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Influence of High Temperature on Morphological Characters, Biomass Allocation, and Yield Components in Snap Bean (*Phaseolus vulgaris* L.)

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Abstract : High temperature in summer is a major limiting factor for the growth of snap bean in the subtropical islands of Okinawa, Japan. The effect of temperature on biomass production, yield components, and morphological characters were studied in five snap-bean cultivars and strains in the phytotron. Plants were initially grown at 24/20°C (day/night temperature, 12/12hr) and transferred to 24/20°C, 27/23°C (control) or 30/26°C at the onset of flowering (34 days after sowing). High temperature (30/26°C) increased single pod weight and the number of flowers and branches, but reduced the number of pods/plant, pod set ratio, and plant weight. 'Haibushi', a heat-tolerant cultivar, had higher pod weight/plant, number of pods/plant, pod weight/pod, pod set ratio, number of branches, and rate of biomass allocation to pods, but lower rates of biomass allocation to leaves, stems, and roots than 'Kentucky Wonder', a heat-sensitive cultivar, in all temperature regimes. The number of flowers, biomass, and accumulative temperature affected both the yield components (number of pods/plant, single pod weight) antithetically. The yield components were estimated by a stepwise multiple regression analysis. The number of pods/plant was estimated from the number of flowers, leaf weight, pod set ratio per branch, and plant weight with a reasonable precision (R^2=0.78). Single pod weight was determined (R^2=0.69) from pod set ratio, number of branches, root weight, and accumulative temperature. The results indicated that higher biomass allocation to pods and higher pod set in branches, which were observed in heat-tolerant cultivars at all temperature regimes, were most effective for the estimation of heat tolerance in snap bean.

Key words : Heat-tolerance, Morphological character, Partitioning, *Phaseolus vulgaris.*

Heat stress can be a principal limiting factor in the distribution, adaptability, and productivity of wild and cultivated plants. A high temperature in summer restricts crop production in the subtropical islands of Okinawa, Japan. Production of snap bean (*Phaseolus vulgaris* L.) is affected by a high temperature due to lack of pollination and the early abscission of flowers and young pods (Anthony et al., 1980; Nakano et al., 1998, 2000; Suzuki et al., 2001; Tsukaguchi et al., 2003; Omae et al., 2005a). Internal plant water status may also be associated with heat tolerance under non-water-stressed conditions (Omae et al., 2005b, c; Kumar et al., 2005). However, there are few reports on the influence of morphological aspects on heat tolerance, and not report on the effects of genotypic variation of heat tolerance (Irit et al., 1991). Drought stresses induces genotypic variation of shoot biomass accumulation, pod and seed number, and biomass partitioning index (Porfirio and James, 1998; Rigoberto et al., 2004). Therefore, heat stress may also affect morphological characters, changing yield and yield components in snap bean. The objective of this study was to evaluate the correlation of morphological characters, biomass production and yield components with heat tolerance in snap bean.

Materials and Methods

Three cultivars, 'Haibushi', 'Kurodane Kinugasa', and 'Kentucky Wonder', and two strains, 92761 and 92783, of snap bean (*Phaseolus vulgaris* L.) were planted singly in drained plastic pots filled with 4000 g soil, a mixture of 3200 g clay soil and 800 g compost containing 0.8 g lime and 1.2 g of 15N-12.5P-6.5K slow-release fertilizer (CDUs 555; Chisso Co., Tokyo, Japan).

Experiments were carried out in a phytotron of the Okinawa Subtropical Station, Japan International Research Center for Agricultural Sciences, Okinawa, Japan. Plants were grown in glass-covered growth rooms under different day and night temperatures, each controlled within ±1.5°C of the designated values.

The seedlings were thinned to one per pot when the first trifoliate leaf appeared. Plants were initially grown under 24/20°C (day/night temperature, 12/12hr), and three uniform plants were transferred to 24/20°C, 27/23°C (control), or 30/26°C at the onset of flowering (34 days after sowing). Data were

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Table 1. Influences of temperatures and genotypes on yield components, biomass, and morphological factors.

Temperature	Cultivar	Pod weight (g plant^{-1})	Number of pods/ plant	Weight/ pod (g pod^{-1})	Number of flowers	Pod set ratio (%)			Number of branches	Plant weight (g)			
						All	Main stem	Branch		Total	Stem	leaf	Root
24/20°C	Haibushi	24.6 a	43.3 ab	0.57 a	48.0 ab	90.5 a	92.3 a	88.7 a	3.33 ab	198.7 a	31.9 b	135.1 a	7.0 b
	92761	19.3 ab	40.7 ab	0.48 a	44.7 ab	91.7 a	92.7 a	89.3 a	4.00 a	210.7 a	33.6 b	146.5 a	11.3 b
	Kurodane kinugasa	28.4 a	66.7 a	0.44 a	80.3 ab	83.5 a	84.3 a	26.3 b	0.67 c	229.4 a	41.4 ab	145.1 a	14.6 b
	92783	13.7 bc	66.3 a	0.23 b	96.7 a	65.7 b	64.0 b	49.7 ab	1.33 bc	229.7 a	53.4 a	150.6 a	12.0 b
	Kentucky wonder	5.1 c	20.3 b	0.23 b	25.0 b	81.5 a	81.3 a	0.0 b	0.00 c	177.0 a	37.9 b	106.9 a	27.1 a
27/23°C	Haibushi	40.1 ab	43.0 b	0.92 a	53.0 b	81.0 a	83.7 ab	86.3 a	1.67 ab	109.3 b	21.5 c	42.9 b	4.8 c
	92761	33.0 ab	40.0 b	0.80 ab	47.7 b	85.5 a	88.0 a	52.7 a	1.33 ab	98.0 b	22.6 c	35.1 b	7.3 bc
	Kurodane kinugasa	44.4 a	79.0 a	0.58 b	124.7 a	62.4 bc	61.0 cd	26.0 a	1.00 ab	173.1 a	38.2 b	79.8 a	10.7 b
	92783	22.7 b	83.3 a	0.27 c	155.7 a	54.1 c	53.3 d	53.7 a	2.67 a	173.6 a	58.1 a	76.4 a	16.3 a
	Kentucky wonder	20.5 b	31.3 b	0.67 b	42.0 b	73.7 ab	73.7 bc	26.0 a	0.33 b	145.6 ab	40.0 b	73.8 a	11.2 b
30/26°C	Haibushi	86.9 a	57.0 a	1.51 a	82.3 b	69.3 a	66.7 a	74.3 a	3.33 ab	151.3 a	18.6 c	44.2 ab	1.7 c
	92761	33.4 b	30.0 b	1.14 b	46.0 b	66.7 a	69.7 a	67.3 ab	3.00 ab	96.0 b	22.7 c	33.9 b	6.0 bc
	Kurodane kinugasa	21.9 bc	32.3 b	0.69 c	148.7 a	21.8 c	22.7 bc	16.0 c	4.33 a	97.2 b	24.5 c	40.2 ab	10.6 ab
	92783	11.9 bc	24.3 b	0.48 c	152.7 a	16.3 c	13.7 c	17.3 c	4.67 a	97.2 b	42.0 a	31.0 b	12.2 a
	Kentucky wonder	7.8 c	19.7 b	0.38 c	53.7 b	36.0 b	34.0 b	40.0 bc	0.67 b	124.8 ab	32.0 b	73.0 a	12.0 a
	Temperature (T)	**	**	**	**	**	**	n.s.	**	**	**	**	**
	Cultivar (C)	**	**	**	**	**	**	**	**	n.s.	**	n.s.	**
	T×C	**	*	**	n.s.	**	**	n.s.	n.s.	n.s.	n.s.	*	**

*,**, and n.s. denote significance level at P=0.05, 0.01, and non-significance, respectively.
Different letters indicate significant differences (P<0.05) by Student's t test.

Table 2. Coefficients of correlation of yield components with biomass, accumulative temperature, and morphological factors.

	Pod weight / plant	Number of pods/plant	Weight / pod
Number of flowers	–0.093	0.437**	–0.349*
Pod set ratio	0.269	0.264	0.139
Pod set ratio (main stem)	0.253	0.231	0.146
Pod set ratio (branch)	0.279	0.254	0.142
Number of branches	0.036	–0.121	0.102
Plant weight	0.030	0.682**	–0.372*
Stem weight	–0.388*	0.630**	–0.707**
Leaf weight	–0.245	0.452**	–0.512**
Root weight	–0.547**	0.374*	–0.735**
Accumulated temperature	0.222	–0.432**	0.471**

* and ** indicate significance at P=0.05 and 0.01, respectively.

taken from three plants, which were considered as three replicates, in each temperature regime. Plants were watered once and twice a day before and after podding, respectively. The numbers of flowers and pods were measured daily and pod weight at 6 days after onset of flowering. Pod set ratio (the number of pods divided by number of flowers on the branches at 6 days after flowering was calculated separately from that on the main stem in each plant. Plants were harvested 84 days after sowing and stem, leaf, and root weights were measured. Accumulative temperature was calculated by multiplication of temperature above 0°C during the growing period. For estimating yield components from the biomass and morphological factors, we performed a stepwise multiple regression analysis by forward inclusion of the best variables using JMP software (Ver. 5.0, SAS Institute, Japan) with PC.

Results

Exposure to a high temperature (30/26°C) increased pods weight/plant in 'Haibushi' and strain 92761 (Table 1). The other three cultivars and strains ('Kurodane Kinugasa', 92783, and 'Kentucky Wonder') showed the highest pod weight/plant at 27/23°C. The number of pods/plant in 'Kurodane Kinugasa', 92783, and 'Kentucky Wonder' were highest at 27/23°C, while that in 'Haibushi' was the highest at 30/23°C and that in 92761 at 24/20°C. Pod weight/pod was heaviest at 30/26°C in all cultivars and strains except in 'Kentucky Wonder', in which it was highest at 27/23°C. The effect of the cultivar was significant, but by the interaction between cultivar and temperature in pods weight/plant, number of pods/plant, and single-pod weight was also significant. 'Haibushi' had a heavier pod weight/plant than 'Kentucky Wonder' and 92783 in all temperature regimes except 27/23°C. At 30/26°C, 'Haibushi' showed the highest pod weight/plant, number of pods/plant, and pod weight/pod among all cultivars and strains, and 'Kentucky Wonder' showed the lowest values. the effects of temperature and cultivar were significant in the number of flowers. 'Kurodane Kinugasa' and 92783 had more flowers than the other cultivars in all temperature regimes except 24/20°C. A high temperature decreased pod set ratio on the branches and main stems. 'Haibushi' and 92761 had higher pod set ratios than 'Kurodane Kinugasa' and 92783 in all stems at 27/23°C and 30/26°C, except in branches at 27/23°C. High temperature increased the number of branches but decreased the weight of whole plants and stems weights. The interaction between temperature and cultivar on leaf and root weights was significant. Stem weight was heaviest in 92783, followed by 'Kentucky Wonder', and was lightest in 'Haibushi' and 92761 in all temperature regimes except 24/20°C. 92761 showed lower leaf weight than 'Kentucky Wonder' at 27/23°C and 30/26°C. 'Haibushi' had a lower root weight, followed by 92761, than other cultivars and strains at all temperatures except at 24/20°C.

Pod weight/plant at 30/26°C was used as an indicator of heat-tolerance, and the number of pods/plant and single-pod weight as yield components. Biomass, accumulative temperature, and morphological factors except pod set ratio were more closely correlated with the yield components (number of pods/plant and single-pod weight) than with pod weight/plant, with the exception of pod set ratio (Table 2). Pod weight/plant was negatively correlated with stem and root weight. The number of flowers and whole plant weight were positively correlated with the number of pods/plant, but negatively with single-pod weight in contrast to the accumulative temperature. The reverse was the case for accumulative temperature. The results indicated that the number of flowers, biomass, and accumulative temperature affected

Table 3. Influences of temperatures and genotypes on allocation of biomass to each organ.

Temperature	Cultivar	Distribution rate (%)			
		Leaf	Stem	Pod	Root
24/20°C	Haibushi	67.8 a	16.1 b	12.5 a	3.5 b
	92761	69.4 a	16.0 b	9.2 ab	5.4 b
	Kurodane kinugasa	63.2 ab	18.0 b	12.5 a	6.3 b
	92783	65.8 ab	23.3 a	5.6 bc	5.3 b
	Kentucky wonder	60.3 b	21.6 a	2.7 c	15.4 a
27/23°C	Haibushi	39.3 bc	19.8 c	36.5 a	4.4 c
	92761	35.1 c	23.3 c	33.7 a	8.0 ab
	Kurodane kinugasa	46.1 ab	22.3 c	25.5 b	6.1 bc
	92783	44.0 abc	33.5 a	13.1 c	9.4 a
	Kentucky wonder	50.6 a	27.6 b	14.2 c	7.6 ab
30/26°C	Haibushi	29.2 b	12.3 c	57.4 a	1.1 c
	92761	32.5 b	27.5 b	33.2 b	6.8 b
	Kurodane kinugasa	39.8 ab	25.9 b	23.3 bc	11.1 a
	92783	30.2 b	44.2 a	13.0 cd	12.6 a
	Kentucky wonder	58.0 a	25.7 b	6.7 d	9.6 ab
	Temperature (T)	**	**	**	n.s.
	Cultivar (C)	**	n.s.	**	**
	T×C	**	*	**	**

*,**, and n.s. denote significance level at P=0.05, 0.01, and non-significance, respectively.
Different letters indicate significant differences (P<0.05), Student's t test.

both yield components (number of pods/plant and pod weight/pod) antithetically, resulting in a weak relationship to yield (pod weight/plant).

The effect of temperature and the interaction between temperature and cultivar were significant in all distribution rates to plant parts in all temperature regimes except to roots (Table 3). The allocation to leaves decreased with increasing temperature in all cultivars except 'Kentucky Wonder'. 'Kentucky Wonder' allocated biomass to leaves at higher rate than 'Haibushi' and 92761 in all temperature regimes except 24/20°C. The rate of allocation to stems increased with increasing temperature except in 'Kentucky Wonder' and 'Haibushi', in which the rate was highest at 27/23°C. The rate of allocation to stem was highest in 92783 among the cultivars at 27/23°C and 30/27°C. The rate of allocation to pods was highest at 27/23°C in all cultivars and lines except in 'Haibushi', in which the rate was increased at a higher temperature (30/26°C). In 'Haibushi, the rate of biomass allocation to pods was higher, but that to leaves, stems, and roots was lower than 'Kentucky Wonder' in all temperature regimes.

The number of pods/plant could be estimated with a reasonable precision (R^2=0.78) from the number of flowers, leaf weight, pod set ratio on branches, and plant weight (Fig. 1). Single-pod weight could be estimated (R^2=0.69) from the pod set ratio, number of branches, root weight, and accumulative temperature.

Discussion

The values of pod weight/plant, number of pods/plant, and single-pod weight all cultivars in the 30/26°C temperature regime was highest in 'Haibushi" (Table 1), showing that 'Haibushi' is a heat-tolerant cultivar. 'Kentucky Wonder', on the contrary, had the lowest values of pod weight/plant, number of pods/plant and single-pod weight and is considered to be a heat-sensitive cultivar. In 'Haibushi', a high temperature is more advantageous for pod production than for the production of the other parts of the plant and for improvement of morphological factors such as pod set ratio and rate of biomass allocation to pods. A higher rate of allocation to pods was observed in 'Haibushi' even in the other temperature regimes. Therefore, it can be concluded that a cultivar which can mobilize photosynthetic assimilate more to reproductive organs irrespective of temperature has a big advantage for higher pod production at high temperature. This character might be hereditary. Porfirio and James (1998) reported that a high partitioning index, chiefly harvest index, showed high heritability contributing to drought stress in common bean.

The higher rate of biomass allocation to pods in 'Haibushi' is strongly linked with a lower rate of

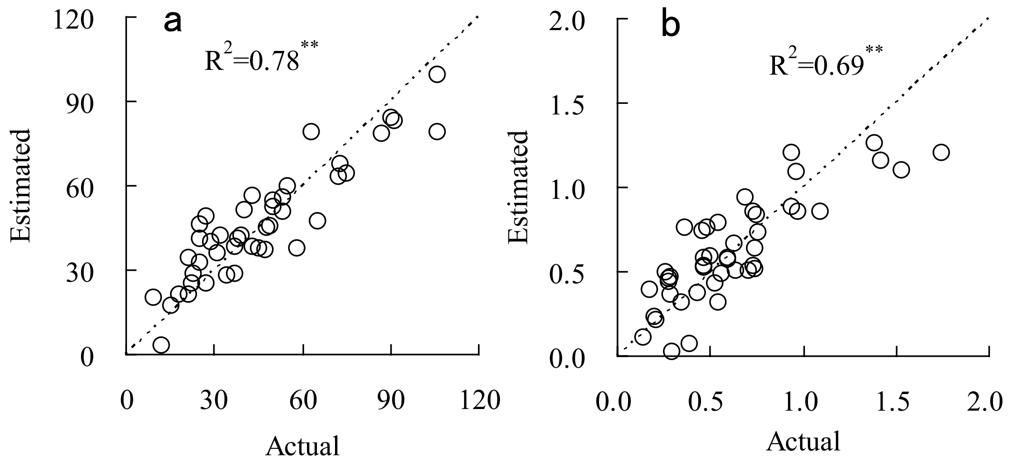

Fig. 1. Relationship between estimated and actual value of (a) number of pods/plant and (b) pod weight /pod. Regression equations are (a) $y=0.21x_1-0.44x_2+0.19x_3+0.57x_4-33.42$ (y: number of pods/plant, x_1: number of flowers, x_2: leaf weight (g), x_3: pod set ratio per branch (%), x_4: plant weight(g)) and (b) $y=0.012x_1+0.032x_2-0.008x_3+0.002x_4-4.36$ (y: pod weight/pod, x_1: pod set ratio (%), x_2: number of branches, x_3: root weight (g), x_4: accumulative temperature).

allocation to roots (Table 3) that leads to a lighter root weight, which was used for the estimation of yield components as an independent variable (Table 3). In addition, multiple regression analysis for the correlation of yield components with the number of pods/plant and single-pod weight indicated that the number of branches and the pod set ratio in the branch were necessary for the estimation of yield components. Irit et al. (1991) reported that high night temperature promoted branching in snap bean. In the present experiment, high temperature (30/26°C) promoted branching, but decreased the pod set ratio. However, ‘Haibushi’ kept a higher number of branches with a small reduction in pod set ratio at 30/26°C compared with other cultivars and strains (Table 3).

The question is how ‘Haibushi’ can keep a higher pod set ratio in high temperature conditions despite the poor allocation of biomass to roots. It may be associated with the inner plant water status. Water stress reduced pollen fertility and pod set ratio in snap bean (Omae et al., 2005b). However, ‘Haibushi’ can maintain higher leaf water content with decreasing leaf water potential than ‘Kentucky Wonder’ under drought and high temperature conditions (Kumar et al., 2005). ‘Haibushi’ showed inferior shoot growth irrespective of temperature, which may contribute to better water status in leaves (Omae et al., 2004; Kumar et al., 2005), higher pod set (Omae et al., 2005a), and higher photosynthetic rate (Omae et al., 2005c).

The increase in the rate of allocation to pods at high temperature at the expense of poor root development has not been reported before. Crop physiologists should pay attention to this point in the identification of heat-tolerant crops. The present results are also important for crop breeders in screening heat-tolerant lines. Further study would clarify the overall mechanism of heat tolerance including phenology and water relations in combination with drought stress.

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