caused a decrease in dry material assimilation rate of the plant (Charles-Edwards *et al*., 1986; Fitter and Hay, 1987; Uzun *et al*., 1998). It was known that the plants having high growing speed, exposed to high temperature was more early-riser will complete their life cycle faster than the plants exposed to low temperature, but they were less yield than the ones exposed to low temperature regarding total yield (Fitter and Hay, 1987; Kürklü, 1994). In addition, because these plants will pass into generative phase early, lengthening and leaving speed in the mid and last period of their lives will follow an opposite process according to the speed in start. To Uzun (1996 unpublished data) as a growing criteria leaf emergence speed in the plants is proportional with the temperature in certain limits.

CONCLUSIONS

In this study, we defined the relationships between faba bean development parameters (rate of progress to emergence, flowering rate, rate of progress to pod onset, rate of height, rate of stem diameter increase and leaf appearance rate), temperature and light. Changes in plant development caused by the effects of environmental conditions (temperature, light, moisture etc.) have been intended to be described by plant growth models. The models of development parameters are, respectively.

$$EM = (-0.305)+\lfloor 6.09E^{-05}\times(at\times st)\rfloor+(0.0802\times st)-(0.00802\times at)-(0.004\times st^2)$$

$$FR = (-0.0221)+(1.58E^{-04}\times T)+(0.011\times L)-\lfloor 6.5E^{-04}\times(T\times L)\rfloor$$

$$P = (-3.157E^{-03})+(37.09E^{-04}\times T)+\lfloor 3.13E^{-06}\times(T\times L)\rfloor-\lfloor 2.6E^{-07}\times(T^2\times L)\rfloor+\lfloor 1.31E^{-10}\times(T\times L)^2\rfloor -\lfloor 1.7E^{-09}\times(T\times L^2)\rfloor$$

$$PHI = (-17.93)-(0.118\times T^2)+(5.24\times T)-\lfloor 4.8E^{-06}\times(T^2\times L)\rfloor$$

$$PSD = (3.246)-(1.74E^{-03}\times T^2)+(3.35E^{-04}\times L)$$

$$LA = (26.99)+\lfloor 5.17E^{-03}\times(T\times L)-\lfloor 1.3E^{-04}\times(T^2\times L)\rfloor-(4.4E^{-02}\times L)$$

The regression coefficients (R^2) of the produced equations for development stages changed from 0.71 (plant leaf speed) 0.99 (flowering rate and rate of progress to pod onset).

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