JARQ 40 (3), 213 – 216 (2006) http://www.jircas.affrc.go.jp

REVIEW

Adaptation to Heat and Drought Stresses in Snap Bean (*Phaseolus vulgaris*) during the Reproductive Stage of Development

Ashok KUMAR[1,2], Hide OMAE[2]*, Yoshinobu EGAWA[3,4], Kouichi KASHIWABA[2] and Mariko SHONO[2]

[1] Department of Agronomy, CCS Haryana Agricultural University (Hisar 125004, Haryana, India)
[2] Okinawa Subtropical Station, Japan International Research Center for Agricultural Sciences (JIRCAS) (Maezato, Ishigaki, Okinawa 907–0002, Japan)
[3] Research Planning and Coordination Division, Japan International Research Center for Agricultural Sciences (JIRCAS) (Tsukuba, Ibaraki 305–8686, Japan)

Abstract

We screened snap bean (*Phaseolus vulgaris* L.) germplasm for heat and drought tolerance during the reproductive stage under extremely hot conditions as well as in the winter seasons in closed net houses to raise the temperatures under field conditions, a practice usually followed by vegetable growers. Substantial genotypic differences were found in morpho-physiological characteristics like phenology, plant water relations, photosynthetic parameters and shoot growth, which were related to the reproductive responses. The associations of days to podding and leaf water content with the number of pods per plant and seed yield were consistent across the different environments and experiments. The leaf water content was maintained by reductions in leaf water potential and shoot extension in response to heat and drought stress. Therefore, these traits can be used as a marker to screen germplasm for heat and drought tolerance. In this paper, we briefly reviewed the results of our studies carried out on heat and drought tolerance in snap bean at Okinawa Subtropical Station, Ishigaki.

Discipline: Agricultural environment / Crop production
Additional key words: phenology, photosynthetic parameters, plant water relations, shoot growth

Introduction

In subtropical islands of Okinawa, vegetable production in the summer season is very difficult due to high temperature and strong solar radiation, and associated effects like drought and infestation by insects and pests. Fresh vegetables are carried from the mainland, which are very expensive and poor in quality. Therefore, snap bean was introduced here aimed at supplying a fresh green vegetable throughout the year especially during the hot summer season. A heat-tolerant cultivar Haibushi was developed by the Laboratory of Environmental Stresses, JIRCAS, Okinawa, by screening the germplasm collected from Southeast Asian countries[6]. However, high temperature in summer is causing drastic reductions in snap bean yield[7,8,11,17–19]. The crop also faces water deficit due to excessive transpiration caused by high temperature[10,14]. Large genotypic differences were found in plant water status in snap bean, which were correlated to crop productivity under drought conditions in a high temperature environment[11]. Even short diurnal fluctuations in the plant water status at the time of anthesis could adversely affect the development and function of reproductive organs[19]. However, these issues have not been investigated well in snap bean.

Plants exposed to heat and drought or water stress have evolved a series of morphological and physiological adaptations, which confer tolerance to these stresses. Photosynthetic parameters have been shown to respond

Present address:
[4] Tropical Agriculture Research Front, Japan International Research Center for Agricultural Sciences (JIRCAS) (Maezato, Ishigaki, Okinawa 907–0002, Japan)
*Corresponding author: fax +81–980–82–0614; e-mail homae@affrc.go.jp
Received 24 August 2005; accepted 26 December 2005.

to heat and water stress[20]. Changes in leaf anatomical characteristics are known to alter the CO_2 conductance diffusion components to maintain photosynthetic rates despite low water status. Phenology is a significant evolutionary force in the adaptation of annual crop plants to different environments including high temperature and drought. Therefore, a better understanding of the influence of heat and drought stress on phenology, plant water relations, photosynthetic parameters, shoot growth and reproductive responses may enable us to identify the plant processes/traits related with these stresses and may be helpful to elucidate the mechanisms of tolerance in snap bean.

Association of photosynthetic parameters with leaf water status

Under field conditions in a hot summer season, the cultivars differed markedly in leaf water status, leaf conductance and intercellular CO_2 concentration, while there were no consistent differences in photosynthesis and transpiration rates, which varied in a narrow range[5]. This indicated that the effect of high temperature on the biochemical factors controlling intercellular CO_2 assimilation was similar in the cultivars. The midday leaf water potential decreased with increasing air temperature but the decline was greater in heat-tolerant Haibushi and Ishigaki-2 than the remaining cultivars. A steeper water potential gradient from soil to plant may enhance the ability of plants to absorb water at a faster rate[3]. This reduced the development of severe internal water deficit in the reproductive organs and increased their survival and growth. It was noteworthy that the heat-tolerant cultivars Haibushi and Ishigaki-2 displayed an association of photosynthesis and leaf conductance with leaf water potential while it was absent in the heat-sensitive cultivars[5,12]. This indicates that the heat-tolerant cultivars possess better stomatal control over CO_2 and H_2O exchange in leaves in response to high temperature. This is evidenced by the fact the sensitive cultivars Kentucky Wonder and 92783 showed greater water loss[13]. Furthermore, in our study, high solar radiation at midday did not increase transpiration in heat-tolerant Haibushi.

Genotypic differences in water relations related with reproductive responses

Our studies revealed that Haibushi, a heat-tolerant cultivar displayed better leaf water status than Kentucky Wonder, a heat-sensitive cultivar, which exhausted soil water quickly resulting in a greater deterioration in the water status[4,9]. The reduction in leaf water content with water potential became faster with the increase in high temperature, and it was larger in the heat-sensitive than in the heat-tolerant cultivar[16] (Fig. 1). Under field conditions, strains 86884 and 92783 and cultivar Kentucky Wonder failed to show any relation between leaf water potential and water content and produced very few pods despite the higher pollen fertility. In contrast, in strains 45817, Ishigaki-2 and 3028520, and cultivars Kurodane-Kinugasa and Haibushi, relatively higher leaf water content was maintained with declining water potential and a larger number of pods were set[13]. Osmotic adjustment and cell wall elasticity enable the plants to maintain higher water content, turgor and other turgor-related processes during water deficit[1,2]. This allows plant organs to survive longer in tolerant than sensitive types. The results of our studies showed that the cultivars with a smaller midday drop of leaf water content showed higher pod setting ratio and produced a larger number of pods per plant and consequently had higher yield than the plants with a larger midday drop of RWC[15] (Fig. 2).

Genotypic differences in drought tolerance

The snap bean cultivars displayed distinct responses to a prolonged drought stress under field conditions. The responses of photosynthetic parameters and shoot extension to leaf water status were related to soil water content. Decrease in soil water caused a decline in leaf water status. The high yielding cultivars displayed a smaller reduction in leaf water content but a larger reduction in leaf water potential than the poor yielder. Such differences in leaf water content and leaf water potential may arise due to differences in osmotic adjustment[3] and cell wall elasticity[1]. The reduction in leaf water potential due to water stress was linearly correlated to reductions in shoot extension rate and leaf water content. A discriminant analysis revealed that the five cultivars displayed two distinct types of responses (Fig. 3). One group included cultivars Haibushi, Ishigaki-2 and Kurodane-Kinugasa, which showed a large reduction of about 16–20% in both shoot extension and water potential, and they produced a higher number of pods per plant and seed yield than cultivars Kentucky Wonder and 92783[13]. Cultivars Kentucky Wonder and 92783, which formed a separate group displayed a comparatively smaller reduction (4–8%) in both water potential and shoot growth. On the contrary, the former group displayed a smaller reduction in leaf water content while the latter group a larger reduction in leaf water content. This suggested that tissue water content was kept high by restricting excessive vegetative growth and a large reduction in water potential. The reduction in shoot growth due to stress contributed to the build up of water-economizing traits such as specific leaf weight and succulence index. Because all cultivars showed quite high rates of photosynthesis, it appeared that drought tolerance in vegetative growth was not related to that in the reproductive growth. The maintenance of relatively higher leaf water content with increasing water deficit plays an important role in terms of higher pod setting[13], pod retention and seed yield in snap bean. The results of this study displayed that leaf water content was positively correlated to photosynthetic parameters (Fig. 4).

Seasonal performance of cultivars

Performance of snap bean cultivars Haibushi, Kentucky Wonder, Kurodane Kinugasa and strains Ishigaki-

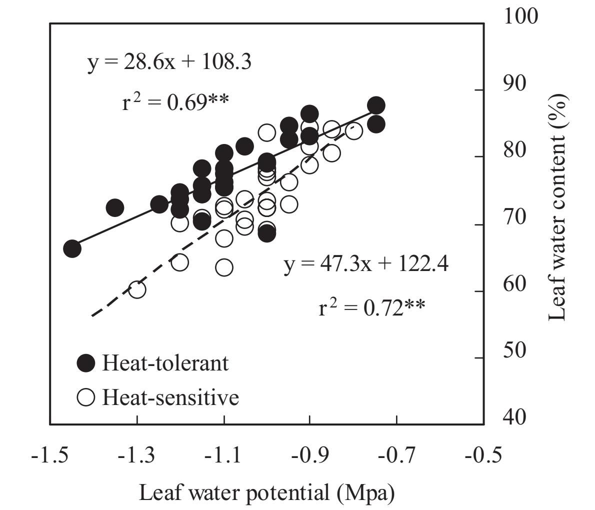

Fig. 1. Association of leaf water content with leaf water potential in heat-tolerant (Haibushi) and heat-sensitive (Kentucky Wonder) cultivars of snap bean
Data were collected at the podding stage after 1, 4 and 7 days of imposing 27/23, 29/25 and 31/27ºC. **: P<0.01.

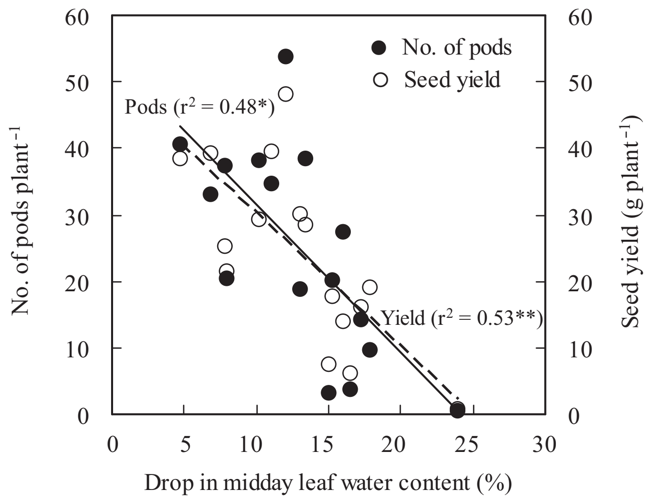

Fig. 2. Association of midday drop in leaf water content (ratio of leaf water content at midday to morning) with the number of pods per plant and seed yield
The measurements were taken on 8 cultivars under irrigated and unirrigated hot conditions during the reproductive stage in 2003. *: P<0.05, **: P<0.01.

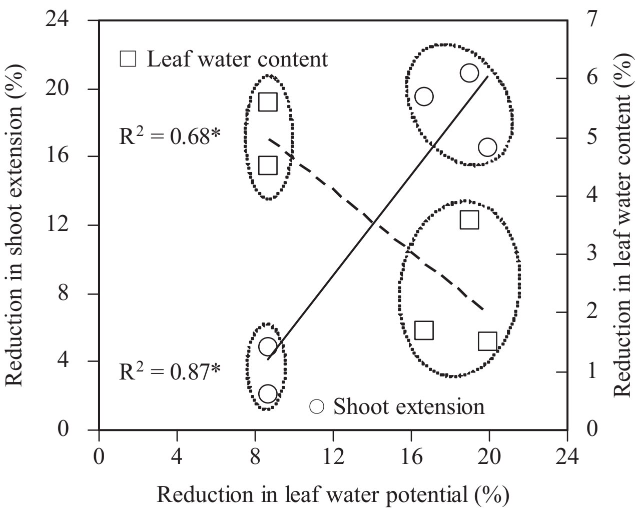

Fig. 3. Relationship of reduction (ratio of unirrigated to irrigated control in percentage) in leaf water potential with shoot extension and leaf water content in 5 cultivars of snap bean
Each dotted circle encloses a group of cultivars/strains recognized by discriminant analysis.
*: P<0.05.

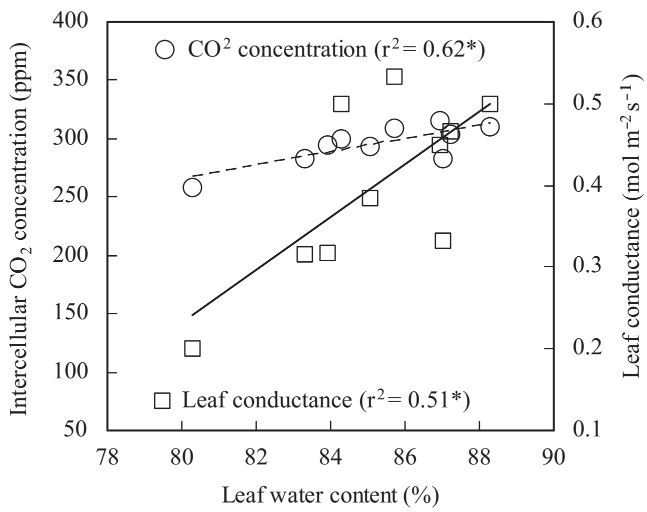

Fig. 4. Association of leaf water content with intercellular CO_2 concentration (circles) and leaf conductance (squares)
Data were collected from 5 cultivars of snap bean grown under irrigated and unirrigated (water application withheld at the podding stage) conditions.
*: P<0.05.

2, 45817, 92783, 86884 and 3028520 was evaluated from 2003–05 in many field and controlled environment experiments during the winter and summer seasons. Across the seasons, the days to pod formation was positively associated with the number of pods per plant, seeds per pod, seed weight and yield ($r > 0.97$). On the contrary, in the cultivars/strains, shorter duration to podding or flowering resulted in a higher number of pods per plant ($r = 0.93$) and number of seeds per pod ($r = 0.82$). Haibushi and Ishigaki-2 produced consistently a higher number of pods per plant and seed yield across the seasons and environments than the remaining cultivars. The number of pods per plant was the most important yield-attribute and was determined accurately by thermal units and the duration between emergence and flowering.

Concluding remarks

Our results revealed that leaf water content was involved in heat and drought tolerance in snap bean, but the supporting system for maintaining high water content is not very clear. The leaf water content was better correlated with leaf vapor pressure deficit, internal CO_2 concentration and leaf conductance than water potential. Therefore, plant water status can be explained better in terms of leaf water content in snap bean. Evaluation of associations of the number of pods per plant and seed yield with midday drop of leaf water content provided clear evidence that it was responsible for the genotypic variations in heat and drought tolerance. A small reduction in leaf water content was displayed by the tolerant cultivars which showed larger reductions in shoot extension and leaf water potential than the sensitive cultivars. Therefore, leaf water content is an important physiological trait for improved productivity, and it can be used as a screening tool for heat and drought tolerance in snap bean.

References

1. Kumar, A. & Elston, J. (1992) Genotypic differences in leaf water relations between *Brassica juncea* and *B. napus*. *Ann. Bot.*, **70**, 3–9.
2. Kumar, A. & Singh, D. P. (1998) Use of physiological indices as a screening technique for drought tolerance in oilseed *Brassica* species. *Ann. Bot.*, **81**, 413–420.
3. Kumar, A. et al. (1984) Differences in osmoregulation in *Brassica* species. *Ann. Bot.*, **54**, 537–541.
4. Kumar, A. et al. (2005a) Influence of water and high temperature stresses on leaf water status of high temperature tolerant and sensitive cultivars of snap bean (*Phaseolus vulgaris* L.). *Jpn. J. Trop. Agric.*, **49**, 109–118.
5. Kumar, A. et al. (2005b) Some physiological responses of snap bean (*Phaseolus vulgaris* L.) to water stress during reproductive period. *In* Int. conf. on sustainable crop production in stress environment: management and genetic options, JNKVV, Jabalpur, India, 226–227.
6. Nakano, H. et al. (1997) "Haibushi", a new variety of snap bean tolerant to heat stress. *JIRCAS J.*, **5**, 1–12.
7. Nakano, H., Kobayashi, M. & Terauchi, T. (1998) Sensitive stages to heat stress in pod setting of common bean (*Phaseolus vulgaris* L.). *Jpn. J. Trop. Agric.*, **42**, 78–84.
8. Nakano, H., Kobayashi, M. & Terauchi, T. (2000) Heat acclimation and de-acclimation for pod setting in heat-tolerant varieties of common bean (*Phaseolus vulgaris* L.). *Jpn. J. Trop. Agric.*, **44**, 123–129.
9. Omae, H. et al. (2004a) Heat tolerance of *Phaseolus vulgaris* 17. Leaf water status of two snap bean (*Phaseolus vulgaris* L.) cultivars differing in tolerance to high temperature stress. *Jpn. J. Trop. Agric.*, **48** (extra issue 1), 5–6.
10. Omae, H. et al. (2004b) Water consumption in different heat tolerant cultivars of snap bean (*Phaseolus vulgaris* L.). *In* 4th Int. crop sci. congr., Brisbane, Australia. Available online at http://www.cropscience.org.au/icsc2004/poster/1/3/4/405_omae.htm. (Verified 7 Dec. 2004).
11. Omae, H. et al. (2005a) Effect of temperature shift on flowering, pod setting and pollen fertility in snap bean (*Phaseolus vulgaris* L.). *Kyushu Agric. Res.*, **67**, 41 [In Japanese].
12. Omae, H. et al. (2005b) Evaluation of snap bean (*Phaseolus vulgaris* L.) genotypes for leaf gas exchange at mid day under high temperature. *Jpn. J. Crop Sci.*, **74** (extra issue 1), 304–305.
13. Omae, H. et al. (2005c) Genotypic differences in plant water status and relationship with reproductive responses in snap bean (*Phaseolus vulgaris* L.) during water stress. *Jpn. J. Trop. Agric.*, **49**, 1–7.
14. Omae, H. et al. (2005d) Heat tolerance of *Phaseolus vulgaris* 19. Cultivars and strains differences in water consumption of snap bean under high temperature. *Jpn. J. Trop. Agric.*, **49** (extra issue 1), 43–44 [In Japanese].
15. Omae, H. et al. (2005e) Midday drop of leaf water content related to drought tolerance in snap bean (*Phaseolus vulgaris* L.). *Plant Prod. Sci.*, **8**, 465–467.
16. Omae, H. et al. (2005f) Influence of level and duration of high temperature treatments on plant water status in snap bean (*Phaseolus vulgaris* L.). *Jpn. J. Trop. Agric.*, **49**, 238–242.
17. Suzuki, K. et al. (2001) Decrease of pollen stainability of green bean at high temperatures and relationship to heat tolerance. *J. Am. Soc. Hort. Sci.*, **126**, 571–574.
18. Tsukaguchi, T. et al. (1999) Pod set ratio as affected by pollen fertility under high temperature at reproductive stage in snap bean (*Phaseolus vulgaris*). *Jpn. J. Crop Sci.*, **68** (extra issue 1), 126–127 [In Japanese].
19. Tsukaguchi, T. et al. (2003) Water status of flower buds and leaves as affected by high temperature in heat-tolerant and heat-sensitive cultivars of snap bean (*Phaseolus vulgaris* L.). *Plant Prod. Sci.*, **6**, 24–27.
20. Turner, N. C. (1986) Adaptation to water deficits: A changing perspective. *Aust. J. Plant Physiol.*, **13**, 175–190.