Influence of Temperature Shift after Flowering on Dry Matter Partitioning in Two Cultivars of Snap Bean (*Phaseolus vulgaris*) that Differ in Heat Tolerance

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Abstract: The partitioning of dry matter (ratio of dry weight of individual parts to that of total dry matter) was analyzed in snap bean cultivars, Haibushi, a heat-tolerant cultivar, and Kentucky Wonder, a heat-sensitive cultivar, at four temperatures after flowering on the subtropical island of Ishigaki, Japan. The temperature regimes included 27/23°C (day/night) as normal, 24/20°C as low, 30/26 as high, and 33/29°C as extremely high. Most growth traits increased after flowering time (35 DAS), displaying a plateau at 68-75 DAS. The total dry matter was similar under all temperature conditions, but differed with the cultivar. Haibushi had a higher value of total dry matter than Kentucky Wonder, which was mainly due to higher pod dry weight although stem and root dry weights were lower in Haibushi. A sharp decline of dry matter partitioning to pods was observed at 35/29 ºC. In the temperature range of 24/20 to 30/26°C, Haibushi showed higher partitioning to pods than Kentucky Wonder, independent of temperature. On the other contrary, Kentucky Wonder showed higher partitioning to pods at 27/23°C than at 24/20°C. These results showed that the partitioning of dry matter, which varied with the cultivar and temperature, played an important role in achieving higher harvest index in the heat-tolerant than in the heat-sensitive cultivars.

Key words: Dry matter, Harvest index, Heat tolerance, High temperature, Snap bean.

The adverse effects of heat stress are a major limitation in realizing the genetic potential of productivity of snap bean (*Phaseolus vulgaris* L.) on the subtropical islands of Japan. The reproductive growth stage is the most thermo-sensitive and a shift of temperature from 27°C (normal temperature) causes substantial yield loss (Nakano et al., 1998, 2000; Tsukaguchi et al., 2003; Omae et al., 2005a). There is a need for improved cultivars to reduce the effects of heat stress on productivity of snap bean. Many studies have been conducted at the Okinawa Subtropical Station, Japan International Research Center for Agricultural Sciences, Ishigaki, Japan to screen and evaluate high-temperature tolerance (Tsukaguchi et al., 1999, 2003, 2005; Suzuki et al., 2001a, b; Omae et al., 2004, 2005a, b, c; Kumar et al., 2005). Many of these studies revealed that reduction in the number of pods per plant and seed biomass due to heat stress was associated with reduced leaf water content. Cultivar Haibushi has been selected for its heat tolerance (Nakano et al., 1997) and produces higher pod yield and maintains higher leaf water content than Kentucky Wonder after exposure to high temperature (Omae et al., 2004, 2005b; Kumar et al., 2005). The pod yield is also directly affected by high temperature due to the lack of pollination, and increased senescence and abscission of flowers and young pods (Suzuki et al., 2001a). Cultivars Haibushi and Kentucky Wonder did not differ in pollen fertility but the former showed higher pod setting and retention than the latter (Omae et al., 2005a). High pod setting and retention require high rates of photosynthesis and resource partitioning to pods. When the photosynthetic rate is lowered by high temperature, the partitioning of photo-assimilates to various plant organs may become more critical in determining the pod yield. However, there has been no attempt to undertake an examination on the effects of different temperatures on the partitioning of photo-assimilates, which may help to understand the mechanism of heat tolerance in snap bean. This study was conducted to determine whether various temperatures from low to extremely high imposed after flowering affects subsequent growth and development of pods by influencing dry matter partitioning to different plant parts in two cultivars in snap bean with different productivity under high temperature conditions.

Materials and Methods

The plants of two cultivars Haibushi, a heat-tolerant cultivar, indeterminate type, and Kentucky Wonder, a heat-sensitive cultivar, indeterminate type, were sown in plastic pots (1/5000 a, 0.02 m³) filled with 4000 g
soil, containing a mixture of 80% clay, 20% compost, 0.02% lime, and 0.03% NPK. Planting was performed on 13 April 2005 in a glasshouse at a normal day/night temperature of 27 ± 0.2°C/23 ± 0.2°C with a day/night thermal period of 12 h under natural daylight conditions. Relative humidity was kept at 70 ± 5% during the day/night periods. Seeds were sown without rhizobacterial inoculum. One plant was grown in each pot after thinning when the first trifoliate leaf appeared. From planting to 39 days after sowing (DAS), all plants were grown at the normal temperature and usually irrigated once per day, depending on the requirement. Flowering occurred at 35 DAS in both cultivars.

At 40 DAS, the plants were transferred to one of four temperatures, low (24 ± 0.2/20 ± 0.2°C), normal (27/23°C), high (30 ± 0.2/26 ± 0.2), and extremely high (33 ± 0.2/29 ± 0.2°C, day/night) with the same day/night thermal period of 12 h and 70 ± 5% relative humidity under natural light conditions. At each temperature, the pots were arranged randomly in the glasshouse with four uniform replicate plants selected from six replicate pots. The same randomization procedure was followed in each temperature treatment. Relative humidity was maintained at 70% in all four temperature treatments. The temperature treatments were continued up to 68 DAS. After 68 DAS, plants at 24/20, 27/23, 30/26 and 33/29°C were returned to the normal temperature. All plants were kept at the normal temperature for 7 days (up to 75 DAS). During the treatment period (40-75 DAS), plants were watered at least twice a day, at 9:00 and 15:30, to a level equal to 70% of the water-holding capacity of the potting medium, 30.3 ± 0.89%.

Leaf growth in terms of the number of leaves and leaf area per plant, dry matter accumulation and partitioning to vegetative parts such as leaves, stems, and roots and to reproductive parts, i.e. pods, were studied at 7-day intervals from 40 to 75 DAS. Roots were washed carefully with a gentle water sprinkler to remove the potting medium. The number of leaves per plant was counted. Leaf area of each plant was measured with an area meter (Model AAM-8, Hayashi Denko Co. Ltd., Japan). For dry matter studies, plants were separated into leaves, stems, roots and pods. Dry weights of roots, leaves, stems and pods per plant were recorded after oven-drying these parts to a constant weight (for 3 days) at 70°C. Total dry matter weight was calculated as the sum of the weights of individual plant parts. Partitioning or allocation of dry matter to leaves, stems, roots, and pods was calculated as the ratio of dry weights of individual components to the total weight of dry matter and expressed as percentage.

Analysis of variance of the data was performed in a factorial design by considering two factors; temperature and cultivar with four replicates pots or plants. The data were statistically analyzed using the JMP computer program (SAS Institute, Japan). The regressions were also determined between dry weight and DAS to calculate the growth rates in terms of total dry matter, pod dry weight, and harvest index by using the JMP computer program.

**Results**

The results are summarized in Table 1. In general, most growth traits increased from 40 to 68 DAS and there was no significant difference between 68 and
Dry matter accumulation. The number of leaves per plant, leaf area, and dry matter accumulation in vegetative parts were higher at 33/29°C than at either 24/20, 27/23 or 30/26°C, with higher values than at 24/20 or 33/29°C. Haibushi had higher values than Kentucky Wonder for the number of leaves, total dry matter, pod dry weight, and harvest index, while Kentucky Wonder had higher values for dry matter accumulation and partitioning to vegetative parts, especially to stems and roots. The two cultivars had similar leaf dry weight and leaf area per plant.

1. Dry matter accumulation

The leaf dry weight showed no significant differences between the treatments up to 54 DAS (Fig. 1a, b). From 61 to 68 DAS, leaf dry weight was significantly higher at 33/29°C than at the other temperatures, but the difference was not significant. After 68 DAS, Haibushi showed higher leaf dry weight than Kentucky Wonder. The stem dry weight also varied with the cultivar, and was higher in Kentucky Wonder than in Haibushi throughout the duration of the temperature treatments (Fig. 1c, d). However, the effect of temperature on Haibushi was recorded at 68 DAS, when the stem dry weight was higher at 33/29°C than at the other temperatures, though the difference was not significant. The dry weight of roots varied with the cultivar, and was higher in Kentucky Wonder than in Haibushi irrespective of temperature (Fig. 1e, f). From 61 to 75 DAS, only the cultivar effect was significant; Kentucky Wonder had higher root dry weight than Haibushi.

The pod dry weight varied with the temperature from 47 to 68 DAS (Fig. 1g, h). The pod dry weight did not differ in Haibushi among the temperatures 24/20, 27/23, and 30/26°C, but was higher at these temperatures than at 33/29°C. In Kentucky Wonder, the pod dry weight was higher at 27/23 and 30/26°C than at 24/20°C whereas no pods formed at 33/29°C. Kentucky Wonder at 24/20 and 33/29°C and Haibushi at 33/29°C showed the lowest dry weight of pods. At 75 DAS, the dry weight of pods was higher at the temperatures 24/20, 27/23, and 30/26 than at 33/29°C. The pod dry weight was higher in Haibushi than in Kentucky Wonder throughout the treatments. The total dry weight did not differ between the treatments (Fig. 1i, j). The effect of cultivar was significant. From 61 to 75 DAS, the total dry weight was higher in Haibushi than in Kentucky Wonder.

2. Partitioning of dry matter

The rate of partitioning of dry matter to leaves was higher at 33/29°C than at other temperatures in both cultivars, and in Kentucky Wonder than in Haibushi irrespective of temperature (Fig. 2a, b). The rate of dry matter partitioning to stems varied with the temperature regimes in the two cultivars (Fig. 2c, d), and was the highest at 33/29°C irrespective of cultivar. Within other temperature regimes, dry matter allocation to stems did not differ in Haibushi but showed differences in Kentucky Wonder from 61-68 DAS, when it was significantly lower at 27/23 than at 24/20 or 30/26°C. Kentucky Wonder showed higher rate of dry matter allocation to roots. At 68 DAS, allocation varied with the temperature in the two cultivars (Fig. 2e, f). At 68 DAS, the rate of dry
matter partitioning to roots was highest at 24/20°C in Kentucky Wonder while it was similar at 24/20, 27/23, and 30/26°C in Haibushi, which was lower than at the other temperature treatments including Kentucky Wonder at all temperatures and Haibushi at 33/29°C. The partitioning of dry matter to pods, or harvest index, varied with the temperature regimes in the two cultivars from 47 to 75 DAS (Fig. 2g, h). At 33/29 °C, the two cultivars showed no differences, while at the other temperatures the harvest index was higher in Haibushi than in Kentucky Wonder. From 61 to 68 DAS, the rate of allocation to pods in Kentucky Wonder was significantly higher at 27/23°C than at either 24/20 or 33/29°C. At 75 DAS, harvest index was higher at 24/20, 27/23 and 30/26°C than at 33/29°C, and was higher in Haibushi than in Kentucky Wonder.

**Discussion**

The rate of dry matter allocation to pods and partitioning of dry matter to pods were the lowest at extremely high temperature (33/29°C) in both cultivars though total dry matter was similar at all temperatures (Table 1). This study confirmed earlier findings reported by Omae et al. (2005b) who considered that 33/29°C was a lethal temperature for snap bean, displaying heavy decline of pod dry weight and harvest index in the two cultivars. This temperature regime was exceptional; therefore, in the following, little emphasis has been given to 33/29°C in the discussion.

Haibushi had a higher value of total dry matter than Kentucky Wonder except at 33/29°C (Table 1, 2, Fig. 1). However, this was caused by higher pod dry weight. The stem and root dry weight in Haibushi adversely showed lower pod dry weight in Haibushi than in Kentucky Wonder. There was no significant difference in either leaf area or leaf dry weight between the two cultivars (Fig. 1). From these results, we consider that the differential heat tolerance of the two snap bean cultivars was mainly due to the difference in dry-matter partitioning to individual plant parts, especially to pods, rather than the photosynthetic capabilities, leaf area and total dry matter production (Table 1).

Cultivar differences in the response of partitioning
at other temperatures (24/20 to 30/26°C) were apparent. The major differences between the two cultivars were that dry matter partitioning to pods was higher in heat-tolerant Haibushi, while that to the vegetative parts was higher in heat-sensitive Kentucky Wonder. The dry matter partitioning to vegetative parts tended to decrease towards maturity in the former but not in the latter, indicating that the photo-assimilates from the vegetative parts were allocated to pods in Haibushi, but not in Kentucky Wonder. At the temperatures from 24/20 to 30/26°C, dry matter partitioning did not differ in Haibushi, while it varied in Kentucky Wonder; higher at 24/20 and 30/26°C than at 27/23°C. This suggests that the dry matter partitioning was independent of temperature in heat-tolerant cultivars and temperature-dependent in heat-sensitive cultivars, but only after a long-term exposure to the temperature. From these observations, we consider that the advantage of higher productivity in Haibushi at a high temperature (30/29°C) is not due to physiological responses to high temperature but is caused by essential growth characteristics of the cultivar which appeared irrespective of temperature.

The rate of change with time in total and pod dry matter and harvest index at 24/20–30/26°C can be elucidated as the linear function of the days after sowing, DAS (Table 2). The slope of the linear regression represented the growth rate. The growth rate was higher in Haibushi than in Kentucky Wonder. Within the above temperatures, there was no difference in growth rate in Haibushi while in Kentucky Wonder the growth rates in pod dry weight and harvest index were significantly higher at 27/23 than at 24/20°C. The difference in growth rate contributed to similar differences in pod dry weight and harvest index, which were temperature-dependent in Kentucky Wonder and temperature-independent in Haibushi.

Haibushi showed reduction in dry matter partitioning to leaves, stems, and roots after the temperature shift, while no such trend was found in Kentucky Wonder indicating wider temperature adaptability of the former than the latter. Therefore, the differential heat tolerance of the two cultivars may be related to the difference in dry matter partitioning that occurred in response to the shift in temperature. However, further investigation in different seasons and under field conditions are necessary.

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Table 2. Rate of change in total dry matter, pods dry weight and harvest index after flowering (40 DAS) in snap bean. The rate was determined by a linear relationship of a trait with days after sowing, DAS, during the temperature stress period (40-68 DAS).

| Temperature/Cultivar | Rate of change | | |
|---------------------|----------------|----------------|----------------|
|                      | Total dry matter | Pod dry weight | Harvest index |
|---------------------|-----------------|----------------|---------------|
| 24/20°C             |                 |                |               |
| Haibushi            | 1.45a           | 1.67a          | 2.32a         |
| Kentucky Wonder     | 0.96b           | 0.24c          | 0.64c         |
| 27/23°C             |                 |                |               |
| Haibushi            | 1.57a           | 1.31a          | 2.32a         |
| Kentucky Wonder     | 1.29b           | 0.74b          | 1.57b         |
| 30/26°C             |                 |                |               |
| Haibushi            | 1.61a           | 1.45a          | 2.63a         |
| Kentucky Wonder     | 0.76b           | 0.43bc         | 1.11bc        |

No relationship was found at 33/29°C. Values followed by different letter(s) in each column were significantly different at P < 0.05.
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