Influence of Day Length on Stem Growth, Flowering, Morphology of Flower Clusters, and Seed-Set in Buckwheat (*Fagopyrum esculentum* Moench)

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**Abstract**: The effects of day length on main stem growth, flowering, morphology of flower clusters and seed-set were examined in three buckwheat cultivars Shinanonatsusoba (summer eco-type), Miyazakizairai (autumn eco-type) and BLO 1999 (a long cluster line which usually develops DM clusters at Kade Research Ltd., Canada). Long-day treatment prolonged the stem elongation period, elevated the first flowering node, delayed the first flowering day, increased the numbers of nodes, flower clusters and flowers on the main stem, and decreased the increase rate of flowering-cluster number, the number of seeds and the seed-set ratio on the main stem. It also increased the frequency of DM clusters, the length of the flower clusters and the number of sub-flower-clusters per cluster in Shinanonatsusoba and Miyazakizairai as well as in BLO 1999. The effects of day length varied among the growth parameters and there were three types of responses to day length. The difference between the summer and autumn eco-type cultivars in the responses to day length was elucidated in four groups of parameters; (1) main stem elongation; (2) first flowering node and first flowering day; (3) increase rate of flowering-cluster number on the main stem; and (4) the number of seeds and seed-set ratio.

**Key words**: Buckwheat, Day length, Eco-type, Flower cluster, Flowering, Growth, Seed-set.

Growth, flowering and seed set in buckwheat are influenced by the seeding date (Yamazaki, 1947; Uehara and Taguchi, 1955; 1956; Nagatomo, 1961; Sugawara, 1973; Michiyama and Hayashi, 1998; Michiyama et al., 1998). It appears that the difference is mostly caused by the change in day length (Tabata et al., 1931; Xu, 1938; Nagatomo, 1961; Sugawara, 1958; 1973; Lachmann and Adachi, 1990; Hayashi et al., 1997; Hagiwara et al., 1998; Michiyama et al., 2003). But how the day length affects each of the growth parameters remains unknown, as the experiments in most of these studies were conducted under only two or three day-length conditions. It is well known that the number of days to flower in rice plants does not show a simple linear correlation with day length (Suge, 1976). Further study is necessary to determine the effect of day-length over a wide range at short intervals such as 30 minutes. Previously (Michiyama et al., 2003), we found that the critical day length varied with the cultivar and the growth parameter in buckwheat. The purpose of the present study was to demonstrate the effect of day length on the growth parameters and to clarify the difference among cultivars in the response of the individual growth parameters to day length, using summer and autumn eco-type cultivars from Japan. We previously observed that long day conditions increased the length of the flower clusters and branched flower clusters, which were named double and multiple clusters (DM clusters) (Michiyama et al., 2003). The long cluster lines and the DM cluster lines were developed by Kade Research Ltd. in Canada (Hayashi, 1999). We therefore investigated the length and branching of the flower clusters under different day lengths in this study, using one of the long cluster lines, which usually develop DM clusters in Canada, in addition to the two Japanese cultivars.

**Materials and Methods**

The experiments were conducted at Meijo University in 2003 using two common buckwheat (*Fagopyrum esculentum* Moench) cultivars; Shinanonatsusoba (‘S’) a summer eco-type cultivar and Miyazakizairai (‘M’) an autumn eco-type cultivar. We also used a breeding line BLO 1999 (‘B’), which is a long cluster line from Kade Research Ltd. in Canada and usually develops double and multiple clusters. Thirty-two pots (1/5000 a), each containing 3 kg soil, were used for growing each cultivar. Five seeds per pot were sown.
on August 28 and were fertilized with 5 g of fertilizer (15N-15P-10K). The resulting seedlings were not thinned. The plants were watered as needed to ensure that the soil was sufficiently moist. No side dressing was applied.

The plants were divided into eight groups and subjected to 13-, 13.5-, 14-, 14.5-, 15-, 15.5- and 16-hour day lengths after sowing throughout the experimental period by supplemented by period with incandescent light (National RF110V 180WH) before sunrise and after sunset to produce day length periods. The natural day length (NDL) on the seeding day was 13 hours and 5 minutes from 5:21 of sunrise to 18:26 of sunset. In the 13-h day-length treatment, the day length was nearly the same as the NDL during the initial period.

Eight to 16 plants per plot were used to measure the growth parameters. The main stem length was measured every fifth day, from emergence until the end of elongation. The date the first flower opened in each flower cluster on the main stem was recorded. In cultivar 'M', stem elongation and flowering were not completed under the 14.5-h~16-h day length, and the measurements of the main stem length and flowering were completed on November 26 (90 days after sowing (DAS)) and on December 1 (95 DAS), respectively. The plants were harvested at the full ripe stage, which ranged from October 21 to November 29, except 'M' under 14.5-h~16-h day length. The 'M' plants under 14.5-h~16-h day lengths were harvested on December 1 to 3, even though stem growth and flowering on the main stem was not completed. The length of the flower-developing region, the number of branches, and the number of sub-flower-clusters in each flower cluster on the main stem were measured. In the DM clusters, these parameters were measured individually on each branch and the values of the longest branch in a cluster were used. The averages of the lengths of the flower clusters and the numbers of sub-flower-clusters per cluster in the 3rd to 5th cluster from the first flowering node were shown in this paper. The numbers of flowers and seeds in each flower cluster on the main stem were counted including the number of withered flowers and the mature seeds. The sum of the number of flowers, the number of seeds and the seed-set ratio in each cluster were shown as the average of the flower clusters on the main stem. Any developing seeds were included in the total number of seeds in 'M' plants under 14.5-h~16-h day length.

In this study, the cotyledonary node on the main stem was used as the zero node and the node positions are not included in the first flowering node.
were numbered from the base to the apex. The cotyledonary node was not included in the number of nodes on the main stem.

Results

1. Stem elongation
   The main stem continued to elongate for 40 DAS reaching the final length of 53 cm under NDL in ‘S’ (Fig. 1). The elongation period was prolonged and the final length increased with increasing day length. The differences of the elongation period and the final length were larger between the 14-h and 14.5-h day length than between the other adjacent day lengths. The response to day length in ‘B’ was similar to that in ‘S’. Under NDL, the main stem elongation period (50 DAS) and the final stem length (67cm) of ‘M’ were longer than those in ‘S’ and ‘B’. The elongation period was also prolonged in ‘M’ more than in ‘S’ and ‘B’ in response to an increase in day length from ND to 14-h. In ‘M’, stem elongation under the day lengths longer than 14-h did not finish at 90 DAS. And the difference between the elongation periods under 14-h and 14.5-h day length was very large as in ‘S’ and ‘B’.

2. Start of flowering and increase rate of flowering-cluster number on the main stem
   The first flowering day was 23 DAS and the first flowering node was the 5th node under NDL in ‘S’ and ‘B’ (Fig. 2). These were the same under all day lengths from NDL to 14-h. However, they increased with increasing day length above 14-h. Under the 16-h day length, the first flowering day was 35 DAS and the first flowering node was the 7.5th node in ‘M’ and ‘B’. Under NDL in ‘M’, the first flowering day was slightly later (25 DAS) and the first flowering node was slightly higher (5.5th node) than in ‘S’ and ‘B’. These increased with increasing day length beyond NDL or 13-h in ‘M’. This shows that the critical day-length of ‘M’ was shorter than that of ‘S’ and ‘B’ (14-h). As a result, the first flowering day was later and the first flowering node was higher in ‘M’ than in ‘S’ and ‘B’ under each day-length. The number of day to flower and the first flowering node sharply increased between the 14-h and 14.5-h day length in ‘M’.

   The increase rate of flowering-cluster number on the main stem was approximately 1 cluster per day in ‘S’ and ‘B’ under NDL (Fig. 3). This rate decreased with increasing day length, particularly from 14-h to 14.5-h, and was approximately 0.4 cluster per day under the 16-h day length. Under NDL, the rate in ‘M’ (0.64 cluster per day) was lower than that in ‘S’ and ‘B’. The rate decreased with increasing day length in ‘M’ as well as that in ‘S’ and ‘B’, but a considerable decrease was observed between the 13-h and 13.5-h day length in ‘M’. The critical day length of ‘M’ was shorter than that of ‘S’ and ‘B’. The increase rate of flowering-cluster number on the main stem in ‘M’ was lower than that in ‘S’ and ‘B’. The rate decreased with increasing day length in ‘M’ as well as that in ‘S’ and ‘B’, but a considerable decrease was observed between the 13-h and 13.5-h day length in ‘M’. The critical day length of ‘M’ was shorter than that of ‘S’ and ‘B’. The increase rate of flowering-cluster number on the main stem in ‘M’ was lower than that in ‘S’ and ‘B’ under each day-length. The rates under the 14.5-h to 16-h day length in ‘M’ were extremely low (0.2 to 0.3 cluster per day).

3. Number of nodes and flower clusters on the main stem
   Under NDL, ‘S’ and ‘B’ had 12 nodes and 8 clusters on the main stem (Fig. 4). The number of nodes and
flower clusters increased with increasing day length beyond 13.5-h in ‘S’ and beyond NDL in ‘B’. But the number of flower clusters in ‘S’ and ‘B’ was increased only slightly with increasing day length beyond 14-h. The plants of ‘M’ under NDL had 14 nodes and 9.5 clusters on the main stem, which were larger than those found in ‘S’ and ‘B’. The number of nodes and flower clusters on the main stem of ‘M’ increased with increasing day length beyond 13.5-h as well as in ‘S’. However, the number of flower clusters decreased with increasing day length above 14-h, as all flower clusters did not develop under a day length beyond 14-h during the 90 DAS. The number of flower clusters in ‘B’ and ‘M’ was usually larger than that found in ‘S’ under the same day length.

4. Flower clusters

The frequency of the plants with DM clusters and the frequency of DM clusters on the main stem increased with increasing day length above 13.5-h in both ‘S’ and ‘B’ (Fig. 5). The frequency in ‘S’ was slightly higher than that in ‘B’. The frequency of the plants with DM clusters stabilized above the 14-h day length at a level of approximately 80 ~ 90 %. In ‘M’, the frequency increased with increasing day length from the NDL up to 14 h and was slightly higher than those found in ‘S’ and ‘B’. However, it decreased above 14-h day length, as all the flower clusters did not develop.

The number of sub-flower-clusters per flower cluster in the 3rd to 5th clusters from the first flowering node also increased with increasing day length, although the number decreased at a day length beyond 15-h in ‘S’ and beyond 14-h in ‘M’ (Fig. 6). The number of sub-flower-clusters in ‘M’ and ‘B’ were larger than that in ‘S’.

The length of the flower-developing region of the 3rd to 5th clusters from the first flowering node also increased with increasing day length, although the length decreased beyond 14.5-h in ‘S’, beyond 13.5-h in ‘B’ and beyond 14-h in ‘M’ (Fig. 6). The length of the flower-developing region in ‘M’ and ‘B’ was larger than that in ‘S’.

5. Number of flowers and seed set

The number of flowers on the main stem and the number of flowers per flower cluster increased with increasing day length above 13.5-h in ‘S’, above 13-h in ‘B’, and above the NDL in ‘M’ (Fig. 7). In ‘M’, the number of flowers decreased above the 14-h day length. The number of flowers was the largest in ‘M’,
followed by ‘B’, with the smallest in ‘S’.

The number of seeds on the main stem and the number of seeds per flower cluster decreased slightly with increasing day length in ‘S’ and ‘B’ (Fig. 8). No difference between the cultivars was observed. The number of seeds in ‘M’ was the same as that found in the other cultivars under day lengths between NDL and 13.5-h, but greatly decreased above 13.5-h in ‘M’.

Seed-set ratio under NDL was 16.7 % in ‘S’, which was slightly higher than that in the other cultivars (about 12.5 %) (Fig. 9). The seed-set ratio decreased with increasing day length in ‘S’ and ‘B’ and became 6.6 % and 4.2 % under 16-h day length, respectively. In ‘M’, the seed-set ratio decreased considerably between the 13.5-h and 14-h day lengths and then stabilized around 4 % under the 14-h to 16-h day lengths.

**Discussion**

Long-day treatment prolonged the stem elongation period, elevated the first flowering node, delayed the first flowering day, increased the numbers of nodes, flower clusters and flowers on the main stem, and decreased the increase rate of flowering-cluster number, the number of seeds and the seed-set ratio on the main stem in this study as was found in previous studies (Tabata et al., 1931; Xu, 1938; Nagatomo, 1961; Sugawara, 1958; 1973; Lachmann and Adachi, 1990; Hayashi et al., 1997; Hagiwara et al., 1998; Michiyama et al., 2003). This study also demonstrated that long day treatment increased the frequency of DM clusters. In general, the results of this study indicated that long day treatment also increased the length of the flower-developing region in the flower cluster and the number of sub-flower-clusters per flower cluster, although they were often decreased in the DM clusters. The response of BLO 1999 to day length was similar to that of summer eco-type in Japan, such as the variety Shinanonatsusoba. It appears that the Canadian long-
cluster lines exhibit their characteristics under long-day conditions, which are approximately 16-h during the summer in Canada, but do not exhibit them under short-day conditions, which are around 13.5-h for autumn cultivation in Japan. These results indicate that buckwheat grown in high latitudes has a high potential for yield owing to an increase in the number of flower clusters per stem, branching of flower clusters (DM clusters), and the number of sub-flower-clusters and flowers per flower cluster. However, the day length period during the seed-set stage in Canada (August) is below 14-h. As the seed-set ratio is affected by day length after the start of flowering (Michiyama et al., 2003), the seed-set ratio appears to be higher in Canada. Therefore it is possible that a high latitude could be adequate for buckwheat production in obtaining high yields.

This study confirmed that the effect of day length varied among the growth parameters. Three types of responses to the day length were observed. Firstly, some of the parameters changed with increasing day length, but a specific day length which would bring about a considerable change of the parameters was not observed, for example the length of the flower cluster and the number of sub-flower-clusters in all cultivars. The first type also included the number of nodes and flower clusters in BLO 1999, the frequency of DM clusters and the number of flowers in the autumn eco-type cultivar, and the number of seeds and seed-set ratio in the summer eco-type cultivars. Secondly, some parameters changed with increasing day length with a specific day length period bringing about a considerable change of the parameters observed, for example stem elongation and the increase rate of flowering-cluster number on the main stem in all cultivars. This type also included the first flowering day, the first flowering node, the number of seeds, and the seed-set ratio in the autumn eco-type cultivar. Thirdly, some parameters did not vary with increasing day length up to 13.5-h or 14-h, but changed with increasing day length beyond that. As an example, the first flowering day and the first flowering node in the summer eco-type cultivars, the number of nodes and flower clusters in Shinanonatsusoba and Miyazakizairai, and frequency of DM clusters and the number of flowers in the summer eco-type cultivars.

In this study, the difference between the summer and autumn eco-type cultivars in their responses to day length was observed in the four groups of growth parameters; (1) main stem elongation; (2) first flowering node and first flowering day; (3) the increase rate of flowering-cluster number on the main stem; and (4) the number of seeds and seed-set ratio. These parameters appeared to be the basis of the classification of eco-types in buckwheat. The stem elongation period was prolonged and the final stem length increased with increasing day length from NDL to 16-h, and they changed markedly between 14-h and 14.5-h day length in both eco-type cultivars. However, they were found to change more in the autumn eco-type cultivar than in the summer eco-type cultivars between NDL and 16-h day length, and a more marked change was observed in the autumn eco-type cultivar between the 14-h and 14.5-h day length. The first flowering node elevated with increasing day length above 14-h and did not vary from NDL to 14-h day length period in the summer eco-type cultivars. However, in the autumn eco-type cultivar it elevated with increasing day length from NDL to 16-h. The first flowering day demonstrated the same response to day length. The increase rate of flowering-cluster number on the main stem was decreased with increasing day length from NDL to 16-h. The rate in the summer eco-type cultivars was higher than that in the autumn eco-type cultivar under the same day length. This was found to decrease considerably between the day lengths of 14-h and 14.5-h in the summer eco-type cultivars, although it was similar to that found between the 13-h and 15.5-h day lengths in the autumn eco-type cultivar. The number of seeds and the seed-set ratio were found to decrease with increasing day length in both eco-type cultivars. They also decreased considerably between the day length periods from 13.5-h to 14-h in the autumn eco-type cultivar, although the response was unclear in the summer eco-type cultivars.

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