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EVALUATION OF BEAN CULTIVARS UNDER HIGH TEMPERATURE STRESS

BY

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MANUSCRIPT

Evaluation of bean cultivars under high temperature stress.[1]

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Abstract: Twenty cultivars of *Phaseolus vulgaris* L. were studied in the greenhouse under high summer temperature conditions to determine the effect of high temperature stress on various plant characteristics as an indication of heat tolerance or intolerance. The influence of auxin on these plant characteristics under high temperature was determined by treatment of half of the replicates with 5 ppm (2-naphthoxy)-acetic acid. 'Provider' and 'Bush Blue Lake 290' showed the greatest tolerance and 'UI 111' the least to the effects of high temperature on seed yield. When cultivars were pooled, auxin significantly reduced seed weight, number of pods with seeds, harvest index, and leaflet drop. When cultivars were considered separately, only a small proportion were significantly affected for these characteristics by the auxin treatment. All cultivars showed a pattern of decreasing values for all characteristics with increasing temperature regardless of auxin treatment. Cultivar differences in response to temperature gradient were evident.

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High temperature has been shown to adversely affect pod set in the common bean, Phaseolus vulgaris L. (1,5,13). Temperatures ranging from 20-25°C have been reported optimum for plant growth and development with temperatures above this harmful (4,10,19). Little or no pod set occurs at temperatures approaching 35°C (11,14). The majority of the fruit that set at high temperature fail to develop and are parthenocarpic (2,14).

Several workers have used auxins to increase pod and seed yield in the common bean with varying degrees of success dependent on environmental conditions, type of growth regulator, and rate and frequency of application used (4,8,12,18,20). Stoffella (15) increased pod and seed weight and seed number for both a heat tolerant and a heat intolerant cultivar with spray application of 5 ppm 2-NOA. Although increases were not significant, he suggested that this was the result of high environmental variation.

Screening techniques for recognizing cultivar differences are an important consideration in any breeding program. Due to erratic field temperatures and limited growth chamber space, Stoner (17) has successfully used a greenhouse during the summer to select for high temperature fruit setting ability in the tomato. Although considerable research has been conducted on the effects of high temperature stress on plant growth and pod set in P. vulgaris, little information is available on screening for heat tolerance among cultivars for the purpose of developing cultivars tolerant to high temperature stress.

Consequently, a greenhouse study was conducted to investigate the effect of high temperature stress on various plant characteristics as an indication of heat tolerance or intolerance and to determine the effect of exogenously applied 2-NOA on plant characteristics under high temperature stress.

MATERIALS AND METHODS

Twenty cultivars of dry or snap beans were used. Three P.I. cultivars (Table 1) received from the USDA Plant Introduction Station, Pullman, WA and 'Bontoc', from Dr. H.M. Munger, Dept. of Plant Breeding and Biometry, Cornell University, Ithaca, NY were included due to their reported heat tolerance. 'Oregon 1604', received from Dr. J.R. Baggett, Dept. of Horticulture, Oregon State University, Corvallis, OR was chosen for its heat intolerance (2). 'UI 111' received from Mr. M. LeBaron, Research-Extension Center, University of Idaho, Kimberly, ID was included as it is an important pinto type grown in Kansas. All other cultivars were received from the Vermont Bean Seed Company, Bomoseen, VT with the exception of 'Bush Blue Lake 290' received from the Asgrow Seed Company, Kalamazoo, MI and 'Aurora' received from Mr. M. LeBaron.

Seeds were planted June 8, 1979 in 5.7 liter pots in a medium composed of silt loam soil: coarse builders vermiculite: sphagnum peat: perlite, 3:2:2:1, and plants were thinned to one per pot at the first true leaf stage. Plants were staked and tied as needed.

A randomized complete block design was used with each treatment replicated six times. Treatments consisted of 5 ppm 2-NOA (recommended concentration for use on dry beans (15)) and 0 ppm auxin as the control. Pots were arranged on a bench 2.4m by 36.5m, each pot spaced on 0.6m centers. Replications ran the length of the bench. Auxin treated plants were removed from the greenhouse when treated to prevent spray drift. To make this removal process feasable, treatments were separated by replication. Odd numbered replications (reps 1,3,5,7,9,11) received the auxin treatment while even numbered replications (reps 2,4,6,8,10,12) served as controls.

Treatments were not randomized within pairs down the temperature gradient of the bench because we expected an abrupt gradient in set of pods with full-sized seed in replications further from the cooling pads, and indeed this was observed.

A temperature gradient of approximately 4°C existed along the length of the bench due to pad and fan installations at opposite ends of the house. The gradient varied from day to day depending on prevailing weather conditions. A gradient of 37-41°C was used in analysis of data as this gradient was typical of those occurring during the study.

All plants were liquid fertilized with 200 ppm N, P_2O_5, K_2O every other day. In addition 10g of 14-14-14 Osmocote was applied to each pot July, 17.

Flowers were removed from all plants at the beginning of the flowering period, July 10-12, due to the absence of high temperature stress conditions at that time. No further flower removal was needed.

Plants were sprayed with the auxin beginning at the half bloom stage, July 18, and treatment continued on a weekly basis for five weeks at which time flowering ceased. Ethanol was used to dissolve the auxin and 'Palmolive' brand dishwashing liquid, 0.5 ml/liter H_2O, was used as a surfactant.

Data was taken on heat related symptoms that developed during the study. Leaflet drop was recorded over a 47-day period beginning July 1 at which time leaflet drop became evident on some cultivars. A stress index was developed to evaluate the effect of heat stress on the foliage. Two heat symptom groups, flecking and russeting, were used to formulate the index. Flecking appeared as small necrotic areas over the entire leaf surface occurring predominately between the major veins. Russeting appeared as reddish necrotic speckling on the upper but not lower leaf surface. The degree of damage for each of these symptoms was scored on a scale of 1-5 with 1 equalling no damage and 5 equalling greater than 50 percent of the leaves affected. The degree to which the affected leaves were damaged was also noted, and each plant was classified as mild or severe in this respect. If damage was mild, the scale value was multiplied by 1 and if severe, the scale value was multiplied by 2 to give weighted score values. All plants were scored by the same investigator on July 20. For each plant the weighted score values for each symptom were added together to obtain the combined value, the stress index, which was used in the statistical analysis.

Upon termination of flowering, Sept. 17, watering of the plants was stopped in order to hasten death and consequent drying. When dry, plants were stripped of leaves; pods, stems, and roots were used to calculate seed weight, number of seeds per pod, number of pods with seed, total pod number, biological yield (16), and harvest index (16). Biological yield, the sum of pod and plant dry weights minus leaf weight, represents the dry matter production ability of a cultivar. Harvest index, the quotient of seed weight divided by biological yield, represents the seed producing efficiency of a cultivar.

RESULTS AND DISCUSSION

Table I shows the mean values per plant for the various plant characteristics. Cultivars have been arranged by seed weight, since this characteristic is the best overall measure of field yield in dry beans. 'Provider' produced the greatest weight of seed and was significantly different from other cultivars with the exception of 'Bush Blue Lake 290'. 'Bush Blue Lake 290' produced significantly more seeds per pod than all other cultivars tested. This cultivar also was greatest in production of pods with seed, followed by 'Provider' and 'Tendercrop'. Although these three cultivars were not significantly different from each other regarding pods with seed, 'Bush Blue Lake 290' and 'Provider' were significantly different from all other cultivars. 'Bontoc' and 'Oregon 1604', the cultivars reported to be heat tolerant and intolerant, respectively (2), were statistically no different from each other for the characteristics seed weight, number of seeds per pod, and number of pods with seed. Both cultivars appeared to be 'average' in their tolerance to the effects of high temperature.

The ability to set pods, even if the pods do not expand, is a necessary but not sufficient factor contributing to increased yield of seed under high temperatures. Total pod number, regardless of pod size, was consequently recorded, since we had previously observed that cultivars can differ markedly in this respect under high temperature stress. PI 300680 and PI 300679 were significantly greater than other cultivars in total pod production although most of the pods expanded only slightly and were either parthenocarpic or contained only partially developed ovules. 'UI 111' showed the least tolerance to the effects of high temperature, as it produced no pods during the course of the study. The poor response of 'UI 111' in these tests suggests that it should be possible to breed a pinto cultivar possessing many of its good features but with greater heat tolerance. Generally speaking, those cultivars showing a bush type growth habit set more pods than did the vine type. Bush type plants set an average of 60 pods per plant while plants having a vine type habit set only 20 pods per plant. This difference in pod setting ability would be expected considering the difference in morphology of the two types. Because of continued vegetative growth the vine type plants would have available less photosynthate for pod production. At maturity nearly all the photosynthate would be available for pod production in the bush type.

The observed inability of pods on PI 300679 and PI 300680 to develop fully at high temperature is not an uncommon phenomenon. Halterlein (2) observed the inability of pods to expand and to accumulate seed weight when P. vulgaris cv. 'Bontoc' and 'Oregon 1604' were grown under continuous high temperature stress (35/20°C day/night). However, plants were found to recover relatively quickly after removal to optimum growing temperature (25/20°C day/night) in terms of pod expansion and seed weight accumulation. Similarily, Stobbe et al. (14) noticed fruit set on P. vulgaris cv. 'Stringless Green Pod' at 35/26°C day/night contained no fully developed ovules, were misshaped, small, and lacked turgidity. Many of these fruits dropped after several weeks.

High temperature is known to affect plant growth adversely by decreasing photosynthetic efficiency. Because it is a measure of photosynthetic efficiency, biological yield is another means of evaluating cultivar tolerance to high temperature stress. PI 300679 was significantly higher in biological yield than other lines with the exception of 'White Marrowfat' and 'Red Kidney'. 'French Horticultural' accumulated the least amount of dry weight over the course of the study.

The greater the proportion of photosynthate a bean plant can transfer into developing seeds, the more efficient it is in terms of grain yield. The harvest index measures this efficiency and showed 'Bush Blue Lake 290' to be significantly higher than all other cultivars.

The stress index did not prove to be as effective in analyzing for heat tolerance as had been anticipated at the time of scoring for it. When evaluating the various heat induced foliar symptoms, we observed striking differences among cultivars and devised the stress index as a means of documenting these differences. However, upon analysis significant differences among cultivars did not occur. PI 199047 had the highest stress index value but it differed significantly from only a few other cultivars.

Leaflet drop was the characteristic which best magnified the differences between bush type and vining types, as affected by high temperature. 'Red Mexican', 'UI 111', and 'Great Northern White', all vining types, were significantly greater in the number of abscised leaflets than other cultivars. PI 199047, a bush type, showed the greatest resistance to leaflet drop. Bush plants dropped an average of 42 leaflets per plant while vines dropped an average of 118 leaflets per plant. This difference undoubtedly results from the much greater ability of vining cultivars to continue to form new leaves throughout the growing season.

Table 2 presents the overall effect of auxin treatment on the various plant characteristics described in this study. Auxin treatment significantly decreased seed weight, number of pods with seed, harvest index, and leaflet drop. The number of seeds per pod and biological yield were decreased by auxin but not significantly so. Pod number was the only variable increased by auxin treatment but this increase was not significant.

When cultivars were considered separately (Table 3) only a small proportion showed a significant response to auxin for the various characteristics. Of those cultivars showing a significant response, almost without exception the auxin caused a decrease in value. The only exception occurred with 'White Marrowfat'. Total pod number on this cultivar was increased by auxin treatment.

It is not clear why the 2-NOA treatment suppressed characteristic values of certain cultivars but one possible answer is that it might have been excessive and therefore toxic. Hardenburg (3) decreased number of pods per plant in *P. vulgaris* using dust applications of alpha-naphthaleneacetic acid at 70-140 ppm. He attributed the decrease in pod set to a toxic effect resulting from an excessive concentration of the auxin.

Cultivar differences in response to the 2-NOA treatment could be due to differences in endogenous auxin levels. A naturally high endogenous auxin content in 'French Horticultural' would explain the toxic effect and resulting reduction in pod number with the addition of an exogenous auxin source. Conversely, a naturally low auxin content in 'White Marrowfat' would explain the increased pod set observed with the application of 2-NOA.

Differences in endogenous auxin levels as affected by changing temperatures might also help explain the inconsistent results obtained when exogenously applied auxins have been used to increase yield in beans. During a period of high temperature, Murneek et al. (8) increased the number of pods per plant on 'Stringless Green Pod' snap beans using 5 ppm 2-NOA. However, application of 2-NOA during more moderate growing conditions resulted in yield decreases due to decreased pod weight. Mehrotra et al. (6) increased the number of pods per plant over control in black gram mung beans (*Vigna mungo*, Hepper.) using spray treatments of 50 ppm 2-NOA during a period of high temperature. The authors hypothesized that an exogenous supply of auxin substitutes for the naturally occurring auxin which becomes limited during adverse weather conditions, thereby increasing pod set over control. While the results of other workers tends to confirm this hypothesis (9,20), the results of Randhawa and Thompson (12) conflict with it.

A temperature gradient of approximately 4°C existed along the length of the bench throughout the study. The gradient used in the statistical analysis, 37-41°C, proved useful in detecting cultivar differences in response to increasing temperature. The average amount of time the temperature exceeded the optimum growing temperature (25°C) was 14.1 hours per day, the length of time varying depending on position along bench. The range for high daily temperature consisted of a low 14°C on August 14 and a high 42°C on September 4 and 5.

The majority of cultivars showed a pattern of decreasing character values with increasing temperature independent of auxin treatment. Table 4 shows regression coefficients for cultivars showing significant response to temperature gradient. A few cultivars showed positive regression coefficients for various characters but none of these values was statistically different from zero. Those cultivars in which increasing temperature had no effect on character value showed low values at lower temperatures making them in actuality extremely heat intolerant. Without exception, significant coefficients were negative in value. Significance resulted due to a pattern of high character value at lower temperatures accompanied by drastic decreases in value with increasing temperatures. A good example of this would be seed weight in 'Provider'. This cultivar showed an 80 percent reduction in seed weight over the first one-third of the gradient (reps 12,11,10 and 9). Thus in actuality, cultivars showing high overall characteristic values displayed no more tolerance to high temperature at the upper end of the gradient than the majority of cultivars.

Smith and Pryor (13) also observed cultivar differences in response to increasing temperatures. They obtained significant negative regression coefficients for percent set in 'Small White' and 'Sutter Pink' but not in 'California Red'.

The results obtained in this study are not necessarily applicable to a field situation. Indeed, the temperatures at which the plants were subjected to were higher and of longer duration than what would normally exist in the field. However, the objective of this study was not to make cultivar recommendations but to screen for heat tolerance. We were able to distinguish differences, some of them dramatic, among cultivars in their response to high temperature. As a result we believe the greenhouse technique to be an effective one for the purpose of screening for heat tolerance in the common bean.

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Table 1. Mean values per plant by cultivar for various plant characteristics.

Cultivar	Habit (bush,b or vine,v)	Seed wt (g, air dried)	No. seeds/pod	No. pods with seed	Total pod no.
Provider	b	3.7	1.4	10.7	59.6
Bush Blue Lake 290	b	2.9	1.9	11.1	16.0
Jacobs Cattle	b	2.2	1.1	5.7	69.0
Black Turtle Soup	v	1.4	1.2	7.0	35.5
Aurora	v	1.3	1.2	3.9	4.3
Tendercrop	b	1.3	1.0	8.8	66.4
PI 300680	b	1.3	0.9	5.2	161.4
Great Northern White	v	1.2	0.5	4.3	10.6
PI 300679	b	1.2	0.8	5.8	127.0
PI 199047	b	1.1	1.1	5.2	80.4
Bontoc	b	1.0	0.9	5.4	48.0
Oregon 1604	b	0.8	1.0	5.0	28.7
French Horticultural	b	0.8	0.6	2.9	45.2
Lowe's Champion	b	0.7	0.7	2.9	62.1
Red Mexican	v	0.3	0.4	2.4	39.4
Red Kidney	b	0.3	0.5	2.5	18.3
White Marrowfat	v	0.2	0.3	1.5	33.3
Vermont Cranberry	b	0.1	0.1	1.4	25.7
Cherokee Wax	b	0.0	0.0	0.0	38.7
UI 111	v	0.0	0.0	0.0	0.0
LSD 5%		1.2	0.5	3.1	25.0

Table 1. (continued)

Cultivar	Habit (bush,b or vine,v)	Biological yield (g)	Harvest index	Stress index	Leaflet drop number
Provider	b	21.8	0.14	6.8	44.2
Bush Blue Lake 290	b	11.0	0.23	7.4	39.8
Jacobs Cattle	b	18.9	0.11	7.4	32.0
Black Turtle Soup	v	24.4	0.05	7.1	67.2
Aurora	v	24.8	0.04	7.6	96.2
Tendercrop	b	17.4	0.07	7.0	28.1
PI 300680	b	22.1	0.06	6.3	26.0
Great Northern White	v	20.2	0.05	5.2	142.0
PI 300679	b	29.4	0.03	5.7	53.8
PI 199047	b	18.1	0.06	8.1	22.5
Bontoc	b	22.8	0.04	6.4	34.3
Oregon 1604	b	9.9	0.07	7.5	44.8
French Horticultural	b	9.6	0.06	7.6	66.0
Lowe's Champion	b	18.9	0.04	4.8	31.9
Red Mexican	v	21.0	0.01	7.0	162.0
Red Kidney	b	28.0	0.01	5.7	81.6
White Marrowfat	v	28.6	0.01	5.5	95.0
Vermont Cranberry	b	14.5	0.00	5.0	23.4
Cherokee Wax	b	18.9	0.00	5.9	64.4
UI 111	v	25.2	0.00	7.6	146.9
LSD 5%		4.0	0.05	1.5	22.9

Table 2. Overall effect of auxin treatment on various plant characteristics.

Treatment	Mean value per plant	Treatment	Mean value per plant
Seed weight (g)		Biological yield (g)	
Control	1.4a[z]	Control	21.4a
Auxin	0.8b	Auxin	19.1a
No. of seeds/pod		Harvest index	
Control	0.8a	Control	0.07a
Auxin	0.7a	Auxin	0.04b
No. of pods w/seeds		Leaflet drop	
Control	5.5a	Control	62.5a
Auxin	4.0b	Auxin	43.3b
Total pod number			
Control	46.4a		
Auxin	50.3a		

[z]Mean separation by Duncan's multiple range test, 5% level.

Table 3. Mean values per plant showing significant differences for various plant characteristics as affected by auxin treatment.

Cultivar	Control	Auxin	LSD 5%
Seed weight (g)			1.4
Provider	4.8	2.6	
Jacobs Cattle	3.3	1.1	
No. of seeds/pod			0.5
Provider	1.7	1.1	
Jacobs Cattle	1.4	0.9	
No. of pods w/seed			3.1
Tendercrop	12.5	5.2	
Jacobs Cattle	7.8	3.7	
PI 300679	7.5	3.8	
French Horticultural	4.6	1.5	
Total pod number			25.0
French Horticultural	64.0	30.0	
White Marrowfat	19.3	50.2	
Biological yield (g)			4.5
Red Kidney	30.9	25.1	
UI 111	27.4	22.9	
Aurora	27.4	22.2	
Jacobs Cattle	22.1	15.7	
French Horticultural	12.5	7.2	

Table 3. (continued)

Cultivar	Control	Auxin	LSD 5%
Harvest index			0.05
Bush Blue Lake 290	0.27	0.20	
Provider	0.19	0.09	
Jacobs Cattle	0.15	0.07	
Tendercrop	0.10	0.04	
French Horticultural	0.09	0.03	
Leaflet drop			20.4
Red Mexican	162.1	72.5	
Great Northern White	126.0	73.3	
Aurora	87.1	59.5	
Red Kidney	80.6	57.5	
Black Turtle Soup	69.0	43.5	
Oregon 1604	56.0	31.5	
Jacobs Cattle	43.3	18.8	

Table 4. Regression coefficients for cultivars showing significant response[z] to temperature gradient.

Cultivar	Control	Auxin
Seed weight		
Provider	-1.12	-1.13
Great Northern White	-0.52	-0.51
PI 300680	-0.44	-0.44
Aurora	-0.43	-0.43
Black Turtle Soup	-0.43	-0.43
No. of seeds/pod		
Aurora	-0.28	-0.28
Black Turtle Soup	-0.27	-0.28
Great Northern White	-0.23	-0.23
PI 300680	-0.16	-0.16
Provider	NS	-0.15
No. of pods w/seed		
Provider	-2.62	-2.55
Black Turtle Soup	-1.87	-1.81
Great Northern White	-1.47	-1.40
PI 300680	-1.27	-1.19
Oregon 1604	-1.22	-1.14
PI 300679	-1.13	NS
Total pod number		
Red Mexican	-12.13	-10.96
PI 300679	-10.53	- 9.51

Table 4. (continued).

Cultivar	Control	Auxin
Biological yield		
Aurora	-2.62	-2.73
PI 300679	-2.08	-2.13
Provider	-1.83	-1.88
PI 199047	-1.39	-1.48
Red Kidney	-1.38	-1.50
Harvest index		
Provider	-0.03	-0.04
Great Northern White	-0.02	-0.02
Oregon 1604	-0.02	-0.02
PI 300680	-0.02	-0.02
Bush Blue Lake 290	-0.02	-0.02
Jacobs Cattle	-0.01	-0.02
Leaflet drop		
Great Northern White	-13.70	-12.09
Red Mexican	-12.11	-10.85
UI 111	-11.27	- 9.27
Oregon 1604	- 6.36	NS
Provider	- 6.23	NS
Aurora	- 6.13	NS

[z]Significance level, P = .05.

APPENDIX

EFFECT OF HIGH TEMPERATURE STRESS ON YIELD AND YIELD RELATED PROCESS IN GRAIN LEGUMES

As a result of studies on blossom drop and pod set in lima beans, Cordner (3) proposed a 'capacity set theory' in which bean plants produce many times more reproductive structures than they are able to maintain through fruit maturation. Fruit setting occurs until a capacity set is attained; the remaining reproductive structures disposed of by abscission. His results showed air temperature and low humidity (external factors) to be negatively correlated with blossom abscission. He concluded that potential yield of lima bean plants depends upon the number of racemes (associated with plant size) and the average set of the racemes. Plant size is a product of the environment before flowering while pod set is the product of the environment during flowering.

In a greenhouse study designed to evaluate the effects of high temperature on yield of bush snap beans, Mack and Singh (16) significantly lowered number of pods per plant and percent set after exposing plants to temperatures of 100-107°F for 5 days, 2 days after first bloom. Plants exposed to the same high temperature treatment 7 days after first bloom were not significantly affected. In a separate field study in which perforated plastic covered cages were used to produce high temperatures, yield was reduced 67 percent by the highest maximum temperature (101°F) and least 22 percent by the lowest maximum temperature (84°F).

Fattah and Wort (5) studied the effect of different light and temperature regimes on vegetative and reproductive growth of bush beans. Light intensities consisted of 16.1, 10.76, and 5.38 k-lux while day/night temperatures consisted of 26/21, 26/26, and 15/15°C. High or medium light intensities coupled with high temperature were necessary for significant increase in total pod number per plant. Pod weight per plant was significantly increased at the two higher light intensities regardless of temperature while plants grown under low light lacked significance.

Studying the effects of maximum temperature on flowering and seed production in P. vulgaris, Smith and Pryor (27) obtained significant negative correlations between percent set and maximum temperatures the day before, the day of, and the day after bloom in 'Small White' and 'Sutter Pink' but not in 'California Red'. Negative correlations between maximum temperature and seed per pod were significant only in 'Sutter Pink'. Seeds per pod in 'California Red' were not affected by temperature. 'California Red' gave the highest yields, highest percent set, and highest seeds per pod.

In a study designed to investigate the effect of environmental factors on pod set and yield of white pea beans, Davis (4) showed temperature to be the climatic factor which exerts the strongest influence on pod set, with humidity exerting only minor influence. According to Davis, approximately 57 percent of the blossoms will set pods if the average maximum temperature for any two consecutive days during the blooming period does not exceed $75^{\circ}F$. For each degree above $75^{\circ}F$ a reduction of approximately 2 percent in pod set will result. Individual plants grown in the field had an average of 31 times more beans and 7 times more leaf area than plants grown in the greenhouse. Contrary to field results, no significant correlation occurred between maximum temperature and percent pod set in the greenhouse. In view of the results, Davis questioned the assumption that results obtained in the greenhouse are applicable under field conditions.

In a study to evaluate the yielding ability of a heat tolerant P. vulgaris cultivar, 'Bontoc' and a heat intolerant cultivar, 'Oregon 1604' following a prolonged period of heat stress, Halterlein (8) observed 'Bontoc' to set more pods on plants grown under high temperature conditions (35/20°C day/night) as compared with pod set on plants grown for 10 days at 35/20°C and then removed to optimum growing temperature (25/20°C day/night). For 'Oregon 1604' pod set was comparable in both temperature regimes. Under continuous heat stress, pods did not expand and there was no accumulation in seed weight. However, both cultivars were found to recover relatively quickly after removal to optimum growing temperature in terms of pod expansion and seed weight accumulation. Under continued high temperature conditions 'Bontoc' set 63 percent of its pods while 'Oregon 1604' set only 27.1 percent suggesting 'Oregon 1604' was more sensitive to heat stress.

Vigilierchio and Went (31) studied growth and fruiting of _P. vulgaris_ cv. 'Kentucky Wonder' under controlled environmental conditions. They observed spindly growth, development of small pale leaves and the absence of flowering on plants grown at 30/24°C day/night temperatures with an 8 hour photoperiod. Plants grown under long-day conditions (14 hrs) grew faster than those under short days (8 hrs). Leaf number increased with increased night temperature while leaf drop initiated from plants under short days at high day and night temperatures. Cyclic fruit production occurred with the frequency of the cycle being increased with night temperature and photoperiod and the amplitude increased with photoperiod. The authors theorized that a limited sugar supply, resulting from high night temperature, would lessen the bud initiation period thus shortening the cycle between harvest. Seeds per pod had no apparent correlation to either temperature or photoperiod variations.

Stobbe et al. (28) studied the influence of temperature on the blossoming and fruit setting patterns in P. vulgaris cv. 'Stringless Green Pod'. Two cycles (blossoming and fruit set) occurred during 60 days at 24.0/15°C and three cycles at 29.5/21.0°C but no definite cycle at 35.0/26.5°C day/night temperatures. When green immature fruit were removed plants remained vigorous, but when fruit were harvested at maturity only one blossoming cycle occurred followed by senescence of the entire plant. Senescence was delayed at the high temperature due to a lack of fruit set until 36 days after initial blossoming. The fruit set at 35.0/26.5°C contained no fully developed ovules, were misshaped, small, and lacked turgidity. Many of these fruits dropped after several weeks. The authors suggest the possibility of sufficiently high auxin levels in fruit of plants grown at high temperatures to prevent the abscission of young fruit even though ovule development does not occur.

Ormrod et al. (25) subjected P. vulgaris cv. 'Stringless Green Pod' to a wide range of temperatures for the purpose of studying the effect of temperature on embryo sac development and flowering. The highest temperature regime at which flowering occurred, 35/26.5°C day/night, resulted in a lower proportion of normal embryo sacs due to degenerated contents within 48 hours after anthesis. The authors concluded that temperature does have an effect on embryo sac development and the almost complete lack of fruit set found at 35/26.5°C can be related to the degeneration of the embryo sac contents beginning approximately at anthesis.

In a study to investigate the influence of high temperature on blossom abscission in dry beans, Ahmadi (1) showed the temperature optimum for pollen grain germination to be 15°C and the critical temperature to be 30°C. Anatomical studies on abscissed blossoms from plants grown at 90°F showed that the blossoms were not fertilized.

In a study on the fertility of pollen, Inoue and Shibuya (10) reported bean pollen as having marked reduction in germination above 25°C, with temperatures above 35°C causing severe reduction in germination. Optimum humidity for pollen germination of beans was shown to be 80 percent.

Studying the effect of high temperatures on pollen grain viability and pollen tube growth in the common bean *P. vulgaris*, Halterlein (7) showed stress temperatures (35/20°C, day/night or 35°C constant) to reduce the percentage of viable pollen for a diversity of cultivars compared with an optimal growing temperature (25/20°C day/night). Cultivar differences were apparent in response to temperature. A net increase in viable pollen grain production at high temperature occurred due to the much larger increase in number of pollen grains produced. Temperature did not reduce the ability of pollen tubes to grow to the base of the style. The authors concluded that the high temperature effect on pollen and pollen tube growth does not play a significant role in the failure of beans to set pods.

In reviewing the literature concerning the adverse effects of temperature on growth and development, Bonner (2) explains how in particular instances damage done by high temperature is due to excessive destruction of particular chemical substances and the inability of the plant to synthesize the chemical in question quick enough to replace that which is destroyed. If the plant can be exogenously supplied with the limiting compound it can be kept from dying. Adenine, amino acids, and vitamins of the B complex are some of the organic compounds that may become limiting with exposure of plants to high temperature.

Ketellapper (13) counteracted the adverse effects of high temperature stress on broadbean (*Vicia faba* L.) and pea (*Pisium sativum* L.) with the application of vitamin C to broadbean and sucrose, vitamin B, or riboside mixture to pea. Since the applied substances did not promote growth at the optimal temperature, 30/23°C and 26/17°C day/night temperature for broadbean pea respectfully, the author concluded that at least part of the growth response to temperature is caused by a temperature induced shortage in one or a few essential metabolites.

Ordin et al. (24) decreased synthesis of lipid and β-glucan and decreased leaf growth by heat treating primary leaves of 8-day-old P. vulgaris plants in water at 46.5 to 47.5°C for two minutes. Upon cooling, synthesis of lipid and cellulose (synthesized from glucan units) increased with time. Leaf growth slowly recovered, with growth reaching 68 percent that of control after 36 hours. According to authors the observed temperature effects are most likely due to the reversibility of enzyme denaturation.

Kuiper (15) studied the response of adenosine triphosphatase of bean roots at various temperatures for the purpose of correlating ATPase activity with water uptake. The activities of the membrane-bound ATPase of the root cell wall, mitochondria, and microsomal fractions showed high Q_{10} values in the low temperature range (0-10°C) and low Q_{10} values at the high temperature range (30-40°C) thus correlating decreased ATPase Q_{10} values with rising temperature. Since temperature has a marked effect on water uptake in bean roots and since enzyme activity is known to be affected by temperature, Kuiper suggested that the lack of water transport through root cell membranes at high temperatures is due to a lack of energy obtained from the hydrolysis of ATP by ATPase.

Yarwood (35), after subjecting P. vulgaris plants to various time/temperature treatments for the purpose of developing heat tolerance, concluded that exposure of plants to 50°C for 25 seconds was optimum for development of acquired heat tolerance, which was based on observed injury to treated leaves. Successive treatment of plants for 20 seconds at 50°C over a period of time raised the acquired heat tolerance only slightly above that acquired from a single treatment. The exposure time required for a 50 percent reduction in fresh weight decreased with increasing temperatures.

After exposing purified fractions of malic dehydrogenase extracted from high temperature hardened and unhardened leaves of _P. acutifolius_ to temperatures ranging from 30 to 62°C for 15 minutes, Kinbacher et al. (14) observed signficantly greater thermostability in heat hardened extracts than in extracts from unhardened tissues. The extracts from hardened tissue also exhibited a significantly higher specific activity over a wide pH range than the extracts from unhardened tissue. These results indicate enzyme denaturation is an important factor in heat tolerance.

After heat treating the root systems of _P. vulgaris_ cv. 'Great Northern' for two minutes at temperatures of 24, 40, and 47.5°C, Itai et al. (11) found the amount of abscisic acid in shoot xylem exudate of plants treated at 47.5°C to be higher than that found in plants treated at reduced temperatures. Cytokinin activity along with shoot and root growth were reduced as a result of heat treatment.

EFFECT OF AUXIN ON YIELD AND YIELD RELATED PROCESSES IN GRAIN LEGUMES

Murneek et al. (22) treated 'Stringless Green Pod' bush beans with 5 and 10 ppm 2-naphthoxyacetic acid (2-NOA) every second and fifth day respectfully. Spray applications during hot environmental conditions increased pods per plant, total pod weight, and leaf chlorophyll content but decreased the number of seeds per pod. The 5 ppm concentration proved to be most efficient. Application of 2-NOA during more moderate growing conditions resulted in yield decreases due to decreased pod weight.

Stoffella and Clayberg (29) significantly decreased percent daily flower abscission on 'Bontoc' a heat tolerant _P. vulgaris_ line using various concentrations of 4-chlorophenoxyacetic acid and 2-NOA. Auxin applications did not significantly alter percent daily flower abscission on 'Oregon 1604' a heat intolerant line. Five ppm 2-NOA increased pod and seed weight and seed no. for both lines, although not significantly so. The authors suggested insignificance resulted due to high environmental variation.

Randhawa and Thompson (26) increased early yield of snap beans using various concentrations of 2-NOA, para-chlorophenoxyacetic acid, a-o-chlorophenoxypropionic acid and 2,4,5-trichlorophenoxyacetic acid. Increase in total yield was obtained only by the application of p-CPA at 2 ppm applied twice a week to fall crop. Spraying the plants with 2-NOA at 5 ppm and with 2,4,5-T in concentrations varying from 2 to 20 ppm depressed total yield in comparison with control. Decreased yield was due to fewer number of pods produced.

Mitchell and Marth (21) retarded maturation, increased average fresh weight per pod and reduced the number of seeds per pod after dip treating 'Black Valentine' snap bean fruit in 4-chlorophenoxyacetic acid at 100 ppm four days before usual harvest. On a dry-weight basis, application of the acid brought about a decrease of 22 percent in final seed weight, but the dry hull weight of treated fruits was 14 percent heavier than that of untreated fruits at maturity. Spray applications of the growth regulator at concentrations ranging from 250 ppm to 1000 ppm to attached fruit reduced the final yield of fresh fruit.

Wittwer and Murneek (34) increased snapbean yield by 40 percent over control using p-CPA at 2 ppm applied weekly during a period of excessively high temperatures. Treatment with 10 ppm 2-NOA during the same period decreased total pod production. The increased yield from p-CPA treatments was due to a greater set of pods, but pod size and seed number were decreased.

In a greenhouse study using P. vulgaris cv. 'Red Kidney', Stromme and Hamner (30) observed a greater amount of fruit set on plants treated with 2,4-dichlorophenoxyacetic acid at 10 ppm, but of the fruits that actually developed there was no significant difference between treated and untreated plants. At harvest time 2,4-D treated plants carried a significantly higher number of leaves per plant. In a separate field study, plants sprayed with 1, 10, and 100 ppm 2,4-D were statistically no different from untreated plants in total pod production although plants treated with 100 ppm showed marked delay in maturity.

Hardenburg (9) decreased the average number of pods per plant on several varieties of Phaseolus vulgaris using a dust preparation of 'Parmone' - naphthaleneacetic acid (NAA) at 70 - 140 ppm applied weekly. He attributed the decrease in pod set to a toxic effect resulting from an excessive concentration of the hormone. In another experiment no significant difference in yield occurred when dry pea bean seed were treated with 'Rootone' - indolebutyric acid (IBA).

Marth and Wester (17) treated Fordhook 242 lima beans with 2,4,5-T at 1.5 and 3 ppm during the early flowering period. Shortly after treatment plants dropped the majority of their flowers and ceased vegetative growth for a period of 20 to 30 days. Upon resumption of growth, vegetative growth was increased by as much as 213 percent and marketable pod number by as much as 35 percent over that of untreated plants.

Performing controlled cross-pollination in lima bean, Wester and Marth (33) increased pedicel diameter of mature pods with an increase in the number of successful crosses from 18.7 percent to 28.8 percent using a mixture of 0.8 percent IBA, 0.2 percent p-CPA, and 3 percent glycerine introduced into a small wound at the base of the flowers. The growth regulator mixture also caused a significant increase in the average number of seed per pod, from 1.95 to 2.43, and doubled the number of seeds per pollination.

Wester and Marth (32) were unsuccessful increasing yield of bush lima beans using NAA. Under good environmental growing conditions applications of NAA in spray or dust at various concentrations had no significant effect on total yield of fresh marketable pods of Fordhook bush lima beans. In another study, a dust preparation of NAA at 50 ppm had no significant effect on yield of fresh marketable pods of 13 varieties of bush lima beans.

Mehrotra et al. (18) increased number of pods per plant over control by 26, 18 and 18 percent respectively in black gram mung beans using spray treatments of 2-NOA at 50 ppm, p-CPA at 5 ppm, and 2-NOA + p-CPA at 50 ppm. Although some increase was evident, seeds per pod was not significantly influenced by differential hormone treatments. Plants sprayed with 2-NOA, p-CPA, p-CPA + 2-NOA, or 1-NAA increased seed yield by 48, 35, 32, and 27 percent, respectively. The authors hypothesized that an exogenous supply of auxin substitutes for the naturally occurring auxin which becomes limited during adverse weather conditions thereby increasing pod set over and above control.

Ohki and McBride (23) observed floral and pod abscission on 'Amsoy' soybean to be significantly increased under high temperature (32/24°C day/night) and high soil moisture conditions. Under these environmental conditions using 2,3,5-triiodobenzoic acid at 25 ppm applied at first flowering, they increased pod dry weight more than double that of untreated plants. Increase in yield resulted due to a retention of a greater number of pods. TIBA proved most effective in reducing floral and pod abscission under high temperature and soil moisture conditions.

Mitchell et al. (20) studied starch hydrolysis in leaves of P. vulgaris sprayed with NAA. Treatment of attached leaves with a one-percent NAA-lanolin and water emulsion decreased the percentage starch and dextrin and increased sugar content more rapidly than control leaves when plants were placed in darkness. Leaves low in carbohydrate content as a result of being kept in darkness accumulated less carbohydrate when treated with NAA and illuminated than did comparable untreated leaves. The authors suggested the hydrolysis of reserve carbohydrate to more readily metabolized forms might explain one of the mechanisms by which NAA affects cell metabolism and associated meristematic activity.

Mitchell (19), after applying an NAA and lanolin mixture to the first internode of P. vulgaris plants, observed a lower percentage of starch, dextrin and sugar in plant structures below treatment site than in comparable parts of controls. These results showed leaves to be photosynthetically active, but synthate was not readily transported to lower portions of plants. In relation to the entire plant, the amount of solid matter synthesized by treated plants was less. All portions, except the primary leaves of treated plants, contained a lower percentage of starch, dextrin, and sugar than did controls. No difference in nitrogen content occurred due to treatment.

Fisher et al. (6) used a dust formulation of NAA and 2,4-D at 10 ppm to reduce abscission of leaves and petioles on P. vulgaris after exposure for a day at 84 to 86°F in an atmosphere containing various gasses known to cause abscission. In the field, pod number was increased by 24 percent over control with two applications of dust containing NAA at 40 ppm, but was decreased with dusts at 160 ppm. Increase in yield was due to a greater number of small high grade beans rather than to larger beans.

Jackson and Osborne (12) studied the effect of auxin and ethylene on Phaseolus vulgaris explant abscission. Abscission was shown to be initiated by a peak in ethylene production during senescence of pulvinar tissue distal to the separation zone. Applications of IAA to the distal end of explants extended the initial period of insensitivity to ethylene. The authors suggest the presence of an auxin-ethylene balance mechanism in the separation zone controlling abscission. The balance would remain in favor of auxin until endogenous levels are sufficiently depleted to allow any ethylene present to initiate irreversibly the biochemical changes leading to final separation.

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EVALUATION OF BEAN CULTIVARS UNDER HIGH TEMPERATURE STRESS

BY

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Twenty cultivars of Phaseolus vulgaris L. were studied in the greenhouse under high summer temperature conditions to determine the effect of high temperature stress on various plant characteristics as an indication of heat tolerance or intolerance. The influence of auxin on these plant characteristics under high temperature was determined by treatment of half of the replicates with 5 ppm (2-naphthoxy)-acetic acid. 'Provider' and 'Bush Blue Lake 290' showed the greatest tolerance and 'UI 111' the least to the effects of high temperature on seed yield. When cultivars were pooled, auxin significantly reduced seed weight, number of pods with seeds, harvest index, and leaflet drop. When cultivars were considered separately, only a small proportion were significantly affected for these characteristics by the auxin treatment. All cultivars showed a pattern of decreasing values for all characteristics with increasing temperature regardless of auxin treatment. Cultivar differences in response to temperature gradient were evident.