Influence of Day Length before and after the Start of Anthesis on the Growth, Flowering and Seed-Setting in Common Buckwheat (*Fagopyrum esculentum* Moench)

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Abstract: The influence of day length before and after the start of anthesis on the growth, flowering process, and seed-setting of common buckwheat (*Fagopyrum esculentum* Moench) was investigated to determine the effect of day length at various growth stages. Exposure to long days (15 h in 2001 and 16 h in 2000) made the node position of the first flower higher, delayed the start of anthesis, decreased the rate of successive flowering, increased the number of nodes and flower clusters on the main stem, and prolonged the main stem elongation period. It increased the number of flowers per flower cluster, but decreased the seed-setting ratio and the number of seeds. The critical day length varied with the cultivar and the growth parameter. 'Miyazakizairai' (autumn eco-type) showed significantly greater responses to long days than 'Shinanonatsusoba' (summer eco-type). The day length before the start of anthesis significantly influenced on the main stem elongation and flowering process thereafter. This suggests that the day length is a more critical factor for the differentiation than the growth of the flower bud. The seed-setting ratio was influenced both by day lengths before and after the start of anthesis. The 15 h day length before the start of anthesis and around 12 h day length thereafter increased the number of double and multiple clusters in 'Shinanonatsusoba' and long clusters in 'Miyazakizairai', resulting in an increase in the number of seeds per cluster. Day length did not influence either the form or weight of seeds.

Key words: Anthesis, Common buckwheat, Day length, *Fagopyrum esculentum* Moench, Growth, Seed-setting.

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Abbreviations: DAS, days after sowing; DM cluster, double and multiple cluster; LD, long day; LDT, LD treatment throughout the experiment; LDAA, LD treatment after the start of anthesis; ND, natural day length plot throughout the experiment; SD, short day.
Materials and Methods

Experiments were conducted in Meijo University in 2000 and 2001. Two common buckwheat (*Fagopyrum esculentum* Moench) cultivars, 'Shinanonatsu-soaba' (summer eco-type cultivar; 'S' hereafter) and 'Miyazakizairai' (autumn eco-type cultivar; 'M' hereafter) were used. Seeds were sown in 1/5000 a Wagner pots containing 2.5 kg soil on 1 September, 2000 and 11 September, 2001, and fertilized with 5 g fertilizer (15N–15P–10K). Three seeds were sown in each pot, and the seedlings were thinned to one plant per pot. Twelve pots of each cultivar were used for each treatment in 2000, and 11 pots of 'S' and 15 pots of 'M' for each treatment in 2001. Plants were irrigated as needed to ensure that the soil was sufficiently moist, and the side dressing was not applied.

The plants were divided into four groups and subjected to the following conditions: LD throughout the experimental period (LDT), LD before the start of anthesis (LDBA), LD after the start of anthesis (LDAA), and natural day length throughout the experimental period (ND). For LD treatment, the plants were placed under incandescent light from 4:00 to 6:30 and from 17:00 to 20:00 to provide a 16-h day length in 2000, and from 4:30 to 6:30 and from 17:00 to 19:30 to provide a 15-h day length in 2001. Because all plants did not reach anthesis before winter under a 16-h day length in 2000, 15-h day length was provided in 2001. Experiments in 2000 and 2001 ended on 26 Oct. (55 days after sowing (DAS)) and 25 Nov. (75 DAS), respectively.

In 2000, the day of the first flower opening in each flower cluster on the main stem was recorded. The observation was ended on 26 Oct. (55 DAS) in 2000, although the cultivar 'M' in LDT and LDBA did not complete vegetative growth and flowering.

In 2001, the main stem length was measured every third day from the emergence till the end of elongation. The day of the first flower opening in each flower cluster on the main stem was recorded. The plants were harvested at the full ripe stage on 25 Nov. (75 DAS), although the stem growth and flowering on the main stem had not completed at that time in cultivar 'M' in LDT and LDBA. At harvest, the final length of each internode and the length of the flower-developing region of each flower cluster were measured and the number of flowers and seeds in each flower cluster on the main stem were recorded by counting the withered flowers and the matured seeds. The developing seeds were involved in the number of seeds of 'M' in LDT and LDBA. We observed the flower clusters forked into two, three or more branches with no leaves, and named them double, triple and multiple cluster, respectively (Hayashi, 1999). In this paper, we combined them, and named the "DM clusters", and recorded their node positions on the main stem, since a lot of DM clusters developed in cultivar 'S' in LDBA. The number of flowers and seeds on each branch of DM clusters were measured individually, and the numbers were expressed by the sum on a DM cluster, and the average on individual branches of a DM cluster.

In this study, the cotyledonal node on the main stem was called the zero node, and the hypocotyl the zero internode, and nodes and internodes were numbered from the base to the apex. The numbers of nodes and internodes did not include the cotyledonal node or hypocotyl.

In 2001, the matured seeds, which turned black, were air-dried for more than one month, and twenty matured seeds were selected from individual plants to measure the seed length and the seed width. The seed width is the longest measure between the ridges of seed. Seeds were weighed, and one-seed weight was calculated. Seed volume and specific gravity were also measured with a pycnometer.

Results

1. Main stem elongation (in 2001)

The main stem elongation of both cultivars 'S' and 'M' stopped at 30 DAS and 36 DAS, respectively, in ND (Fig. 1). In LDT, the elongation rate of the main stem during early growth stage was lower than that in ND in both cultivars, but the final main stem length in LDT was larger than that in ND because the elongation continued for a longer period. Although the main stem elongation of 'S' in LDT stopped at 48 DAS, the elongation of 'M' in LDT continued after the final measurement at 68 DAS. Both cultivars in LDBA showed an elongation pattern similar to that in LDT, and both cultivars in LDAA showed the same pattern as in ND.

In both cultivars in ND the hypocotyl length was approximately 9 cm (Fig. 2). The first and the second internodes were slightly shorter than the hypocotyl, the third to sixth or seventh internodes were longer than the hypocotyl, and the fifth internode was the longest (14–15 cm). The higher the internode position beyond the fifth, the shorter the internode length. In LDT, the lengths of the hypocotyl and the first and the second internodes were about 12 cm, and the third and the fourth internodes were the longest. The length of the higher internodes gradually decreased as the internode position increased. The number of internodes developed was higher in LDT than in ND. The lengths of internodes except for the fifth to seventh internodes were longer in LDT than those in ND. In LDBA, the pattern of the internode lengths was similar to that in LDT, and in LDAA, the pattern was the same as in ND.

2. Anthesis

In both experiments (in 2000 and 2001), all of the 'S' plants started to open flowers before the end of the experimental period (Table 1). However, only 56–86% of 'M' plants started to open flowers before 55 DAS in 2000 (16-h LD), although all of them started to open
flowers before 55 DAS in 2001 (15-h LD).

The start of anthesis in cultivar 'S' in ND was 21.8 and 23.4 DAS in 2000 and 2001, respectively (Table 1). The start of anthesis was 7 days later in the 16-h LDT (in 2000) than in ND, and 4.2 days later in the 15-h LDT (in 2001) than in ND. The start of anthesis of 'M' in ND was at 24.6 and 23.6 DAS in 2000 and 2001, respectively. Since the number of non-flowered plants was not included in the data of 16-h LDT, the start of anthesis in LDT was approximately 10 days later than that in ND in 2000. However, in 2001, the plants opened flowers in the 15-h LDT, and the start of anthesis was 19 days later than in ND.

The first flower node of 'S' was 4.7 in ND in both years (Table 1). It was 2 nodes higher in the 16-h LDT. The first flower node in the 15-h LDT was slightly higher than that in ND, although the difference was not significant. The first flower nodes of 'M' in ND were 5.0 and 4.4 in 2000 and 2001, respectively, which were close to that of 'S' in ND. Since we did not include the number of non-flowered plants in the data of 16-h LDT, the first flower node in the 16-h LDT was 7.6, which was only 2.5 nodes higher than that in ND. On the other hand, in the 15-h LDT where all plants flowered, the first flower node was 8.5, which was 4.1 nodes higher than in ND.

Fig. 1. Elongation of the main stem in different day-length conditions in 2001.

The rates of successive flowering on the main stem of 'S' in ND was 1.22 and 1.09 in 2000 and 2001, respectively. The rate in the 16-h LDT was 0.55 which was less than half the rate in ND, and that in the 15-h LDT was 0.64 which was only 60% of the rate in ND (Table 1). The rate in cultivar 'M' in ND was 0.75 and 0.90 in 2000 and 2001, respectively, which were lower than that in 'S'. The rate in the 16-h LDT was markedly low (0.25), and the rate in the 15-h LDT was also significantly low (0.26) compared with that in ND.

In ND of 2001, 'S' had 11.8 nodes (except cotyledonal node) and 8.1 clusters, and 'M' had 13.2 nodes and 9.9 clusters on the main stem. In LDT, 'S' had larger number of nodes (13.8) and clusters (9.8) than in ND. 'M' did not complete the development of clusters (nodes), and was developing new clusters (nodes) even at the end of the experiment. 'M' in LDT in 2001 had three more nodes than in ND, but the same number of flower clusters as in ND. If we had continued...
Table 1. Flowering in different day-length conditions in 2000 and 2001.

| Cultivars and treatments | Number of bloomed plants / number of tested plants* (%) | Start of anthesis (DAS) | First flower node** | Rate of successive flowering (clusters / day) | Number of nodes on the main stem** | Number of flower clusters on the main stem |
|--------------------------|------------------------------------------------------|------------------------|--------------------|-----------------------------------------------|----------------------------------|------------------------------------------|
| Shinanonatsusoba         |                                                      |                        |                    |                                               |                                  |                                          |
| LDT                      | 100                                                  | 28.8 a                 | 7.0 a              | 0.55 b                                        | 13.8 a                           | 9.8 a                                    |
| LDAA                     | 100                                                  | 22.1 b                 | 4.6 b              | 1.30 a                                        | 10.9 b                           | 8.1 b                                    |
| ND                       | 100                                                  | 21.8 b                 | 4.7 b              | 1.27 a                                        | 11.8 b                           | 8.1 b                                    |
| Miyazakizairai           |                                                      |                        |                    |                                               |                                  |                                          |
| LDT                      | 56                                                   | 34.5 b***              | 7.5 b***           | 0.25 b***                                     | 16.8 a***                       | 9.3 a***                                 |
| LDAA                     | 100                                                  | 24.4 c                 | 4.9 c              | 0.65 a                                        |                                  |                                          |
| ND                       | 100                                                  | 24.6 c                 | 5.0 c              | 0.75 a                                        |                                  |                                          |
| (Sown on 11 September, 2001 and 15 hours LD treatment) | | | | | | |

The figures with the same letters within a column are not significantly different at 5% level by the Fisher's LSD test.

* The data at 55 DAS were shown both in 2000 and 2001.
** Cotyledonary node was not included in the first flower node and in the number of nodes on the main stem.
*** The observation was ended at 55 DAS and the values were average of bloomed plants.
**** The numbers were still increasing at 75 DAS when the numbers were counted.

the observation, the numbers of clusters and nodes might have increased more in LDT than in ND.

Thus, the position of the first flower node, the rate of successive flowering, and the numbers of the main stem nodes and flower clusters in LDBA were the same as in LDT and those in LDAA were similar to those in ND.

3. Flowering in each flower cluster and flower-cluster types (in 2001)

Cultivar 'S' had most flowers in the second flower cluster from the lowest cluster (Fig. 3). The higher the node of the cluster, the fewer the flowers per cluster. In 'S', the highest number of flowers per cluster in LDT was two-fold of that in ND. The number of flowers per cluster in LDAA was the same as in ND. The number of flowers in LDBA was higher than that in LDT, and was triple of that in ND, although the number of flowers per clusters at the nodes higher than the tenth node was nearly the same as that in LDT. The flower clusters between the fifth and ninth node in LDAA developed the DM clusters frequently. The solid line of LDBA in Fig. 3 showed the total number of flowers on a DM cluster, and it was high number of flowers between the fifth and ninth node. The dotted line of LDBA in Fig. 3 showed the average number of flowers on individual branches in a DM cluster, and it was as low as in ND.

In cultivar 'M', the number of flowers per cluster was higher than that in 'S' in ND. 'M' had slightly more flowers in LDT than in ND since the observation ended before flowering completed due to cold temperature. In cultivar 'M', LDT increased the number of flowers (compared with ND) so much as in 'S'. In 'M', the number of flowers in LDBA was the same as in LDT, and that in LDAA was the same as in ND.

In cultivar 'S', the number of clusters on the main stem in LDT was higher than in ND, that in LDBA was the same as in LDT, and that in LDAA was the same as in ND (Table 2). The average number of DM clusters on the main stem per plant was 1.9 in LDT, but it was not significantly different from that in ND (0.8). However, the number of DM clusters in LDBA was 4.0, that was four times the number in ND, and the percentage of DM clusters in LDBA was significantly higher than in ND. In LDAA, the number of clusters and the percentage of DM clusters were similar to those in ND.

In 'M', there were no differences in the number of clusters on the main stems among the treatments, and the development of clusters was not completed in LDT and LDBA during the experimental period. The number of DM clusters and the percentage of DM clusters in LDT were slightly higher than in ND, though not significantly.

The longest flower cluster (the length of the flower developing region of each flower cluster) on the main...
stem was on the first or the second flower node in all conditions in both cultivars, and the higher the nodes, the shorter the cluster length (Fig. 4). In cultivar 'S', the longest flower cluster lengths were almost the same in LDT and ND, but the length decreased as the position of the nodes became higher rapidly in ND and rather gradually in LDT. The flower cluster length in LDBA was similar to that in LDT, and that in LDAA was similar to that in ND. In cultivar 'M', the flower cluster development did not stop before the end of the experiment in LDT and LDAA, and the clusters at high nodes were still growing. The cluster length at lower nodes in LDBA, which stopped growing, was slightly (3 mm) longer than that in other conditions.

4. Seed-setting (in 2001)

In cultivar 'S', the yield of seeds from the flower clusters on the main stem in ND, LDT, and LDAA was 2.1-2.3 g. The number of seeds was almost the same (60.4-64.8) in these conditions, but that in LDBA was more than other treatments; the yield of seeds was 3.1g, and the number of seeds was 93.9 (Table 3). The seed-setting ratio was 46.5% in ND, and 40.6% in LDAA, but that in LDT and LDBA was only 19.6% and 23.8%, respectively. In cultivar 'M', the yield of seeds and the number of seeds in ND were the same as those in 'S', but the seed-setting ratio was lower (24.5%) than in 'S'. In LDT, the yield of seeds was 0.5 g, the number of seeds was 14.2, and the seed-setting ratio was significantly low (4.1%). The seed yield of 'M' in LDBA and LDAA were nearly the same and in the middle of those in ND and LDT.

The number of seeds per flower cluster on the main stem was the highest on the second node from the lowest, and the higher the nodes of flower clusters, the less the number of seeds per cluster in all conditions (Fig. 5). In cultivar 'S', the largest number of seeds per flower cluster in ND and LDAA were 16.3 and 14.8, respectively. That in LDT was lower (12.7) than in other conditions, and that in LDBA was rather high (21.1). In LDBA, cultivar 'S' had many DM clusters and the total number of seeds in a DM cluster was higher than 20 at the sixth and the seventh node, but the average number on individual branches of DM cluster was 7-9 (Fig. 5). In cultivar 'M', the largest number of seeds per flower cluster was 10.2 in ND, 7.3 in LDAA, and 5.4 in LDT, which was half of that in ND. Although 'M' in LDBA did not have many DM clusters, the number of seeds per cluster was as high as 16.8.

In cultivar 'S', the seed-setting ratio in the flower cluster was higher on the lower nodes, and decreased as in higher node (Fig. 6). The highest seed-setting ratio in ND was 53.7%, but that in LDT was 28.6%. In LDAA, the seed-setting ratio in the flower cluster at the fourth to seventh node was almost the same as in ND, but the ratio at higher nodes was as low as in LDT. The
Table 3. Seed yield and seed-setting ratio on the main stem in different day-length conditions in 2001.

| Cultivars and Treatments | Seed yield of seeds (%) |
|--------------------------|-------------------------|
| Shinonanatsusoba         |                         |
| LDT                      | 60.4b 19.6b             |
| LDBA                     | 93.9a 23.8b             |
| LDAA                     | 62.4b 40.6a             |
| ND                       | 64.8b 46.5a             |
| Miyazakizairai           |                         |
| LDT                      | 14.2b 4.1c              |
| LDBA                     | 46.4a 16.8b             |
| LDAA                     | 46.9a 17.7b             |
| ND                       | 63.1a 24.5a             |

See the note of Table 1.

5. **Seed form and weight (in 2001)**

In cultivar 'S', the seed length was slightly shorter in LDT and LDBA than in other conditions, and the specific gravity of seed was slightly heavier in LDT, but there were no significant differences in one-seed weight, seed width, or seed volume among the treatments (Table 4). In cultivar 'M', the effect of LD treatment was not observed.

**Discussion**

In the autumn eco-type cultivar 'M', the first flower node was higher, its anthesis was later, and the rate of successive flowering was lower in summer cultivation than in autumn cultivation, but in the summer eco-type cultivar 'S', such differences between summer and autumn cultivations were hardly observed (Michiyama and Hayashi, 1998). In this study, both cultivars grown in 16-h LDT, which was longer than ND in summer in Nagoya (the experiment site), exhibited higher first flower node, later anthesis, and lower rate of successive flowering than in ND. These suggest that a summer eco-type cultivar requires longer critical day length to cause changes in flowering process than an autumn eco-type cultivar. However in our previous studies (Michiyama and Hayashi, 1998; Michiyama et al., 1998), the number of nodes on the main stem and the number of flowers per flower cluster were increased, the elongation period and the flowering period were prolonged, and the seed-setting ratio and the number of seeds were decreased in both cultivars by summer cultivation compared with autumn cultivation as well as in both cultivars in LDT compared with ND in this study. Moreover, the first flower node was not different between 15-h LDT and ND in cultivar 'S', but was higher in 15-h LDT than in ND in cultivar 'M'. Therefore, it is concluded that most differences in the growth, flowering process and seed-setting between summer and autumn cultivations are caused by day length, although the critical day length varies with the cultivar and growth parameter.
Table 4. Seed form and weight in different day-length conditions in 2001.

| Cultivars and treatments | One seed weight (mg) | Length of seed (mm) | Width of seed (mm) | Volume of one seed (mm³) | Specific gravity of seed |
|--------------------------|----------------------|---------------------|------------------|--------------------------|-------------------------|
| Shinanonatsusobu         |                      |                     |                  |                          |                         |
| LDT                      | 38.3 a                | 6.3 b               | 4.5 a            | 32.9 a                   | 1.19 a                  |
| LDBA                     | 37.7 a                | 6.4 b               | 4.5 a            | 32.7 a                   | 1.16 b                  |
| LDAA                     | 38.2 a                | 6.7 a               | 4.5 a            | 34.0 a                   | 1.12 b                  |
| ND                       | 41.3 a                | 6.7 a               | 4.6 a            | 36.5 a                   | 1.13 b                  |
| Miyazakizairai           |                      |                     |                  |                          |                         |
| LDT                      | 31.7 a                | 6.1 a               | 4.3 a            | 28.4 a                   | 1.11 a                  |
| LDBA                     | 32.1 a                | 6.2 a               | 4.3 a            | 29.0 a                   | 1.11 a                  |
| LDAA                     | 33.3 a                | 6.4 a               | 4.2 a            | 29.4 a                   | 1.13 a                  |
| ND                       | 34.2 a                | 6.5 a               | 4.5 a            | 30.0 a                   | 1.14 a                  |

See the note of Table 1.

Hayashi, 1998). In ‘M’, the start of anthesis in 16-h LDT seemed to be later than described here, because only 56-86% of plants started to open flowers within the experimental period (55 DAS) although 100% of plants started flowering in 15-h LDT. LD treatment significantly decreased the rate of successive flowering. It was one cluster per two days in ‘S’, and one cluster per three or four days in ‘M’ in LDT, although it was one cluster per day in ND. The main stem elongation period in LDT was 18 days longer than in ND in cultivar ‘S’, and more than 32 days later in cultivar ‘M’ in which the elongation in LDT had not stopped at the end of observation. We suspect that the main stem elongation in ‘M’ might not stop in LD conditions. In cultivar ‘S’, LD treatment decreased the seed-setting ratio from 40.5% (in ND) to 19.6%, but did not decrease the number of seeds significantly, and increased the number of flowers. On the other hand, in cultivar ‘M’ LD treatment decreased the seed-setting ratio from 24.5% to 4.1%, and markedly decreased the number of seeds. Thus, the effect of day length on cultivar ‘M’ was stronger than that on ‘S’, suggesting that the magnitude of the effect of day length vary among cultivars.

Concerning the effect on the main stem elongation and flowering process, LDBA was similar to LDT, and LDAA to ND. Day length during the 2nd and 16th day after emergence influenced axillary flower bud differentiation...
(Hagiwara et al., 1998), and in this study, the day length from emergence till the start of anthesis significantly influenced the growth and flowering process thereafter. These results suggest that the day length is more critical to the differentiation than to the development of flower bud. And it is important that the day length during the flower bud differentiation affects the growth and flowering process after the completion of the differentiation.

In cultivar 'S', the seed-setting ratio in the flower cluster in LDBA was similar to that in LDT, and the ratio in the flower clusters at lower nodes in LDAAB was the same as that in ND, but the ratio at higher nodes in LDAAB was as low as that in LDT. In cultivar 'M', although the seed-setting ratio in LDBA was the same as in ND when compared the ratios at the same node clusters, the number of flower clusters with a high seed-setting ratio was lower in LDBA, and the average seed-setting ratio in LDBA was in the middle of those in ND and LDT. Thus, it is clear that the seed-setting is influenced by both day lengths before and after the start of anthesis. This result is similar to the report of Sugawara (1958).

In cultivar 'S' in LDBA, the number and yield of seeds were high owing to a large number of DM clusters, and in cultivar 'M' in LDBA the number of seeds per cluster was high owing to the extended flowering region of flower clusters. These results suggest that DM and long clusters might be produced in a 15-h LD during flower bud differentiation and in a 12-h SD during flowering and seed-setting period. In general, buckwheat in Japan is cultivated in autumn when daylength is 13.5 h to 12 h. In a high altitude area like Canada, buckwheat is sown in early summer when the day length is longer than 16 h and harvested when the day length is about 13 h. Although some buckwheat strains in Canada have double clusters, multiple clusters, and long clusters (Hayashi, 1999), such morphological characters might be induced by environmental factors in Canada. Since these responses are associated with the yield, further studies on these characters and the difference among cultivars are required.

This study clarified that day length influenced neither the size of seed, one-seed weight, nor specific gravity of seed. It seemed that the difference in apparent quality of buckwheat grain is not attributed to the difference in day length, and might be attributed to that in temperature and other environmental factors.

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