Genotypic and Environmental Variation of Lag Period of Pod Growth in Soybean

Shao-Hui Zheng, Akinori Maeda and Masataka Fukuyama

Faculty of Agriculture, Kyushu University, Fukuoka 812-8581, Japan

Abstract: Pod growth in soybean (Glycine max (L.) Merr.) begins several days after flower opening, compared with more immediate growth in other beans. We investigated the relationship between genotype, raceme order of pod set, assimilate supply or photoperiod and the length of lag period of pod growth (LP, days from flower opening to the time when pod length reaches 10 mm). Soybean (five cultivars) plants were grown in a greenhouse and in the field in 2001. The lengths of pods developed from 20 flowers which opened on the same day and set on the same raceme order, were measured every other day. The length of LP varied with the cultivar from 5 to 16 days and it was longer in late cultivars. The LP in the primary raceme (early flowers) was 15 days but that in the secondary raceme (late flowers) was 8 days. Both late sowing and short photoperiod (10h) after the start of flowering shortened the LP by up to 7 days in Enrei and 5 days in Fukuyutaka. However, neither sink (except the target racemes) removal nor BA application to the target racemes at the start of flowering affected the length of LP, even though these treatments were expected to stimulate pod growth.

Key words: Lag period, Photoperiod, Pod growth, Soybean.

The period of reproductive growth in soybean is very long (70 to 90 days after the start of flowering) compared with that in cereals. The pod shells in soybean develop after flowering, whereas the husks in rice or wheat, those function is the same as that of pod shell in soybean, are formed before flowering. Therefore, the seed filling begins about four weeks after flowering in soybean (Konno, 1976), but about one week after flowering in rice or wheat (Sofield et al., 1977; Chowdhury and Wardlaw, 1978). In some legumes, such as mung bean, cowpea and common bean, the period from flowering to maturation is also shorter than that in soybean (Egli, 1998).

Several studies documented that the pod formation is very slow after flowering in soybean. Umezaki (1991) reported that the time of pod appearance (the ovary developed more than 10 mm in length) varied from 6 to 18 days after the start of flowering among 71 late maturing cultivars. Heitholt et al. (1986) also reported a difference in time of pod growth between genotypes. The delay of pod growth seems to lengthen the reproductive growth period. On the other hand, Saiitho et al. (1998) indicated that the delay of pod growth is much longer in the low order racemes (early opening flowers) and is reduced in high order racemes (late opening flowers). It is suggested that the timing of pod formation plays a role in the regulation of synchronous pod maturation in soybean (Saiitho et al., 1998). However, there are no further investigations focused on the delay of pod growth in soybean. The understanding of this function may be helpful to understand the mechanism of pod set, seed filling and yield.

It is well known that the vegetative growth continues for a while even after the start of flowering in soybean. Thus, the competition for assimilate supply between reproductive and vegetative growth after the start of flowering could inhibit the pod growth (Brun and Betts, 1984; Baba et al., 2003). Furthermore, the pod set could be stimulated by cytokinin (Peterson et al., 1990), and the pod filling duration is shortened by a short photoperiod (Thomas and Raper, 1976; Raper and Thomas, 1978). In this study, we investigated the process of pod formation and the effects of genotypes, raceme orders of pod set, assimilate supply and photoperiod on the pod growth.

Materials and Methods

Soybean and the other three legumes were grown in a greenhouse (pot experiment) and in the field in 2001 at Kyushu University, Fukuoka of Japan. The varieties used and sowing dates are shown in Table 1. In the pot experiment, paddy soil mixed with 5 g compound fertilizer (N : P₂O₅ : K₂O = 3 : 10 : 10) and 3 g lime were compacted in a plastic pot (4 L in volume) before sowing. After emergence, one plant per pot was allowed to grow. In the field, the planting density was 60 cm × 15 cm spacing. The same compound fertilizer and lime (100 g m⁻² each) were applied before planting. When the plants began flowering, the lengths of the pods from 20 flowers that opened on the same day and on the same raceme order in each experimental group were measured every other day. To determine the environmental and physiological effects on the pod growth, following treatments were applied.

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1. Short photoperiod treatment

After the first flower opened, five pots with plants were moved into the apparatus having the roof that automatically open at 8:00 and close at 18:00 everyday. In the apparatus, plants were exposed to a 10-hour photoperiod under natural light and temperature conditions. The treatment was continued until the plant matured.

2. Sink removal and BA (Benzyladenine) application

After the first flower opened, all of the racemes except two at the target nodes (the lowest two nodes without a branch on main stem), and the tops of main stem and all branches were removed, in order to concentrate the assimilate supply to the target racemes. In the other groups, a water solution containing 200 mg L⁻¹ BA (Peterson et al., 1990) was carefully sprayed on the target racemes (0.0 mL for each raceme) once. Five plants (10 racemes) were selected from a bordered block (5.4 m × 4.2 m) in the field for each treatment.

Results

Fig. 1 shows the changes with the lapse of time of pod length after flower opening in four legumes. The rate of pod growth was obviously slow in soybean compared with that in the other three crops. Soybean pods reached the maximum length 15 to 25 days after flower opening against 7 days in mung bean, and 10 days in azuki bean and common bean.

The differences in pod growth were also observed among soybean cultivars (Fig. 2). In two early maturing cultivars, Kitamusume and Orihime, the pods began to grow immediately after the flower opened, while in the other three cultivars, the pods began to grow more than 10 days late. Therefore, the lag period of pod growth (LP, days from flower opening to the time when pod length reaches 10 mm) was about 5 days in Kitamusume and Orihime, 10 days in BR37, 15 days in Fukuyutaka and 16 days in Enrei. The elongation rate after the LP seemed to be the same in all cultivars. Thus, the time when the pod reached the maximum length was delayed as the LP was prolonged.

The timing of flower opening also affected the length of LP (Table 2). The pods set on the primary raceme which opened the flowers first had the longest LP in both Fukuyutaka and Enrei independent of sowing date. There were no significant differences in the length of LP among secondary, secondary with a leaf and tertiary racemes in both cultivars except for Enrei when sown on 8 June.

The later the sowing date, the shorter the LP in all racemes in both cultivars (Table 2). However, the secondary and tertiary racemes in the plants sown on 1 August had only a few flowers. Moreover, no pods set were observed on the primary and terminal racemes in Fukuyutaka sown on 8 June, indicating that all of the flowers in these racemes aborted.

Table 1. Crops and cultivars used in the experiment.

| Crop       | Cultivar     | Maturity* | Sowing date |
|------------|--------------|-----------|-------------|
| Soybean    | Fukuyutaka   | IV-c      | 8 June, 9 July, 1 Aug. |
|            | Enrei        | II-c      | 8 June, 9 July, 1 Aug. |
|            | BR37         | Unknown   | 9 July      |
|            | Orihime      | II-a      | 24 Apr.     |
|            | Kitamusume   | I-a       | 24 Apr.     |
| Common bean| Himetebou    |           | 8 May       |
| Mung bean  | Bundoumame   |           | 8 May       |
| Azuki bean | Erimoshouzu  |           | 8 May       |

*: Maturity in soybean is graded from I-a to V-c in Japan, as from I to X in the United States.

![Fig. 1. Comparison of pod growth among four crops. Soybean-A: Kitamusume; Soybean-B: Fukuyutaka.](image)

![Fig. 2. Differences of pod growth on primary raceme in five soybean cultivars. Sowing dates are 24 April in Kitamusume and Orihime, 8 June in Enrei and 9 July in Fukuyutaka and BR37, which are common sowing dates for respective cultivar.](image)
Table 2. Lag period of pod growth in different order racemes in two soybean cultivars.

| Raceme   | Flowering date | Lag period (d) | Flowering date | Lag period (d) | Flowering date | Lag period (d) |
|----------|----------------|----------------|----------------|----------------|----------------|----------------|
| Enrei    | Sown on 8 June |                | Sown on 9 July |                | Sown on 1 August |                |
| Primary  | 0              | 17.0 ± 2.49    | 0              | 10.0 ± 1.89    | 0              | 4.7 ± 0.70     |
| Terminal | 4              | 14.1 ± 1.14    | 4              | 7.8 ± 0.94     | 2              | 4.7 ± 0.74     |
| Secondary* | 8              | 13.3 ± 1.10    | 10             | 5.8 ± 1.47     | -              | -              |
| Secondary | 11             | 9.8 ± 1.07     | 14             | 7.7 ± 1.38     | -              | -              |
| Tertiary | 21             | 8.2 ± 1.13     |                |                |                |                |
| LSD (P<0.05) | 2.45     |                | 1.39           |                |                | 0.55           |

Fukuyutaka

| Raceme   | Flowering date | Lag period (d) | Flowering date | Lag period (d) | Flowering date | Lag period (d) |
|----------|----------------|----------------|----------------|----------------|----------------|----------------|
| Primary  | 0              | +             | 0              | 16.6 ± 1.55    | 0              | 9.3 ± 1.00     |
| Terminal | 4              | +             | 6              | 12.6 ± 2.76    | 4              | 8.0 ± 1.00     |
| Secondary* | 13             | 13.3 ± 1.24   | 13             | 8.2 ± 1.03     | -              | -              |
| Secondary | 13             | 15.7 ± 2.14   | 15             | 7.5 ± 2.67     | -              | -              |
| Tertiary |                | -             | 24             | 9.0 ± 0.60     | -              | -              |
| LSD (P<0.05) | 1.46     |                | 2.94           |                |                | 0.89           |

* : Secondary raceme with a compound leaf.  
+ : No flower opened.  
# : Days after the first flower opened on the plant.

Since the photoperiod during plant growth varies with the sowing date, we exposed one group of the plants to a 10-hour photoperiod under natural light and temperature conditions after the first flower opened. The natural photoperiod was about 15 hours in early July (the time of flowering in Enrei sown on 8 June) and 14 hours in middle August (the time of flowering in Fukuyutaka sown on 9 July). Exposure to a short photoperiod shortened the LP by 7 days in Enrei and 5 days in Fukuyutaka, but did not affect the length of LP of the secondary raceme in Enrei, and secondary and secondary with a compound leaf racemes in Fukuyutaka (Fig. 3).

Neither sink removal nor BA application significantly affected the length of LP of Fukuyutaka in the field (Fig. 4). However, the elongating rate after the LP seemed to be increased by sink removal (data is not shown).

Discussion

In this study, we found that the pod growth after flower opening was very slow in soybean as compared with other legumes (Fig. 1). The length of LP varied not only with the cultivar but also with the raceme order of pod set (Fig. 2, Table 2). Heitholt et al. (1986) reported that the accumulation of dry matter in the pod was slower in Kent (Maturity group: IV) than in McCall (Maturity group: 00). Umezaki (1991) recorded a great variation in the timing of pod formation among cultivars within the same maturity group. It seemed that the earlier maturing cultivar had a shorter LP was observed. However, in BR37 which opened its flowers at the same time as Fukuyutaka, had a shorter LP than Fukuyutaka (Fig. 2), indicating that some factors which are not associated with the maturing habit also affect the length of LP.

Since more than 2/3 of vegetative organs develop after the start of flowering in soybean (Shimada et al., 1990;
The physiological meaning of the LP needs to be investigated further.

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*In Japanese with English abstract.
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