Photoperiod Responses of *Phaseolus* Plant Introductions in Hawaii[1]

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Abstract. Tropical lines of *Phaseolus spp.* planted in Hawaii in spring or early summer included types which bloomed in the usual 30–45 days and types which did not bloom until days had begun to shorten in the fall. Short-day types bloomed at daylengths between 11¾ and 13¼ hr, with the majority blooming between 12½ and 13 hr. *P. vulgaris, P. lunatus,* and *P. calcaratus* included both short-day and day-neutral types. All lines of *P. aconitifolius, P. acutifolius,* and *P. angularis* were day-neutral. Single lines of *P. erythroloma* and *P.* cf. *stenolobus* were short-day, and single lines of *P. pilosus, P. radiatus,* and *P. bracteatus* were day-neutral.

Introduction

In recent years the United States Department of Agriculture has placed increasing emphasis on the introduction of species of *Phaseolus,* particularly from Latin America, their center of origin (5). Unlike cultivars grown in temperate regions, many tropical lines will flower only under short-day conditions. At Pullman, Washington, the location of the Regional Plant Introduction Station with primary responsibility for increasing and distributing bean introductions, inductive daylengths occur too late in the growing season to permit seed production of short-day lines. For this reason, Western Regional Project W-6 has supported a project to grow beans in Hawaii, since short-day types will flower in the winter when the temperature is still favorable for growth and maturation of the seed.

Photoperiod responses in various *P. vulgaris* cultivars adapted to the temperate zone have generally been found to be absent or of a quantitative nature in which flowering is delayed under increased lengths of photoperiod (1, 2, 3, 4). Allard and Zaumeyer (1) subjected to various photoperiods 79 lines of *P. vulgaris* L., 11 lines of *P. lunatus* L. (lima bean), 1 line of *P. coccineus* L. (scarlet runner bean), 1 line of *P. aconitifolius* Jacq. (moth bean), 1 line of *P. acutifolius* var. *latifolius* G. Freeman (tepary bean), 1 line of *P. angularis* (Willd.) W. F. Wight (adzuki bean), 1 line of *P. aureus* Roxb. (mung bean), 1 line of *P. calcaratus* Roxb. (rice bean), and 2 lines of *P. mungo* L. (urd bean). They classified 25 of the *P. vulgaris* lines tested as short-day, and 54 as day-neutral. All lima beans were day-neutral. *P. coccineus* was a long-day species and all others were short-day except for one strain of *P. mungo,* which was day-neutral. All classifications were based on whether flowering was delayed under longer or shorter photoperiods.

Although Allard and Zaumeyer thoroughly surveyed the cultivars of *P. vulgaris* and *P. lunatus* in the United States in the early 1940's, their materials would not be expected to represent the range of photoperiod responses possible in any of the species reported here. Cultivars with a strong short-day response would not be successful in most parts of the United States, because they would not bloom early enough to mature before frost in the fall of the year. Other than *P. vulgaris* and *P. lunatus,* only 1 or 2 lines of each species were tested. Growing numerous tropical lines of most of these species in Hawaii has made it possible to detect different responses within some of the species, as well as to estimate the critical daylength required for flowering in the short-day types.

Materials and Methods

Lines of *Phaseolus* from the Regional Plant Introduction Station at Pullman, Washington were planted directly in the field at the Manoa Experimental Farm in Honolulu. Since the only information transmitted from Pullman is the species and country of origin, and since growth and seed production are usually better in the summer, the seeds were planted as soon as possible after receipt. This paper reports the blooming dates (date of first open flower) of lines included in 2 plantings, one on July 15, 1965, and the other on May 1, 1967. In both plantings there were a large number of lines which bloomed in the usual 30–45 days from planting and were presumably day-neutral, and others which did not bloom until the days had become shorter in the fall and were considered to be short-day types. Also reported are some lines planted January 24, 1967 which bloomed for a short period in the spring, and then stopped blooming during the summer. New blooming dates in the fall were not recorded for those lines still alive, however.

In Honolulu (Lat. 21° N) the daylength, including civil twilight, when the sun is 6° below the horizon, varies from a little more than 14 hr in June to a little less than 12 hr in December. The daylengths and temperatures for the period when the short-day lines bloomed (September 1 to November 20) are given in Table 1. The mean temperature varied from 75.9° to 81.7° F during the 2 years covered in this table.

Included in the 2 plantings were the following numbers of *Phaseolus* lines: *P. aconitifolius*-19, *P. acutifolius*-9, *P. angularis*-12, *P. bracteatus*-1, *P. calcaratus*-17, *P. erythroloma*-1, *P. lunatus*-120, *P. pilosus*-1, *P. radiatus*-1, *P. vulgaris*-126. All lines of *P. aconitifolius* and *P. angularis* were bushes. All other lines were vines except for 8 lines of *P. vulgaris,* P.I. Nos. 282,005; 282,007; 282,093; 282,100; 282,101; 282,105; 282,117; 298,108.

Table 1. Daylengths (including civil twilight) and temperatures at Honolulu (Lat. 21° N) from September 2 to November 13.

Date	Daylength (hr)		Maximum[a] Temp.	Mean[a] Temp.	Minimum[a] Temp.
September 2	13¼	1965	84.7	77.9	71.1
		1967	89.5	81.5	73.5
September 15	13	1965	86.6	79.7	72.7
		1967	89.4	81.7	73.9
September 29	12¾	1965	86.3	78.9	71.5
		1967	88.9	80.9	72.9
October 13	12½	1965	85.4	78.4	71.4
		1967	86.6	78.9	71.2
October 27	12¼	1965	84.0	75.9	67.7
		1967	86.1	79.3	72.4
November 13	12	1965	81.6	76.4	71.2
		1967	83.8	76.9	69.9

[a]Average for 2-week period.

[1]Received for publication December 18, 1968. Published with the approval of the Director of the Hawaii Agricultural Experiment Station as Journal Series No. 1057.

Table 2. Daylengths (including civil twilight) at which *Phaseolus vulgaris* lines bloomed.

12 hours		12¼ hours		12½ hours		12¾ hours		13 hours		13¼ hours		Day neutral	
P.I. No.	Origin	P.I. No.	Origin	P.I. No.	Origin	P.I. No.	Origin	P.I. No.	Origin	P.I. No.	Origin	P.I. No.	Origin
298,822[a]	Peru	291,006	Peru	203,916	Mexico	202,081	Mexico	202,831	Mexico	202,832[c]	Mexico	150,414	El Salvador
298,824[a]	Peru	298,821[a]	Peru	203,921	Mexico	203,914	Mexico	203,919	Mexico	202,834[c]	Mexico	193,672	Ethiopia
		304,109[b]	El Salvador	203,923	Mexico	203,924	Mexico			282,095[c]	Chile	201,489	Mexico
				290,998	Peru	290,999	Peru			282,106[c]	Chile	204,963	Guatemala
				291,001	Peru					282,112[c]	Chile	205,358	Guatemala
				291,002	Peru					291,005	Peru	205,361	Guatemala
										304,115[c]	El Salvador	209,621	Cuba
										304,118[c]	El Salvador	282,002	Chile
												282,005	Chile
												282,007	Chile
												282,067	Chile
												282,092	Chile
												282,093	Chile
												282,094	Chile
												282,099	Chile
												282,100	Chile
												282,101	Chile
												282,104	Chile
												282,105	Chile
												282,108	Chile
												282,109	Chile
												282,111	Chile
												282,115	Chile
												282,117	Chile
												298,104–298,114	Brazil
												304,108	El Salvador
												304,116	El Salvador
												304,117	El Salvador
												304,119	El Salvador

[a]Related lines 298, 819, 820, 823 died before blooming.
[b]Did not bloom before plowed up October 25.
[c]Possibly day-neutral.

Table 3. Daylengths (including civil twilight) at which *Phaseolus lunatus* lines bloomed.

12¼ hours		12½ hours		12¾ hours		13 hours		13¼ hours		Short-day[a]		Day-neutral	
P.I. No.	Origin	P.I. No.	Origin	P.I. No.	Origin	P.I. No.	Origin	P.I. No.	Origin	P.I. No.	Origin	P.I. No.	Origin
299,386	Brazil	186,986	Gold Coast	195,342	Guatemala	194,314	Ethiopia	249,027	Nigeria	249,026	Nigeria	164,891	Guatemala
		188,697	Africa	249,020	Nigeria	195,339	Guatemala	249,030	Nigeria	249,029	Nigeria	180,324	India
		195,344	Guatemala	249,024	Nigeria	249,031	Nigeria	249,034	Nigeria	249,032	Nigeria	189,070	Belgian Congo
		195,345	Guatemala	249,025	Nigeria	249,047	Nigeria	249,040	Nigeria	249,037	Nigeria	209,051	Cuba
		249,021	Nigeria	249,035	Nigeria	249,056	Nigeria	249,041	Nigeria	249,045	Nigeria	214,170	India
		249,022	Nigeria	249,049	Nigeria	249,059	Nigeria	249,043	Nigeria	249,046	Nigeria		
		249,023	Nigeria	249,053	Nigeria	256,399	El Salvador	249,048	Nigeria	249,050	Nigeria		
		249,028	Nigeria	249,061	Nigeria	256,404	El Salvador	249,057	Nigeria	249,054	Nigeria		
		249,033	Nigeria	249,066	Nigeria	256,848	Peru	249,063	Nigeria	249,058	Nigeria		
		249,036	Nigeria	256,382	El Salvador	299,385	Brazil	309,694	Mexico	249,062	Nigeria		
		249,038	Nigeria	256,384	El Salvador	310,620	Guatemala			256,383	El Salvador		
		249,039	Nigeria	256,386	El Salvador					256,385	El Salvador		
		249,042	Nigeria	256,387	El Salvador					256,407–256,422	Costa Rica		
		249,044	Nigeria	256,388	El Salvador					256,423	El Salvador		
		256,393	El Salvador	256,389	El Salvador					256,804	Colombia		
		256,397	El Salvador	256,390	El Salvador					256,805	Colombia		
		299,381	Brazil	256,392	El Salvador					256,806	Colombia		
		299,383	Brazil	256,395	El Salvador					256,807	Colombia		
		299,384	Brazil	256,396	El Salvador					256,808	Colombia		
		299,387	Brazil	256,398	El Salvador					256,810	Colombia		
		299,388	Brazil	256,400	El Salvador					256,811	Colombia		
		299,389	Brazil	256,401	El Salvador					256,812	Ecuador		
		310,623	Guatemala	256,402	El Salvador					256,815–256,822	Ecuador		
		310,625	Guatemala	256,403	El Salvador					256,823–256,847	Peru		
		310,626	Guatemala	256,405	El Salvador					256,849	Peru		
				256,406	El Salvador					256,850	Peru		
				299,382	Brazil					306,196	Peru		
				310,621	Guatemala					306,197	Peru		
				310,622	Guatemala					306,198	Peru		
				310,624	Guatemala								
				310,627	Guatemala								

[a]Short-day, but daylength requirement not determined.

Table 4. Daylengths (including civil twilight) at which *Phaseolus calcaratus* lines bloomed.

12 hours		13 hours		13¼ hours		Day neutral	
P.I. No.	Origin	P.I. No.	Origin	P.I. No.	Origin	P.I. No.	Origin
195,331	Guatemala	194,783	India	208,460	India	247,686	Belgian Congo
304,149	Honduras					247,687	Belgian Congo
311,156	Guatemala					247,688	Belgian Congo
311,157	Guatemala					247,689	Belgian Congo
						247,690	Belgian Congo
						247,691	Belgian Congo
						247,692	Belgian Congo
						247,693	Belgian Congo
						251,948	Belgian Congo
						286,299	Ivory Coast
						286,300	Ivory Coast

Results

In Tables 2, 3, and 4 are listed the lines of *P. vulgaris, P. lunatus,* and *P. calcaratus* which bloomed at various daylengths. All 3 species included both short-day and day-neutral lines. No *P. vulgaris* or *P. lunatus* lines from temperate areas are listed, because all these lines have shown a day-neutral response under Hawaiian conditions. All of the *P. vulgaris* lines were planted July 15, 1965. There was thus a small amount of overlap between late-blooming day-neutral lines and the short-day lines which bloomed under 13¼ hr daylengths. All the rest of the lines except the *P. lunatus* from Brazil were planted May 1, 1967. In this planting there was no overlap between late day-neutral lines and short-day lines.

Table 5. Lines of *Phaseolus aconitifolius, P. acutifolius,* and *P. angularis* which all were day-neutral.

Species	P.I. Number	Origin
P. aconitifolius.....................	164,419	India
	164,444	India
	164,530	India
	165,382	India
	173,931	India
	182,976	India
	213,013–014	India
	214,332	Oklahoma
	214,333	India
	215,648–649	India
	216,038	India
	218,101–102	Pakistan
	223,521	Afghanistan
	223,801	Afghanistan
	271,399	India
	271,489	India
P. acutifolius......................	200,749	El Salvador
	200,902	El Salvador
	201,268	Mexico
	239,056	Morocco
	269,378	Chile
	310,800–803	Nicaragua
P. angularis.......................	157,625–626	Korea
	157,628	Korea
	157,633	Korea
	157,640–643	Korea
	157,649	Korea
	175,240	India
	196,173	Korea
	221,974	Japan

In Table 5 are listed all the lines of *P. aconitifolius, P. acutifolius,* and *P. angularis* which were grown. None of these lines showed a short-day behavior. The *P. aconitifolius* and *P. angularis* lines are all from more or less temperate areas, but the *P. acutifolius* lines are mostly from Central and South America and might have been expected to have a short-day response.

In addition to the species reported in Tables 2–5, single lines of several other species were grown. *P. erythroloma* (P.I. 164,047) from Brazil showed a short-day response. Planted January 24, 1967, it bloomed April 10 for about one month, and then remained vegetative during the summer, blooming again in the fall. *P.* cf. *stenolobus* (P.I. 311,151) from Honduras, also planted January 24, 1967, grew very slowly at first, and did not bloom until November 22, at a daylength of about 11¾ hr. By that time it had made a large, vigorous vine. *P. pilosus* (P.I. 306,376) from Costa Rica, *P. radiatus* (P.I. 291,366) from China, and *P. bracteatus* (P.I. 158,831) from Paraguay were all day-neutral.

Discussion

For plant breeders desirous of using introduced germplasm in their breeding programs, particularly germplasm from the center of origin of the species, difficulties may arise if the introduced lines will not bloom under the normal growing conditions available to the breeder. An attempt has been made here primarily to report the daylength requirements for lines of *P. vulgaris* and *P. lunatus* introduced from tropical areas which may be used by plant breeders in the United States. The lines reported in this paper are not a random sample, however, since the majority would be lines that could not be successfully matured in the field at Pullman, Washington.

Although some short-day lines bloomed under a daylength of 13¼ hr, most required a shorter daylength, the majority between 12½ and 13 hr. All lines with the exception of *P.* cf. *stenolobus* (P.I. 311,151), were in bloom once the daylength had reached 12 hr. It should be noted that considerable variation occurred from line to line from the same country. The *P. lunatus* lines from Nigeria (P.I. 249,020–249,066) showed a range from 12½ to 13¼ hr. Likewise, the *P. lunatus* lines from El Salvador (P.I. 256,382–256,406) showed a range of 12½ to 13 hr, but the majority of these lines (16 out of 20) bloomed at 12¾ hr.

The day-neutral responses of *P. aconitifolius, P. acutifolius,* and *P. angularis* do not agree with the short-day response reported by Allard and Zaumeyer (1). However, they listed the latter 2 species as short-day types because of a delay in flowering under extremely long days. Neither species showed a delay under a 14½ hr daylength, longer than the longest daylength obtainable naturally in Hawaii. *P. aconitifolius,* however, began to show a delay in flowering under the 13 and 13½ hour daylengths. In Hawaii, however, all the *P. aconitifolius* lines, planted May 1, bloomed from June 1 to June 21, when daylengths would have been at their maximum, about 14 hr. Allard and Zaumeyer reported that *P. aconitifolius* took 98 days to flower at a 14-hr daylength, so there must be more variability in this species than is present in the lines reported in this paper.

Several lines of *P. coccineus* from numerous countries have been grown successfully in other plantings in both winter and summer with no evidence of a long-day response as reported by Allard and Zaumeyer (1). But Allard and Zaumeyer based their conclusions on a delay in flowering under a 10-hr photoperiod. They reported no delay under a 12-hr photoperiod, a daylength which is attained in Hawaii for only about 2 months in the winter and which is only a little longer than the shortest day.

Nearly all the lines exhibiting a short-day response were introduced from Central or South America. The only exceptions are the large number of *P. lunatus* lines from Nigeria, 3 other *P. lunatus* from Africa, and the 2 *P. calcaratus* lines from India. A likely explanation for this would be that most beans introduced into Africa or Asia were introduced via Europe, rather than directly from their Latin American center of origin. Thus, only day-neutral types that could mature in Europe would be likely to be introduced by this route. However, there has also probably been some direct introduction as evidenced by the large number of short-day lines of *P. lunatus* which came from Nigeria.

Previous studies[2] (2) have shown that the photoperiod responses in beans may be influenced by temperature factors. No attempt has been made here to evaluate any response to temperature, but the relatively small temperature variation during the period that these lines were blooming (Table 1) makes it unlikely that this was a major factor for the response of these lines. These temperatures are fairly similar to those available during the summer in most areas where beans are grown and these short-day lines could probably be expected to remain vegetative unless subjected to a daylength of 12–13 hr or less.

If a plant breeder in continental United States wishes to use a short-day line in his breeding program, he should have no difficulty growing the plants in a greenhouse under natural winter daylengths to make his crosses. However, he would waste a great deal of effort if he should try to evaluate any of these lines in the field during the summer, since they would probably not mature any pods before they were killed by frost. Problems may also arise in evaluating segregating progenies, since a

[2]Mack, H. J., and W. A. Frazier. 1967. Effects of temperature and photoperiod on flowering and fruiting of snapbean varieties and breeding lines. Abstracts 64th Ann. Mtg. Amer. Soc. Hort. Sci.; 8. Padda, D. S., and H. M. Munger. 1967. Physiological-genetic studies of photoperiod response in beans, *Phaseolus vulgaris* L. Abstracts 64th Ann. Mtg. Amer. Soc. Hort. Sci.: 9.

Variable Branching Patterns in the Strawberry Inflorescence[1]

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Abstract. The selection 'La. 9-1158' as grown in Louisiana bears each fruit in what appears to be a cluster of individual flower stems arising from the crown in contrast to the branched inflorescence of most cultivars. This character was found to vary with environment. Under Indiana conditions inflorescences initiated during the winter in the greenhouse or under short days in climate chambers appear unbranched. However, inflorescences initiated on plants grown in the greenhouse during the summer and on field grown plants that flower in the spring are normally branched. Elongation of winter-initiated inflorescences by use of gibberellic acid indicates that the apparent unbranching inflorescence represents an extreme type of "basal branching," i.e. each of the flower stems is a branch of a single inflorescence that has compressed internodes. The growth habit of the inflorescence is influenced by photoperiod. In the greenhouse, fruit size and achene number decrease with the ripening sequence in unbranched inflorescences of 'La. 9-1158' the same as in normally branched cultivars.

Introduction

Uniformly large fruit size is one of the important breeding objectives in the strawberry. The decline in fruit size through the harvest season is related to the ripening sequence down the inflorescence (4). The creation of selections that appear to produce a single fruit per peduncle and thus uniform size (2) prompted the present study of inflorescence branching.

The selection 'La. 9-1158' as grown in the field at Baton Rouge, Louisiana produces an inflorescence markedly different from other cultivars. Within each inflorescence, each flower appears to arise on a single peduncle from a common point in the crown, although branching may increase near the end of the season.

Dormant plants of 'La. 9-1158' sent from Louisiana to Indiana in the spring of 1967 quickly flowered in the greenhouse and the subsequent inflorescences appeared unbranched as observed in Louisiana. However, the inflorescences of plants that reflowered during the summer in the greenhouse were branched as in ordinary cultivars. Subsequent studies were carried out in Indiana to determine what factors affect the variable branching pattern in this selection.

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Procedure, Results and Discussion

Branching behavior of 'La. 9-1158'. This selection was grown in the field, greenhouse, and in climate control chambers at Lafayette during 1967 and 1968. The behavior under these conditions is summarized in Table 1.

Table 1. Inflorescence branching of La. 9-1158.

Location	Flowering date	Inflorescence type
Baton Rouge, Louisiana		
Field planting	3/67	Unbranched
Field planting	3/68	Unbranched
Lafayette, Indiana		
Greenhouse[a]	2/67	Unbranched
Greenhouse	7/67	Branched
Environmental control chamber (12 hour day-length)	2/68	Unbranched
Greenhouse	3/68	Unbranched
Field planting (1967)	6/68	Branched
Greenhouse	6/68	Branched

[a]Dormant plants received from Louisiana 12/67. These plants provided the stock for all future plantings at Lafayette.

At Lafayette the inflorescences are unbranched when flowers are initiated during the winter in the greenhouse or under short days in climate control chambers as under Louisiana field conditions. However, in Indiana when the selection initiates flowers during the summer in the greenhouse or when field grown and blooming in the spring from flowers initiated in the previous summer or fall, the

Table 2. Effect of gibberellic acid on the internode length of the branch bearing the primary flower of 'La. 9-1158'.

Treatment	Internode length (cm)[a] peduncle 1	2	3	Total
Control[b]	0.0	0.0	9.6	9.6
Gibberellic acid	19.9	21.5	8.1	49.5
	12.0	10.9	15.8	38.7
	21.5	8.5	4.5	34.5
	20.0	3.5	4.8	28.3
	21.8	1.9	3.6	27.3
	0.0	1.7	20.5	22.2
	1.7	3.1	16.7	21.5
	16.0	1.0	2.2	19.2
	1.6	4.2	12.9	18.7
	0.0	0.9	17.7	18.6
	14.0	0.6	2.8	17.4
	1.0	4.3	11.9	17.2
	0.0	0.9	14.8	15.7
	0.0	0.0	14.4	14.4
	0.0	0.3	12.6	12.9
	0.0	0.0	10.2	10.2
	0.0	0.0	10.0	10.0
	0.0	0.1	9.2	9.3

[a]Internode designation as below:

1 2 3 ○ flower

[b]Average of 15 inflorescences.

number would be expected to show the short-day character and not bloom until too late in the season for evaluation. However, it can be expected that lines from the center of origin may carry resistance to diseases not found in other regions and the need for this resistance may make it necessary to use these short-day lines.

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