Garlic Flowering in Response to Clone, Photoperiod, Growth Temperature, and Cold Storage

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Abstract. The effects of cold storage, photoperiod, and growth temperature on flowering incidence in four clones of garlic (*Allium sativum* L.) were studied. While flowering percentage was influenced most by clone, interactions with photoperiod, growth temperature, and storage occurred. Clone R81 flowered equally well in all conditions, whereas flowering percentage of clones D129, D130, and PI485592 was reduced by cold (4C) storage of either bulbs or plants, long (16-h) photoperiod, and at 18C relative to 10C. The highest flowering percentage in all garlic clones was achieved by growing plants at 10C under short (9- to 10-h) photoperiod with no cold storage of bulbs before planting.

Garlic is an obligate apomict, reproducing by underground cloves or vegetative topsets on the flower. For these reasons, garlic improvement has focused on tissue culture-induced mutations and field selection of variant types. Sexual reproduction, either natural or human-facilitated, is imperative to breeding garlic. Attempts to obtain terminable seed from garlic have been successful in only a few fertile clones, but with low seed yield (Etoh, 1983; Etoh et al., 1988). To understand and enhance sexual reproduction in garlic, it is necessary to understand factors that influence flower induction and development. Most garlic research has concentrated on development of the economically important bulb, rather than the flower (Rahim and Fordham, 1988). Nakamura (1985) and Takagi (1990) recently reviewed flowering in garlic clones that usually flower when grown outdoors in Japan. Flowering and seed production in onion (*Allium cepa* L.) has been studied in detail (Bertaud, 1988; Brewster, 1982a, 1982b, 1983; Woodbury, 1950). The garlic and onion literature suggested that the most important floral induction factors in these biennial vegetables were variety, photoperiod, growth temperature, and bulb storage duration and temperature. Our goal was to identify optimum conditions for rapid, reliable floral induction of garlic and induce flowering in clones that rarely flower outdoors in Wisconsin. In this experiment we tested the effects of photoperiod, growth temperature, and bulb or plant cold-storage conditions on flowering in readily

flowering and rarely flowering garlic clones.

The experiment, designed as a split-split plot, was conducted from 5 Oct. 1989 to 14 June 1990 (when all plants had senesced), in greenhouses at the Univ. of Wisconsin Horticultural Station at Arlington. Factorially combined main plot factors were two photoperiods (long = 16 h or short = 9 to 10 h) and two constant growth temperatures (10C or 18 ± 3C). The subplot factors were seven plant or bulb cold-storage treatments [no cold storage (16-20C curing from August harvest until planting), or 4 ± 2C storage for 4, 8, or 12 weeks beginning 5 Oct. of either nonplanted bulbs ("bulb" storage) held in darkness or growing plants ("plant" storage), with 8-h photoperiod provided by cool-white fluorescent lighting (35 μmol·m⁻²·s⁻¹)]. Four garlic clones (R81, D129, D130, and PI485592) were the sub-sub-plot factor. Natural daylight was supplemented with cool-white fluorescent lamps in all greenhouses (250 μmol·m⁻²·s⁻¹ at the top leaves), and temperatures were monitored using recording thermographs. Photoperiod was controlled using black cloth. Eight cloves were grown for each combination of

photoperiod, growth temperatures, storage, and clone. Thirty-two cloves (eight cloves of each of four clones) plus 28 border cloves were planted in 89 × 61 × 21 -cm flats in 1 field soil: 1 compost: 1 peat: 1 sand (by volume). Cloves were irrigated initially with Banrot fungicide (Grace-Sierra, Milpitas, Calif.) (0.2% solution) and fertilized monthly with 175 mg N/liter from 20N-17P-9K (5.6% nitrate, 3.9% ammonia, 10.4% urea). No mineral deficiency symptoms were visible. The short photoperiod, 10C, no-storage treatment was repeated in 1991-92 with these four clones (15 plants each, three replications). Flowering incidence also was evaluated for these four garlic clones during 1987-91. Eight to 26 cloves of each clone were planted in Miami silt loam (fine-loamy, mixed, mesic; Typic Hapludalf; Udalf; Alfisol) soil in cold frames for each clone between 15 Sept. and 15 Oct. in Madison, Wis. Flowering occurred the following June or July.

Percent flowering differed greatly among clones in the experiment. However, neither photoperiod nor growth temperature were influential (Table 1). Percent flowering was also influenced by clone interaction with photoperiod and growth temperature (Tables 1 and 2). Clone R81 flowered in all growing conditions irrespective of bulb treatments. A separate analysis of variance of R81 indicated no effect of photoperiod, growth temperature, or storage on flowering incidence, which ranged from 20% to 54% among treatments (data not presented). For the other three clones, flowering was <8% for all bulb storage treatments in three of the four photoperiod-growth temperature combinations (16 h/10C, 16 h/18C, 9-10h/18C; Table 2). However, natural short (9- to 10-h) photoperiods and 10C was the most effective photoperiod-temperature combination in promoting flowering of all clones.

Storage conditions interacted with the clone in promoting flowering (Table 1). This interaction was demonstrated under the low-temperature, short-photoperiod conditions where roughly linear reduction in flowering occurred with longer cold storage of either bulbs or growing plants for all three clones, except R81, which flowered equally well under all storage conditions (Table 2).

Our observations indicated a need for low temperature and short photoperiod to induce

Table 1. Analysis of variance of flowering percentage in garlic as influenced by photoperiod, growth temperature, storage condition, and clone.

Source of variation	df	Mean square	F value	P value
Photoperiod (P)	1	4.32	0.21	0.726
Growing temperature (T)	1	17.29	0.84	0.528
P × T (error A)	1	20.57		
Storage conditions (S)	6	0.74	2.31	0.165
S × P	6	1.24	3.85	0.063
S × T	6	1.24	3.87	0.062
S × P × T (error B)	6	0.32		
Clone (C)	3	25.73	47.32	0.001
C × P	3	0.11	0.20	0.897
C × T	3	1.31	2.41	0.101
C × P × T	3	1.74	3.20	0.048
C × S	18	1.38	2.54	0.028
C × P × S	18	0.86	1.58	0.171
C × T × S	18	0.77	1.41	0.236
C × P × T × S (error C)	18	0.54		

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Table 2. Incidence of flowering in four garlic clones as influenced by growth, storage, or outdoor conditions in Wisconsin.

Factors	Percent flowering ^z			
	Clone			
	R81	D129	D130	PI485592
<i>Growing conditions</i>				
Photoperiod (h)/ growing temp (°C)				
9-10/10	43	13	18	29
9-10/18	21	0	0	0
16/10	21	0	0	7
16/18	36	0	0	7
Interaction LSD _{0.05} ≤ 12.4				
<i>Cold storage (4C)</i>				
Material/ duration (wk)				
Bulb/0	34	6	19	13
Bulb/4	22	0	6	19
8	28	6	0	15
12	22	0	0	13
Plant/4	34	9	9	3
8	28	0	3	9
12	38	0	6	3
Interaction LSD _{0.05} ≤ 10.1				
Clone means	30	3	7	12
	84 (55-100)	55 (29-100)	47 (25-100)	11 (0-40)

^zPercent flowering = percentage of plants producing flowers.

^yMean (range over 4-5 years) in Madison, Wis.

flowering in garlic as reported by Nakamura (1985) and Tagaki (1990) for a wider range of growing conditions. Contrary to this earlier work, we found no increase in flowering incidence due to preplanning cold treatment of bulbs or growing plants (Table 2). Nakamura (1985) and Takagi (1990) proposed that a minimum critical cold period was needed for floral induction in garlic. These divergent observations could be due to differences in clones used or differences in growth temperature after cold treatment [13C for Nakamura (1985) and Tagaki (1990) vs. 10C, which was the successful temperature for floral induction in our work]. As cool weather during the first year of growth is important for floral induction in onion (Brewster, 1982a), this also could be an important factor accounting for differences in flowering percentage for garlic grown in Wisconsin and Japan.

The ability to induce >25% flowering in recently harvested garlic bulbs without cold storage would accelerate the reproductive cycle. However, <2 months is gained, since plant growth at 10C is slow. When plants were grown at 10C and a 9- to 10-h photoperiod without storage, similar percentages of flowering among four clones were noted (Table 2), whereas flowering incidence of plants grown outdoors varied greatly (Table 2). Flowering percentage of clones such as R81, which typi-

cally flower prolifically outdoors, was not improved by this greenhouse regime. In contrast, flowering percentage of PI485592, in which 11% of plants flowered outdoors (Table 2), was improved by this regime [29% flowered at 10C and 9- to 10-h photoperiod (Table 2)]. We have repeated the 9- to 10-h photoperiod, 10C treatment in 1992 with similar success for these clones (percent flowering for clones: R81, 31%; D129, 22%; D130, 20%; and PI485592, 25%).

The significant effect of garlic clone on flowering might be expected, given their diverse origins. Clone R81 from Moldavia flowers in early summer in Wisconsin. In the greenhouse, R81 produced flowers 3 weeks before the other clones, with a high flowering percentage, as it did in the field (Table 2). Clones D129 from China and D130 from Russia flowered later than R81 in the Wisconsin summer growing season. In the greenhouse, these clones flowered only under short photoperiods. D129 flowered only under the cool (10C) regime, while D130 flowered under both temperature regimes. Clone PI485592 from Canada flowered fairly well in the 10C greenhouse, under short photoperiod conditions, but rarely under Wisconsin field conditions (Table 2).

Flower induction and development in garlic is a complex process and depends not only

on environmental factors but on genetic background. This process may begin during the first year of bulb growth. Some clones, such as R81, will flower under a wide range of environments, whereas others may fail to flower under any conditions. As in onion, photoperiod, growth temperature, cold storage conditions, and genetic background have interactive effects on garlic flower induction.

Our results indicated that to achieve maximum greenhouse flowering in garlic clones of unknown optimal photoperiod, growth temperature, and storage requirements, Wisconsin-grown cloves should be planted directly (no storage) and grown under the natural winter photoperiod (9 to 10 h) at low (10C) temperatures. Even clones such as PI485592, which flower rarely when grown outdoors in Wisconsin, flowered fairly well under these greenhouse conditions. Further work should determine if garlic clones that fail to flower when grown outdoors can be induced to flower under 9- to 10-h photoperiod at 10C.

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