Effect of Photoperiod and Temperature on the Development of Sorghum[1]

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ABSTRACT

Three varieties of *Sorghum bicolor* (L.) Moench, (i.e., 'Early Hegari,' '80-Day Milo,' and 'Wheatland') were grown in controlled environment chambers and subjected to all combinations of 10-, 12-, and 14-hour photoperiods, 27 and 32 C day temperatures, and 16 and 21 C night temperatures. Days to floral initiation were determined for each variety under each treatment combination. In addition, days to anthesis and days in the floral period (from initiation to anthesis) were determined for the treatment combinations involving 21 C night temperatures.

Ten-hour days hastened floral initiation and anthesis of each variety at all temperature combinations. Fourteen-hour days delayed development, but with some temperature regimes the delay was not significant, compared to the shorter days. The rate of development for the varieties under 12-hour days was highly dependent upon day and night temperatures, since floral initiation ranged from as early as that obtained with 10-hour days to later than that obtained with 14-hour days.

The response to day temperature during the floral period was small, but statistically significant. The time to anthesis followed a pattern similar to that for the time to floral initiation.

Additional index words: Sorghum bicolor (L.) Moench, Floral initiation, Anthesis.

VERY little of the enormous germplasm bank in the world collection of sorghums [*Sorghum bicolor* (L.) Moench] has been used successfully by plant breeders. The primary deterrent to the use of this variability has been the sensitivity to photoperiod exhibited by most tropical varieties. During summers in temperate areas of the world, many of these varieties will not mature.

Controlled environment chambers may be useful tools for plant breeders, enabling a wider use of these sources of germplasm. With such facilities, breeders *(a)* may learn more exactly the effects of photoperiod and temperature on sorghums, *(b)* may produce environments under which special selection procedures can be utilized, and *(c)* may induce flowering of tropical sorghums to facilitate crossing with adapted varieties.

Quinby (7) reviewed the literature related to the maturity of sorghum and showed that many sorghums mature more rapidly under 10-hour days than under normal days in Texas. Several workers (1, 5, 6, 7) have shown that differences in temperature cause differences in photoperiod reaction. They suggested that certain thermal requirements must be met before a response to photoperiod could be exhibited, and that the "critical" photoperiod was controlled by the temperature. Critical photoperiod is the length of light period needed to delay floral initiation. Lane (4) reported the critical photoperiods for four milos to be between 12 and 13 hours. He concluded that the varieties in his study had the same basic phytochrome mechanism and that genetic differences in time required for floral induction operated through a dark-dependent step subsequent to phytochrome action.

Francis, Grogan, and Sperling (2) reported a method for identifying photoperiod-insensitive varieties of corn (*Zea mays* L.) in controlled environment chambers, and Francis et al. (3) reported a method of screening corn varieties for photoperiodic reaction in the field.

Vergara, Chang, and Lilis (8) reviewed the literature concerning maturity in rice (*Oryza sativa* L.) and indicated that most varieties are considered short-day plants. Vergara and Visperas[3] showed that night temperature affected the maturity of new, improved rice varieties more than did day length or day temperature.

This study was designed to determine the effects of several photoperiod and temperature regimes on the development of three varieties of sorghum, to determine the stages of plant development during which sorghums respond to these regimes, and to develop techniques for evaluating sorghums in controlled-environment chambers.

MATERIALS AND METHODS

Three sorghum varieties ('Early Hegari,' '80-Day Milo,' and 'Wheatland') were subjected to night temperatures of 16 and 21 C, day temperatures of 27 and 32 C, and photoperiods of 10, 12, and 14 hours in controlled-environment chambers. One to 2 hours were required for alternating between the warm day temperatures and the cool night temperatures. The specified temperature, at all other times, was maintained within 1 C. Approximately 1,615 lux (150 foot-candles) of incandescent light were supplied during the first and last 15 min of each light period. During the remainder of the period a combination of incandescent lights and Sylvania cool white, very high output, fluorescent bulbs provided about 37,675 lux (3,500 foot-candles) of light at the top of the plants.

Twelve seeds of each variety were planted in each of 24 6-liter plastic pots containing a mixture of two parts sterilized loamy sand, one part peat, and one part perlite. About 3 g of 11-5-6 fertilizer was applied to each pot at 2- to 3-week intervals, depending upon the amount of vegetative growth. Approximately 15 days after planting all but six plants of each variety in each pot were removed. The mean number of days from planting to floral initiation was determined from four plants taken at random from the six available from each variety in each pot. In the regimes that included the 21 C night temperature (Fig. 1, 2, and 3) one plant of each variety in each pot was left until anthesis. Days from planting to the beginning of anthesis were recorded for each plant. To observe a greater number of photoperiod-temperature combinations in a limited time anthesis was not recorded for regimes that included the 16 C night temperature.

There were two trials of each combination of day length and temperature. The experimental design was a split-plot with main plots consisting of day length, day temperature, and night temperature. Varieties were the subplots. Within main plots and subplots a completely random arrangement of entries was used. The LSD's presented in the figure captions may be used to compare means of the simple effects for each factor indicated.

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[3] Vergara, B. S., and R. M. Visperas. 1970. Effect of photoperiod and temperature on the growth duration of improved rice varieties. Agron. Abst. p. 40.

Rate of development was measured by days from planting to floral initiation and by days from planting to anthesis. Thus, three intervals of development were measured. The vegetative period included the time from planting to floral initiation. The floral period, or period of flower development, spanned the interval from floral initiation to anthesis. The third interval, from sowing to anthesis, was the sum of the other two intervals.

RESULTS

Figure 1 shows that Wheatland, 80-Day Milo, and Early Hegari at the warmer night temperature all reached anthesis quickly under 10-hour days, with no significant differences due to day temperatures. The varieties differed, at the 0.05 probability, for days to anthesis under 10-hour days, except for 80-Day Milo and Early Hegari at the 32 C day temperature, and for 80-Day Milo versus Wheatland at 27 C. Under 12- and 14-hour days the varieties again differed significantly at both day temperatures, except for Wheatland and 80-Day Milo at the 14-hour, 32 C (14-hour photoperiod and 32 C day temperature) regime. Under the 12-hour photoperiod the number of days to anthesis for each variety was highly dependent on temperature. When grown in the 12-hour, 32 C regime, the three varieties reached anthesis in about the same number of days as under the 10-hour photoperiods. In the 12-hour, 27 C regime anthesis was delayed significantly. The 5 C decrease in day temperature under 12-hour photoperiods delayed anthesis 15.1, 15.5, and 15.3 days for Wheatland, 80-Day Milo, and Early Hegari, respectively.

At both day temperatures anthesis was delayed significantly under 14-hour as compared to 10-hour photoperiods. Under 14-hour days only Wheatland was affected significantly by the 5 C difference in day temperature. The long photoperiod and warm day temperature delayed the time to anthesis more for Wheatland and 80-Day Milo than they did for Early Hegari. Wheatland reached anthesis later under the 12-hour, 27 C regime than under the 14-hour, 27 C condition. This observation suggests that an accumulation of heat units is responsible for the photoperiod reaction, but the delay shown with the 14-hour, 32 C condition does not support that concept.

Figure 2 indicates that days from planting to floral initiation at the warmer night temperature followed a pattern similar to that for days to anthesis at that temperature. However, the only significant difference among varieties within the 10-hour treatment was between Wheatland and 80-Day Milo at 32 C. Under 10-hour photoperiods the day temperatures produced no significant effects on the three varieties. Under the 12-hour, 32 C regime the plants initiated floral tissue at about the same age as under a 10-hour, 32 C regime, and Wheatland was significantly later than the other varieties. At the 27 C day temperature in the 12-hour photoperiod treatment, 80-Day Milo and Early Hegari reached floral initiation at an age that was intermediate, although not significantly different from either the 10- or 14-hour days.

Wheatland initiated floral tissue sooner under the 14-hour, 27 C regime than under the 12-hour, 27 C

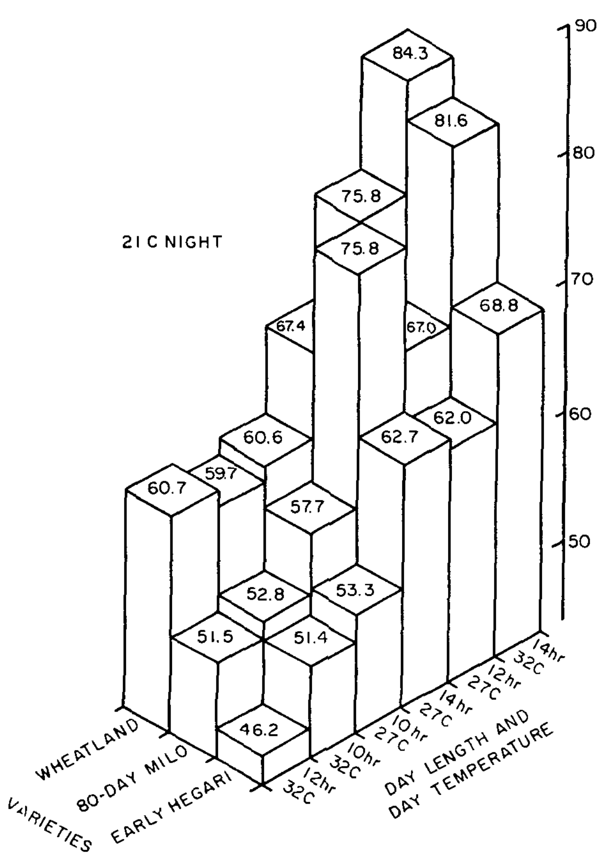

Fig. 1. Effect of day length and temperature on days to anthesis of three sorghum varieties. (LSD .05 for day length and temperature = 8.8, for varieties = 4.2)

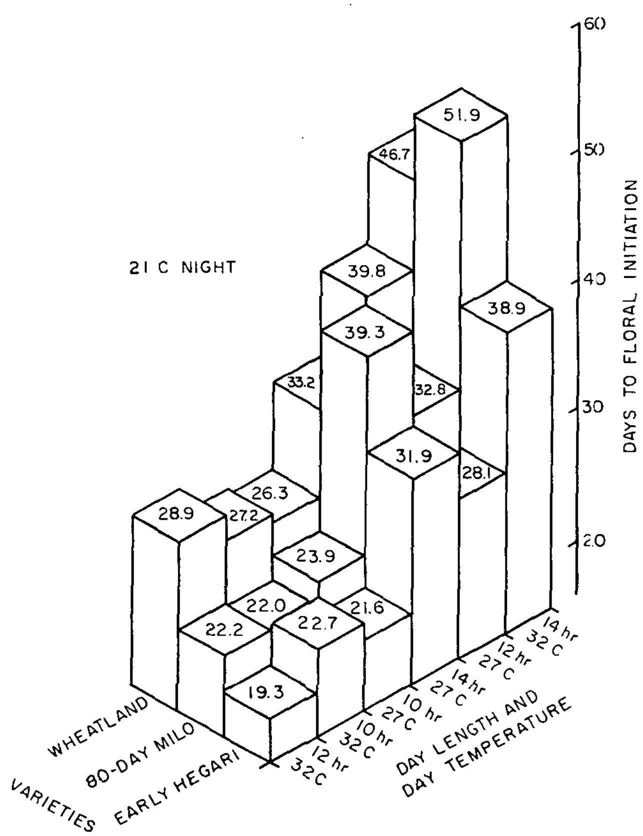

Fig. 2. Effect of day length and temperature on days to floral initiation of three sorghum varieties. (LSD .05 for day length and temperature = 10.5, for varieties = 4.9)

condition. However, the difference of 6.6 days was not significant. Wheatland and 80-Day Milo reached floral initiation 13.5 and 12.6 days later under the 14-hour photoperiod when the temperature was increased 5 C. Early Hegari was delayed less by the 14-hour days at 32 C than were the other varieties.

Figure 3 shows much less variation among treatment regimes for floral period than were in evidence for days to floral initiation and days to anthesis. This helps explain the similarity in the pattern of Fig. 1 and 2. Figure 3 shows that floral period of the varieties was not affected significantly by day temperatures under the 10-hour photoperiod. With a 12-hour day the development of all varieties was delayed significantly by the 27 C temperature as compared to 32 C.

The floral period of Wheatland was significantly longer than that of Early Hegari under every photoperiod-temperature combination except the 12-hour, 27 C regime; and even then, the difference approached significance. The floral period for Wheatland was longer than that of 80-Day Milo only under the 14-hour, 32 C condition. The 14-hour, 27 C regime was the only treatment in which 80-Day Milo had a significantly longer floral period than did Early Hegari. Different day lengths at 27 C did not significantly affect the floral period of Early Hegari, 80-Day Milo, or Wheatland. At 32 C, however, Wheatland had a significantly longer floral period under the 14-hour photoperiod that it did with 10- or 12-hour days.

Analyses of variance indicated that day lengths were responsible for highly significant differences in length of vegetative period and days to anthesis, but did not affect floral period. On the other hand, day temperature did not affect days to floral initiation or anthesis, but it did influence length of floral period. Although day temperatures *per se* did not significantly affect days to floral initiation or anthesis, the interaction of day temperature with photoperiod was highly important. These data indicated that 14-hour days may permit extended vegetative development and that 27 C days allow a relatively long period for floral development. However, these conditions produce plants that mature slowly, and they must be grown under near-ideal conditions for maximum expression of grain yield.

The analysis of variance for days to floral initiation showed that day temperatures did not affect time of floral initiation significantly, but day length, night temperature, and variety each had a significant effect. Therefore, the response to day lengths and night temperatures at the 32 C day temperature is shown in Fig. 4 and at the 27 C day temperature in Fig. 5 to illustrate their interactions with day temperature. The figures show that 10-hour days hastened floral initiation of all varieties under all combinations of temperatures. Early Hegari and 80-Day Milo initiated inflorescences 20 to 24 days after planting in 10-hour days. Wheatland initiated floral tissue 3 to 7 days later than the other varieties under 10-hour days. All variety differences involving Wheatland were significant except for Wheatland versus 80-Day Milo in the 10-hour, 27/21 C regime (10-hour photoperiod, 27 C day temperature, and 21 C night temperature).

In all instances the varieties initiated floral tissue later under 14-hour than 10-hour photoperiods. However, Wheatland under the 10-hour, 27/16 C regime was not significantly different from the 14-hour, 27/21 C treatment. With 14-hour days, Early Hegari initi-

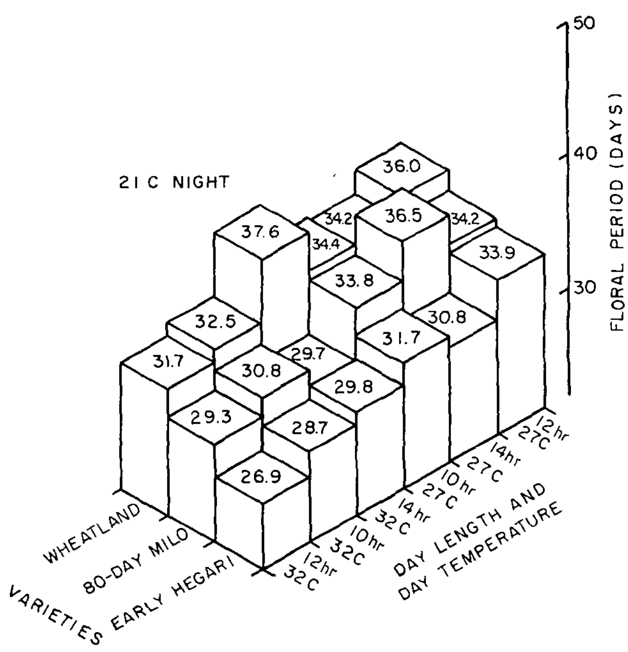

Fig. 3. Effect of day length and temperature on days in floral period of three sorghum varieties. (LSD .05 for day length and temperature = 3.6, for varities = 2.4)

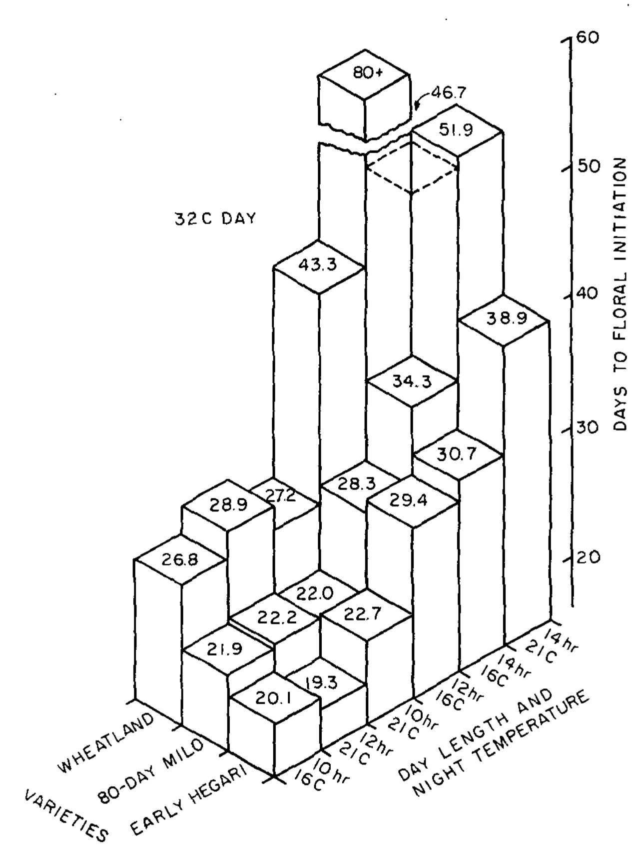

Fig. 4. Effect of day length and night temperature on days to floral initiation of three sorghum varieties at 32-C day temperature. (LSD .05 for day length, day temperature, and night temperature = 7.1, for varieties = 3.8)

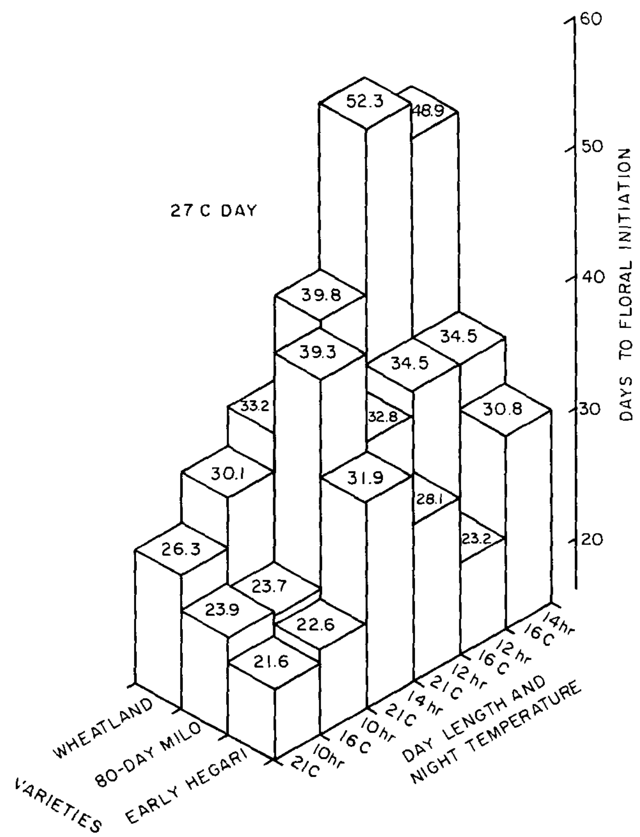

Fig. 5. Effect of day length and night temperature on days to floral initiation of three sorghum varieties at 27 C day temperature. (LSD .05 for day length, day temperature, and night temperature = 7.1, for varieties = 3.8)

ated inflorescence about 31 days after planting with both night temperatures at the 27 C day temperature (Fig. 5), and at the 16 C night and 32 C day temperature (Fig. 4). However, the 14-hour, 32/21 C regime delayed initiation significantly (8 days). A similar pattern was obtained for 80-Day Milo, although it reached floral initiation much later than did Early Hegari during the 14-hour, 32/21 and 27/21 C regimes.

Wheatland responded quite differently from the other varieties to 14-hour photoperiods. Wheatland initiated floral tissue later than did Early Hegari under every 14-hour day, and was earlier than 80-Day Milo only under the 21 C night regimes. The 14-hour, 27/21 C treatment caused Wheatland to initiate floral tissue in 33.2 days. This was only a few days later than its responses with 10-hour days. Wheatland showed floral initiation at about the same age when subjected to 14-hour days with 32/21 C and 27/16 C. When the experiment was terminated at 80 days after planting, Wheatland had not yet initiated inflorescence under the 14-hour, 32/16 C regime.

Wheatland initiated floral structures significantly later than did Early Hegari and 80-Day Milo under every 12-hour day. Early Hegari was earlier than 80-Day Milo when the 12-hour day was combined with the cool day temperature. The 16 C night temperature caused a significant delay in floral initiation for Early Hegari in the 12-hour, 32 C regime and for Wheatland with the 12- and 14-hour, 27 C day conditions. Early Hegari and 80-Day Milo were significantly later in the 14-hour, 32/21 C regime than they were in other treatments.

The response of Early Hegari to 12-hour days with 32/21 C and 27/16 C temperatures was about the same as it was for 10-hour days. However, Early Hegari in 12-hour days with 32/16 C and 27/21 C temperatures showed floral initiation in a similar number of days as it did in 14-hour days. Early Hegari did not exhibit a threshold response except, possibly, when the warmer day and night temperatures (32/21 C) were combined with the longest day (14-hours). For this regime, floral initiation occurred 39 days after planting.

Floral initiation for 80-Day Milo occurred as soon under the 12-hour, 32/21 C treatment combination as it did under the 10-hour day treatments. However, 80-Day Milo in 12-hour, 32/16 C, and 27/21 C temperature regimes developed floral tissue in an intermediate number of days between regimes with 10- and 14-hour days. In the 12-hour, 27/16 C treatment the response was similar to that obtained in the 14-hour, 27/16 C regime. Like that of Early Hegari, floral initiation of 80-Day Milo was delayed most by 14-hour days with warmer temperatures during both day and night.

DISCUSSION

The varieties studied tended toward earlier floral initiation and anthesis under the 10-hour days. Response to the 12-hour day was highly dependent upon day and night temperature. The 14-hour day usually caused a significant delay in floral initiation and anthesis. It seems, therefore, that 10-hour days with any of the temperature combinations likely would provide a satisfactory environment in which sorghum breeders could induce floral initiation in short-day varieties. However, since the responses to 14-hour days were affected somewhat by both day and night temperature, a light period longer than 14 hours may be necessary to eliminate short-day plants from segregating populations.

Night temperatures significantly affected the time required to reach floral initiation, except under 10-hour days. Night temperature was more important in determining the time of floral initiation for Early Hegari and 80-Day Milo in the 14-hour, 32 C regimes than in the 14-hour, 27 C regimes. When subjected to the warmer day temperature, these two varieties initiated inflorescence earlier with the cool night temperature. Wheatland showed earlier floral initiation when grown in the warm night temperature combined with either 14-hour, 32 C or 27 C days, than it did at the cooler night temperature of the same day length and day temperature. This indicates that the effect of night temperature on the photoperiodic response of sorghum is dependent upon both the variety and day temperature. Further studies are needed to determine the combination of day length and temperature best suited for observing the long-day response of sorghum.

Day temperatures were more important in determining length of the floral period than they were in determining the time required to reach floral initiation or anthesis. Although the differences in floral period with the various treatment combinations were often statistically significant, they were so small that the interval of development, for practical purposes, seems fairly constant. Since time and space often are limiting in growth chamber studies, days to floral initiation seems the preferred criterion for measuring the effect of temperature and photoperiod on plant development. In field studies, where time and space are of lesser concern than the labor required, days to anthesis may be a more accurate measure for estimating relative rates of development. In rice, the floral period is often assumed to be 35 days (8). The data here indicate that 35 days may be slightly longer than the average period required to complete floral development in sorghum.

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