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FINAL REPORT
SRC PROJECT BS1S
EFFECT OF FAR-RED RADIATION ON FLOWERING OF *SACCHARUM* SPP. HYBRIDS

by

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ABSTRACT

Many tropical sugarcane clones (*Saccharum* spp. hybrids) are unavailable for hybridization because of poor flowering. Methods are required to improve the flowering of such clones. This study was conducted to determine whether far-red radiation (> 700 nm) at end-of-day would improve flowering. Three treatments in a photoperiod facility (PPF) were compared to an external control (EC) under natural photoperiod. A basic treatment known as modified Florida (MF) was used in all PPF treatments and served as the internal control. This was altered to provide a far-red (FR) treatment, by addition of either 5 or 10 min of far-red radiation at end-of-day, and a day interrupt (DI) treatment, by imposition of 2 hr of darkness in mid afternoon. Percent flowering as harvested panicles was 21.0, 24.2, 24.6, and 9.5 for FR, DI, MF, and EC, respectively. Total flowering was 23.4, 28.9, 27.0, and 10.7, respectively. The PPF treatments did not differ significantly for either measure. All were highly significantly greater than EC. The far-red treatments did not differ for harvested panicles. Treatments differed significantly for time of flowering. The flowering sequence was EC, MF, FR, and then DI. There were significant differences among clones in all treatments for emergence day, initiation day, elapsed days, and pollen test. Correlations among these measures were varied, with some being significant. Far red at end-of-day neither stimulated nor inhibited flowering in the PPF treatments. The FR and DI treatments delayed emergence of flowering.

Flowering is essential for the production of new improved clones of sugarcane. However, numerous clones desirable as parents either fail to flower or flower so sparsely or late in the season that they cannot be used for breeding. Methods are needed to increase and accelerate the flowering of such clones.

The physiology, control, and manipulation of sugarcane flowering have been reviewed by Moore (1985, 1987) and Moore and Nuss (1987). Sugarcane flowering is a day length, or photoperiod, dependent response occurring naturally under the gradually shortening day lengths of autumn. Inductive photoperiods are longest for *Saccharum spontaneum* and shortest for *S. officinarum*. Commercial clones are complex hybrids of these two species. They are induced to flower by intermediate photoperiods ranging from 12 hr 48 min to 12 hr 12 min. Clones that are induced at the shorter day lengths often are inhibited by cooler night temperatures which occur in late autumn. Photoperiod facilities (PPF) can be used to create shorter days earlier in the year to advance the flowering of normally late or sparse flowering clones.

Research on many species has demonstrated that plants may recognize photoperiod through ratios of alternate forms of the light absorbing pigment phytochrome. Each form has a specific wave length absorption maximum and a specific physiological activity. In a simplified version, phytochrome is postulated to influence flowering as follows. Under high daylight intensities, there is an abundance of red light (660 nm). This is absorbed by the red-absorbing phytochrome (P_r) which is converted to the far-red absorbing form (P_{fr}). The latter is inhibitory to flowering of short day plants (SDP) and stimulatory to flowering of long day plants (LDP). Far red radiation (730 nm) or darkness converts P_{fr} back to P_r to cause short SDP flowering. Sugarcane behaves as a SDP in this respect.

Borthwick *et al.* (1952) hypothesized that a drop in P_{fr} concentration should promote SDP flowering. They reported that 30 min of far-red (FR) light at the beginning of the dark period shortened the dark requirement for flowering of *Xanthium* (a SDP) by about 2 hr. Red (R) light lengthened the dark period requirement by about 30 min.

Flowering of seedlings of the SDP *Pharbitis nil* was inhibited by end-of-day FR. It was promoted by R previous to a 16 hr inductive dark period (Nakayama *et al.*, 1960). There was no response to end-of-day FR or R in older plants. King (1974) confirmed these results and showed that FR near the end-of day shortened the critical night, provided the night was preceded by 5 min of R. However , FR lengthened the critical dark period when it was given 9 hr before the onset of 5 min R, followed by darkness. Heide *et al.* (1986) showed the response of *Pharbitis* to FR preceding an inductive dark period varied with a 12 hr rhythmicity. The strongest promotion of flowering was when FR followed by 5 min R was near the dark period. In summary, FR could supplement the critical dark period and increase the flowering of *Pharbitis* but not in the direct method suggested by Borthwick *et al.* (1952). Stage of plant development and precision of timing due to a rhythmic sensitivity are apparently crucial.

Williams and Morgan (1979) found that end-of-day FR promoted flowering of sorghum, another SDP, without the requirement for 5 min R. The response was common to all cultivars tested.

The role of phytochrome in the flowering of sugarcane is not clear. Julien and Soopramanien (1975) used pure light sources of R and FR. They showed that all stages of panicle development from induction to initiation of the spiklet primordia gave expected short-day responses to light interruption of the night. Red light was inhibitory to flowering. Far-red light alone was the same as darkness but could not reverse the inhibitory effect of R. These authors did not test the effect of end-

of-day FR on flowering.

Coleman (1960) reported the work of Burr that FR at end-of-day was inhibitory to flowering. However, control data were not given and the light spectra of the FR source was not measured. The FR was obtained by cellophane filtration of incandescent light. Undoubtedly, it contained significant amounts of R which would have been inhibitory. Coleman (1963) concluded that FR during the dark period does not inhibit floral induction but R does. Furthermore, FR did not reverse the effect of R as was reported for several other SDP.

Chang (1986) attempted to use FR, R, or both at end-of-day and end-of-night to promote flowering of reluctant-flowering clones. He reported that a mixture of FR and R at both ends of the dark period promoted flowering. Spectral data presented showed that the R source contained 50% FR. The treatments should have been nearly the same as FR alone. They were not.

The role of phytochrome and the response of many physiological and developmental processes to FR and R is well established. These include flowering, seed germination, cold hardening, etiolation, and gibberellin responsiveness. The conflicting reports of FR and R on flowering may result from species or cultivar differences. They may also result from poor experimental methods such as using light mixtures and variable stages of floral development. Reinvestigation of the effects of FR light is desirable. This may resolve these problems and develop a practical way to increase flowering of reluctant-flowering sugarcane clones. In this report we compare the effect of FR at end-of-day with two other PPF treatments and an external control.

MATERIALS AND METHODS

Research was conducted at Meringa in the photoperiod facility (PPF). The PPF consists of three chambers each 3 m wide x 15 m deep x 8 m high. Each chamber accommodates a train of four trolleys. Each trolley held 32 53 L black polythene pots in a sheet steel tray 120 mm high that maintained a water table 100 mm deep. The ratio of incandescent to fluorescent light wattage was adjusted to approximately 40:60. This was to achieve a balance between photosynthetically active radiation (PAR, 400 - 750 nm) and FR/NIR radiation (750 - 1500 nm). The wattage ratio used was close to the ideal of 30:70. The other major variation was in the configuration of the trolleys in the externally parked position. Previously, the three trains had been parked adjacent to each other on parallel N-S tracks. Immediately before the commencement of the PPF treatments for this research, the configuration was altered so the trolleys were offset when parked externally. All trolleys in each train then received full exposure to the sun from sunrise to sunset.

The FR treatments applied to plants in one chamber were compared to treatments in the other two chambers as well as an external control (EC). The conditions given plants in all chambers were identical except variations in photoperiod regimes. All PPF treatments received a general modified Florida (MF) photoperiod regime (Table 1). The MF treatment served as the internal PPF control. Additional treatments provided specific conditions for the FR and the day interrupt (DI) treatments (Table 1). The DI treatment was suggested as a possible cheaper alternative to FR radiation by Dr L.T. Evans (Division Plant Industry, CSIRO, Canberra).

The FR radiation was provided by luminaries of a design by W.A. Bailey (Downs and Hellmers, 1975). The design was expanded to allow treatment of a single PPF trolley of 1.95 m x 3.48 m as a unit. Three

luminaries were used. Each was a box of aluminium sides and ends of dimensions 660 mm high x 1300 mm wide x 2500 mm long. The top of the box was closed with a lid of aluminium and wood construction that served as a plenum. The exterior aluminium surface supported two high volume centrifugal fans for cooling. Seventy two 150 W incandescent lamps were suspended from the internal plywood surface of the lid in a 6 x 12 pattern at 200 mm spacing in both horizontal dimensions. The bottom of the luminary consisted of a 10 mm perspex sheet sealed into the aluminimum housing. This seal was watertight to allow the use of water as a filter to remove long wave (> 1000 nm) radiation. Westlake FRF 700 filter sheets (Westlake Plastic Co. Lenni, Pennsylvania) 3.2 mm thick were fixed 25 mm below the perspex bottom. The luminary construction was light proof so no unfiltered light escaped.

The luminaries were suspended from industrial scaffolding above the trolley track into one chamber of the PPF. The bottom of the luminaries was 3.54 m above the pot surface. At the commencement of treatment, the upper-most leaves were touching the bottom of the luminary assemblies. The pot surface was 0.81 m above the ground. The luminaries were powered by a 50 kVA generator. The FR treatments (Table 1) were given from 31 January to 12 March 1989, inclusive.

Thirty two clones were used in this study (Table 2). Code numbers are assigned these clones to allow later graphical presentation of results. The clones were drawn from a number of tropical and subtropical/temperate programs. They represent a diverse range of genetic material found in modern *Saccharum* spp. commercial hybrids. Most had been used in earlier PPF experiments at Meringa.

Plants of these clones were established by germinating one-eye setts. These were planted on 22 - 23 August 1988 after hot water treatment for 20 min at 50°C. Plants were established in 75 mm peat

pots. Germinating eyes were planted to these from 30 August to 10 September. Once well established, these were transplanted to the 53 L pots filled with unsieved river sand from 3 - 17 October. Each trolley held one pot of each of the clones. Each trolley served as a replicate. The EC also contained four replicates. Plants of each clone were ranked for growth and allocated to replicates (PPF and EC) in a stratified manner. One replicate received the tallest plants of all clones through to the last replicate which received all the smallest plants. This stratification was assigned to trolleys at random.

Liquid fertilizer [400 mL Wuxal liquid foliar nutrient - 17.4 : 7.6 : 10.9, + trace elements (Schering Pty Ltd)] was mixed in the water in each trolley tray on seven occasions between 10 Oct. and 19 Dec. 1988. No fertilizer was applied from 19 Dec. to 13 March. This was to decrease plant N before and during the inductive period. This was aided by frequent and prolonged leaching using the drip irrigation system combined with emptying of the trays. Fertilizer at half the rate (200 mL) was applied in the post-inductive phase on four occasions from 13 March to 24 April 1989. The plants in the EC were established and maintained like those in the PPF. There were two differences. They were maintained in a water table on a concrete slab while those on the PPF trolleys were maintained in steel trays. Fertilizer was applied to each pot rather than into the water around the pots. Each pot in the PPF treatments received 60 mL of fertilizer (Wuxal: 600 mL per 9 L H_2O) in the pre-inductive period. This difference in fertilizer application was an attempt to achieve a uniform distribution in a larger volume of water. The fertilizer rate was halved in the post-inductive period. The timing again was identical with the PPF.

Measurements:

The growth of the plants was monitored during the experiment. The height of the primary shoot from the last exposed dewlap (LED) to the

pot surface was measured monthly from 1 November 1988 to 30 March 1989. The LED is a commonly used growth reference point. Plants on one trolley (replicate) chosen at random from each chamber were measured.

Immediately before commencement of the photoperiod treatments all immature stalks and basal shoots were removed. Immature stalks were those with fewer than three mature internodes. The remaining stalks had the sixth leaf below the LED leaf (= one) dated weekly from 1 February to 8 March. This allowed estimation of initiation day. Moore (1974) determined that commercial *Saccharum* spp. hybrids contain nine primordial leaves in the meristem. At panicle emergence, counting down the leaf canopy for 18 leaves yielded the date (initiation day) of the last leaf produced before initiation of the panicle. The flag leaf was taken as the first leaf for this count.

An ISCO spectroradiometer (Model SR) was used to measure the spectral output of the FR luminaries and the light profiles in the PPF. The ratio of PAR:FR/NIR light being used for induction in the PPF also was determined .

Panicles were scored for date of emergence (emergence day) when the first spiklets opened. A panicle sample was taken and a standard, simple starch-iodine test was performed as an indicator of pollen maturity/fertility (Berding and Skinner, 1981). The subjective rating given in the pollen test took the form of a three digit number. The first digit indicates the abundance of pollen: 0 = sparse: 1 = average; 2 = abundant. The last two digits indicate the percent of pollen grains present that are darkly stained.

The experiment was terminated on 28 Aug. 1989. All remaining stalks were cut from the pots. Any stalks showing an extension of the leaf sheath region were sliced to determine if initiation had occurred. The total number of stalks per pot equalled the number of panicles harvested

and the number of residual stalks. This allowed calculation of % harvested panicles and % total flowering. The time from initiation day to emergence day, or elapsed days, was calculated.

Chi squared tests were used for the analysis of results even though all treatments were replicated. Use of this was considered safer than analyses of variance because of nature of the data. A simple correlation analysis of emergence day, initiation day, elapsed days, and pollen test was also conducted for each photoperiod treatment.

RESULTS AND DISCUSSIONS

The plants in the eastern and western chambers were interchanged before commencing the experiment. The FR treatment was to be applied to plants in the eastern PPF chamber. The trolleys in all three chambers had been parked adjacent to each other on parallel N - S tracks up until the experiment. There was a pronounced edge effect on the eastern trolleys. Plants on the eastern side of these trolleys were the smallest. Those on the western side were the largest and were comparable to those on the middle and western trains. Use of plants with this gradient was considered undesirable for the FR treatment. The exchange was made although prior randomization was violated.

The photoperiod treatments commenced on January 31 with a commencing night length of 11 hr 15 min. A fault in the PPF lighting circuits was not detected until 2 February. The first effective photoperiod and FR treatments did not occur until the evening of 2 February. As the reference day for the experiment was 1 February (Table 1), the commencing night length was then 11 hr 15 min less 30 sec.

Plant growth

Growth of plants in the PPF was more than adequate. For clarity, only data for the smallest (77N1232) and largest (H56-752) clones and the population average are presented (Fig. 1.). Clone 77N1232 was approximately 1.5 m high at the commencement of the PPF treatments. Physiological age should have been adequate for flowering. There was no quantitative measure of the plant N. Cessation of fertilizer application, intense leaching, and drainage from this time until the commencement of the PPF treatments reduced plant lushness. The paleness and yellowing of the canopy was considered indicative of a low plant N conducive to flowering.

Radiation output

Early measurements of the radiation emitting from the FR luminaries

indicated relatively high energy at wavelengths above 1000 nm. This energy could have damaged the plant canopies because of their proximity to the luminaries during FR treatment so the luminaries were flooded with 40 - 50 mm of water to remove this long wave output.

The water-filtered output of the luminaries was excellent for energy and quality (Table 3). The ratio of FR:R exceed 8.2 in all positions measured. The luminary output was acceptable for FR treatment of plants as the ratio exceeded 4.0 (L.T. Evans, pers. comm., 1989). We do not have data that we specifically can compare with the specifications for the FRF sheet. An approximation is possible. The specifications for the FRF sheet indicate the transmission between 680 - 700 nm is 10.1% that between 700 - 720 nm. Our data indicate the transmission between 650 - 700 nm was 21.3% of that between 700 - 750 nm. The transmission of R light was obviously higher than expected. The reasons for this discrepancy are not known.

The energy profile in the PPF indicates the quantity and quality of light was adequate for photoperiod extension (Downs and Hellmers, 1975). The balance between PAR and FR/NIR radiant energies is approximately equal at all levels of the profile (Table 4). This indicates that the present mix of incandescent and fluorescent lights (Table 1) is right. The lowest profile level (Table 4) was mid canopy at the start of the experiment. The second highest level approximated panicle level at the completion of the experiment. The discrepancies between the two upper profile levels for PAR and FR/NIR radiation arose because of the spatial arrangement of the light fittings. At these levels the sensed radiation was influenced by the proximity of a particular light type. Better mixing obviously occurred at levels lower in the profile.

Flowering

The number of stalks was lowest in the EC. The middle chamber (DI)

of the PPF produced fewer stalks than the exterior chambers (Table 5). This probably reflects the more competitive nature of these environments. The pots in the EC were in an 8 x 16 arrangement with an access alley down the middle of the long axis. The pots on the PPF trains were in a more open arrangement of 4 pots wide x 32 pots long. Plants in the PPF pots were grown up to the time of the experiment with the trains parked adjacent to each other on N - S lines. The reduced exposure of the middle trolley could have suppressed the stalk population.

Flowering in the three PPF treatments differed little from each other for both harvested panicles and total flowering. The level of flowering in the PPF treatments was not high. All PPF treatments exceeded the flowering in the EC by a factor exceeding two (Table 5) and were highly significantly better than EC (Table 6). The number of initials found after the experiment was smallest in the EC and largest in DI. The FR and DI treatments neither stimulated nor inhibited flowering compared to the MF treatment. All PPF treatments were highly significantly better than the EC (Table 6).

The levels of flowering in the two FR treatments (Table 1), as measured by harvested panicles, were not significantly different from each other (Table 7). As the FR output was adequate in both quantity and quality, future experiments with these luminaries will be able to use a 5 min treatment.

Although there were no significant differences between PPF treatments, differences did exist in the time of emergence of the panicles (Fig. 2). Cumulative flowering was expressed as a percent of total flowering in MF. There were differences in the date of first panicle emergence. The EC produced the first panicle on day 128. First flowering progressed through FR (day 138), MF (day 145), and DI (day 152). Approximately 70% of the flowering in the EC occurred early, by

day 170. In contrast, flowering in the PPF treatments was later. Flowering in MF preceded that in the FR which in turn preceded that in DI. This pattern persisted for most of the experiment until day 223 when cumulative flowering for DI surpassed FR (Fig.2).

The differences in time of emergence of panicles in the PPF was tested statistically with a one-way Chi-square test for departure from 1:1:1 expectation. Data were panicle counts at 10 day intervals from 160 through 220 days. There were highly significant differences among treatments at 160 and 170 days. Differences at 180 and 190 days were just below significance (P = 0.07). The remaining data through to 220 days were non significant.

There are two possible explanations for the delayed appearance of flowers in the PPF treatments. It may be a consequence of starting the induction at too short a night length (Table 1). For practical applications this can be resolved by starting treatment at the same night length and commencing induction earlier in the year. This is important when synchronization of PPF and natural flowering is required. The PPF treatments also could commence with a longer night length than used in this experiment. There is a slight danger then that the induction of clones requiring shorter night lengths may be missed if the commencing night length is increased too much. Alternatively, the delayed flowering pattern in the PPF treatments may be a consequence of the reduced rate of night length increase (Brett and Harding, 1974; Nuss, 1980). The MF treatment is based on an increase of 30 sec / night (Table 1). This contrasts with the natural increment at Meringa of approximately 60 sec. For clones that require longer night lengths for induction, more nights must elapse at the lower increment to reach an inductive night length. These consequences may not be mutually exclusive.

Except for a crossover in the FR and MF plots early in the experiment, the FR treatment consistently delivered flowers later than the MF control (Fig. 1). The only difference between these was the addition of the FR treatment to the basic MF regime (Table 1). This difference must be ascribed to the FR given in the inductive period for 39 days. The FR and MF treatments did not differ significantly in level of flowering (Tables 5 and 6). Consequently, while FR at end-of-day neither stimulated nor inhibited flowering, these results suggest that FR delayed floral development.

Flowering from the DI treatment was delayed over that of the FR treatment, at least up until day 208 (Fig. 2). The DI treatment was exposed to 2 hr less sunlight per day than both the MF and FR treatments. This treatment risked reducing the carbohydrate reserves available to the meristems. These then would be less responsive to photoperiod induction. This was not the case, as there were no significant difference between the DI and MF treatments. It is conceivable that reduced carbohydrate reserves affected the rate of panicle development and maturity, and emergence was delayed.

The number of clones flowering in the FR, DI, MF and EC treatments was 20, 15,20, and 7 respectively. Twenty four of these clones also flowered in field plots at Meringa in 1989 (Table 8). Twelve clones flowered in all PPF treatments. All of these except H68-2775 flowered in the field. Seven clones failed to flower in any of the PPF treatments. However, four of these (B49119, Q90, Q101, and Q113) flowered in the field. There may be real differences between field grown and potted plants. Alternatively, inductive treatments provided in the PPF treatments were deficient in some respect, e.g. the rate of photoperiod change may be critical. All except Q101 have flowered in an earlier PPF treatment. This was the South African treatment which differed from MF (Table 1) in having a natural sunset. Six and seven clones,

respectively, either flowered in a combination of two PPF treatments or only a single treatment. Examination of these patterns is not instructive as no measure of significance can be attached.

Emergence day

Cumulative flowering relative to MF has been considered (Fig. 2). However, the time of emergence of panicles of individual clones is of interest (Fig.3). Clonal codes have been detailed (Table 2). Means with zero standard deviation are mostly single values. Emergence day ranged from 134 (clone 16, EC) to 213 (clone 29, DI). There are relatively few significant differences among clones in the EC treatment, although clonal numbers are small. There were many significant differences in the PPF treatments. Clone 16 (77N638) was the earliest, or among the earliest flowering clones in all treatments.

There appears to be an interaction of clones with treatments. This is not unexpected. Relative to MF, the internal control, not all clones in the DI treatment flowered considerably later than those in the FR.

Initiation day

Initiation day should be estimated precisely as it is the result of a rather specific biological event. The meristem is transformed from a vegetative to reproductive state. A period of 10 to 20 inductive nights is required to induce sugar cane (Coleman, 1965; 1969). The actual number of days required for induction is conditioned by interactions with other environmental factors like temperature and moisture. This interaction is limited in a sense as extremes will abort the inductive process. The accuracy of estimating initiation day will be determined largely by the accuracy of the estimate of the number of leaves to emerge after floral induction. This is unreported.

The time of initiation was estimated from leaf dating undertaken from February 1 to March 8. This span of dating proved close to ideal.

There were few instances at emergence where the 18th leaf below the flag leaf was not a dated leaf. During the leaf marking period the average emergence was a leaf a week. This was used in cases where the 18th leaf was not dated to approximate the date at which such leaves were formed.

Clone 11 (77N638) was induced earliest, on average, on day 38, or February 7 (Fig. 4). The clone with the latest estimated average emergence date over the three PPF treatments was number 28 (Q117). This was day 62, or March 3. This was 24 days after the earliest clone. There were clones that initiated even later than Q117, but not in all PPF chambers (Fig. 4).

There are many significant differences among clones for estimated initiation day in all treatments (Fig. 4). The range of initiation day for the EC was less than that shown for the three other treatments (Fig. 4), although fewer clones were included in the data. Some clones appear to have initiated beyond day 69 (March 10) in certain PPF treatments. If these estimates for initiation day are reasonable, initiation in the PPF treatments is spread over a wide range.

The best comparison that can be made with initiation in the EC treatment is for Q117 (clone 28), the latest induced clone. The estimated initiation day for the EC treatment was day 53. This was similar for MF but was at variance with FR (67) and DI (68). This difference approximates the effective offset of the first inductive night length for the earliest induced clone in the PPF treatments discussed earlier.

As with emergence day, the data again suggest certain clones interact with specific photoperiod treatments. The data are not extensive enough to warrant discussion in detail.

Elapsed days

There are many significant differences among clones for this character (Fig. 5). This was true for all four treatments. Again,

there was an indication of interaction of clones and treatments. For many of the clones which flowered in all three PPF treatments there are relatively minor differences. In contrast, there are a number of clones which show large differences across environments. Clone 18 (78N430) had approximately similar values in the FR (124) and MF (119) treatments, but had a value of 159 in the DI treatment. Clone 29 (Q124) had values for MF, FR, and DI of 122, 141, and 153, respectively.

Pollen test

There are many significant differences among clones for pollen test in all four treatments (Fig. 6). The effect of the maintained night minimum of 21°C in the PPF on pollen test is obvious (Fig. 6). This confirms similar results obtained in earlier work in the Meringa environment (Berding and Skinner, 1981). Three clones in the EC treatment (3, 28, 31; CP57-603, Q117, and Q133, respectively) recorded pollen tests sufficient to be classified as male, i.e. ≥ 210. In the PPF treatments, FR, DI, and MF produced 15, 9, and 14 male tests, respectively. Of the clones recording male tests in the EC treatment, all recorded male tests in the PPF treatments except for Q117 in the DI treatment.

Clones that recorded female tests in the EC treatment (16, 21; 77N638 and 79N1348, respectively) generally did not respond similarly in the PPF treatments (Fig. 6). Clone 77N638 was a rather strong male in all treatments. Clone 79N1348 also was a male in all treatments but was weakest in the FR treatment, with a test of 222.

Several clones produced variable results. Clones 11 (H71-0505) and 23 (Q96) were scored as males in the FR and MF treatments but as females in the DI treatment. Clone 19 was a weaker male in the FR treatment but a female in the DI and MF treatments. Clone 30 (Q130) was scored as a strong male in the FR treatment but a female in the MF

treatment. Such results indicate possible interaction of clone and photoperiodic treatment. As indicated for the other measures of panicle development discussed earlier, this is not surprising. Substantial discussion is difficult because of the partial data set available when not all clones flowered in all treatments.

Some clones are female for presumably genetic reasons, showing no tendency for development of maleness in one or more of the PPF treatments. Clones 14 (77N557) in MF, 20 (78N713) and 25 (Q100) in FR and MF, 29 (Q124) in all PPF treatments provide examples of this.

Correlation study

A correlation study of relationships among the four panicle measures revealed significant values in all treatments (Table 9). The pattern is rather variable. The correlation between emergence day and elapsed days is highly significant and positive for all treatments. In part these may be spurious. The greater value for the EC treatment reflects the smaller range in initiation day than the PPF treatments. This is obvious from Fig. 4. Initiation day and elapsed days were significantly but negatively correlated in all treatments except EC. These may be spurious in part. An earlier initiation period would produce shorter rather than longer elapsed days, primarily because of the temperature dependence of developmental processes. This tendency is suggested by the differences in correlations for the PPF and EC treatments.

Initiation day is positively and significantly correlated with emergence day in all treatments except DI. This is despite clones differing significantly for initiation day, emergence day, and elapsed days (Fig. 3, 4, and 5).

Pollen test is negatively correlated with emergence day in all treatments but significantly so in only the DI and MF treatments. Under natural conditions this would appear to have a logical biological basis

as the later the emergence day the less likely would be a strong pollen test because of the influence of lower temperatures on pollen development. These correlations may well be a genetic sampling artifact.

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Table 1. General and specific conditions of three treatment regimes applied in the photoperiod facility, Meringa, 1989, and an external control.

GENERAL CONDITIONS:

- ARTIFICIAL SUNSET (= NATURAL SUNSET FOR TIMING)
- ARTIFICIAL DAWN
- COMMENCING NIGHTLENGTH 11 HR 15 MIN (FEB. 1)
- NIGHT LENGTH INCREASE OF 30 SEC PER DAY
- NIGHT MINIMUM OF 21°C
- LIGHTING - 10 * 150 W INCANDESCENT
  - 54 * 36 W FLUORESCENT
- DRIP IRRIGATED, WITH 100 MM BOTTOM MAINTAINED WATER TABLE

SPECIFIC CONDITIONS:

1. FAR RED
   - MOVED INDOORS (LIT) 29 MIN BEFORE ALMANAC SUNSET
   - MOVED OUTDOORS AT CIVIL TWILIGHT
   - FAR RED TREATMENT - 2 REPS * 5 MIN
     - 2 REPS * 10 MIN
   - RETURNED INDOORS (UNLIT)
2. DAY INTERRUPT
   - MOVED INDOORS (UNLIT) 3 HR BEFORE ALMANAC SUNSET
   - MOVED OUTDOORS 1 HR BEFORE ALMANAC SUNSET
   - MOVED INDOORS (LIT) 29 MIN BEFORE ALMANAC SUNSET
3. MODIFIED FLORIDA
   - INTERNAL CONTROL
4. EXTERNAL CONTROL
   - NATURAL SUNSET AND SUNRISE

Table 2. Coding and identification of the thirty two clones used in the photoperiod experiments at Meringa, 1989.

CODE	CLONE	CODE	CLONE
1	B49119	17	77N1232
2	B51116	18	78N430
3	CP57-603	19	78N636
4	F154	20	78N713
5	F176	21	79N1348
6	H50-3511	22	Q90
7	H56-752	23	Q96
8	H64-936	24	Q99
9	H68-2775	25	Q100
10	H70-0144	26	Q101
11	H71-0505	27	Q113
12	H74-1715	28	Q117
13	66N2008	29	Q124
14	77N557	30	Q130
15	77N606	31	Q133
16	77N638	32	Q138

Table 3. Levels of red (R) and far-red (FR) radiation, and their inverse ratio (FR:R), at four positions below the far red luminaries.

	Radiation ($\mu W\ cm^{-2}$)		
Distance (mm)	R (600-700 nm)	FR (700-800 nm)	FR:R
80	135	1,106	8.2
565	129	1,066	8.3
1,064	91	780	8.6
2,100	51	485	9.5

Table 4. Levels of photosynthetically active (PAR), far-red /near infrared (FR/NIR), and total (PAR + FR/NIR) radiation at four positions below the ceiling of the photoperiod facility.

	Radiation ($\mu W\ cm^{-2}$)		
Distance (mm)	PAR (400-750 nm)	FR/NIR (750-1500 nm)	Total
685	274	208	482
1,530	272	277	549
4,015	162	139	300
5,240	72	60	132

Table 5. Total panicle production (harvested), residual initials, and stalk counts, and two measures of flowering in three photoperiod facility regimes and the external control.

TREATMENT	# PANICLES	# INITIALS	# STALKS	% HARVESTED PANICLES	% TOTAL FLOWERING
FAR RED	71	8	338	21.01	23.37
DAY INTERRUPT	72	14	298	24.16	28.86
MODIFIED FLORIDA	83	8	337	24.63	27.00
EXTERNAL CONTROL	24	3	253	9.49	10.67
	250	33	1,226	20.39	23.08

Table 6. Chi - square tests of two measures of panicle production for three photoperiod facility treatments and the external control.

MEASURE	TREATMENT	STATISTIC	DAY INTERRUPT	MODIFIED FLORIDA	EXTERNAL CONTROL
HARVESTED PANICLES	FAR RED	X^2	0.905	1.258	14.233
		P	0.342	0.262	0.0
	DAY INTERRUPT	X^2		0.019	20.481
		P		0.891	0.0
	MODIFIED FLORIDA	X^2			22.320
		P			0.0
TOTAL PANICLES	FAR RED	X^2	2.481	1.180	15.858
		P	0.115	0.277	0.0
	DAY INTERRUPT	X^2		0.271	27.763
		P		0.603	0.0
	MODIFIED FLORIDA	X^2			24.088
		P			0.0

Table 7. Comparison of flowering in two far-red photoperiod treatments.

TREATMENT	# PANICLES	# STALKS	% HARVESTED PANICLES
5 MIN	33	166	19.88
10 MIN	38	172	22.09

$X^2 = 0.249$; $P = 0.618$

Table 8. Mean flowering percent, for harvested panicles, for 32 clones in three photoperiod regimes and an external control, and emerged panicles in field grown plots, at Meringa, 1989.

CLONE	FAR RED	DAY INTERRUPT	MODIFIED FLORIDA	EXTERNAL CONTROL	FIELD[1]
B49119	0	0	0	--	15.5
B51116	0	0	0	0	0
CP57-603	40.0	100.0	20.0	25.0	54.7
F154	0	0	0	0	--
F176	75.0	41.7	71.4	0	27.2
H50-3511	40.0	0	62.5	0	29.9
H56-752	9.1	0	0	0	5.3
H64-936	7.7	0	0	0	0
H68-2775	68.8	40.0	71.4	0	0
H70-0144	0	0	33.3	0	6.9
H71-0505	20.0	45.5	36.4	0	6.1
H74-1715	0	0	0	0	0
66N2008	0	15.4	0	0	3.7
77N557	0	0	7.1	0	0.3
77N606	0	62.5	0	0	5.4
77N638	37.5	70.0	26.7	10.0	36.3
77N1232	25.0	0	33.3	0	14.9
78N430	25.0	36.4	50.0	0	0.4
78N636	33.3	36.4	21.4	84.6	49.7
78N713	11.1	0	57.1	0	0

(continued)

Table 8. (continued)

CLONE	FAR RED	DAY INTERRUPT	MODIFIED FLORIDA	EXTERNAL CONTROL	FIELD
79N1348	60.0	38.5	15.4	11.1	76.7
Q90	0	0	0	0	2.0
Q96	36.4	40.0	27.3	57.1	39.8
Q99	14.3	0	0	0	0.7
Q100	22.2	0	20.0	0	0
Q101	0	0	0	0	0.2
Q113	0	0	0	0	0.5
Q117	66.7	85.7	100.0	33.3	11.4
Q124	40.0	44.4	31.3	0	2.2
Q130	16.7	0	12.5	0	0
Q133	36.4	100.0	63.6	42.9	6.0
Q138	0	16.7	22.2	0	21.9
Average[1]	21.0	24.2	24.6	9.5	16.2

[1] The value for "Field" is an overestimate as stalks and panicles were counted only for clones flowering in the field.

Table 9. Correlations, over clones, between four measures of panicle development: pollen test and three temporal measures, initiation day (ID), emergence day (ED), and elapsed days (ED - ID), for three photoperiod regimes and an external control.

VARIABLE	INITIATION DAY	EMERGENCE DAY	ELAPSED DAYS
	FAR RED (N = 63)		
POLLEN TEST	-0.135	-0.300	-0.207
INITIATION DAY		0.381**	-0.337**
EMERGENCE DAY			0.742**
	DAY INTERRUPT (N = 68)		
POLLEN TEST	-0.227	-0.491**	-0.266*
INITIATION DAY		-0.216	-0.514**
EMERGENCE DAY			0.723**
	MODIFIED FLORIDA (N = 77)		
POLLEN TEST	-0.282*	-0.281*	-0.093
INITIATION DAY		0.411**	-0.286*
EMERGENCE DAY			0.756**
	EXTERNAL CONTROL (N = 14)		
POLLEN TEST	0.306	-0.102	-0.255
INITIATION DAY		0.604*	0.290
EMERGENCE DAY			0.938**

*, $P \leq 0.05$; **, $P \leq 0.01$.

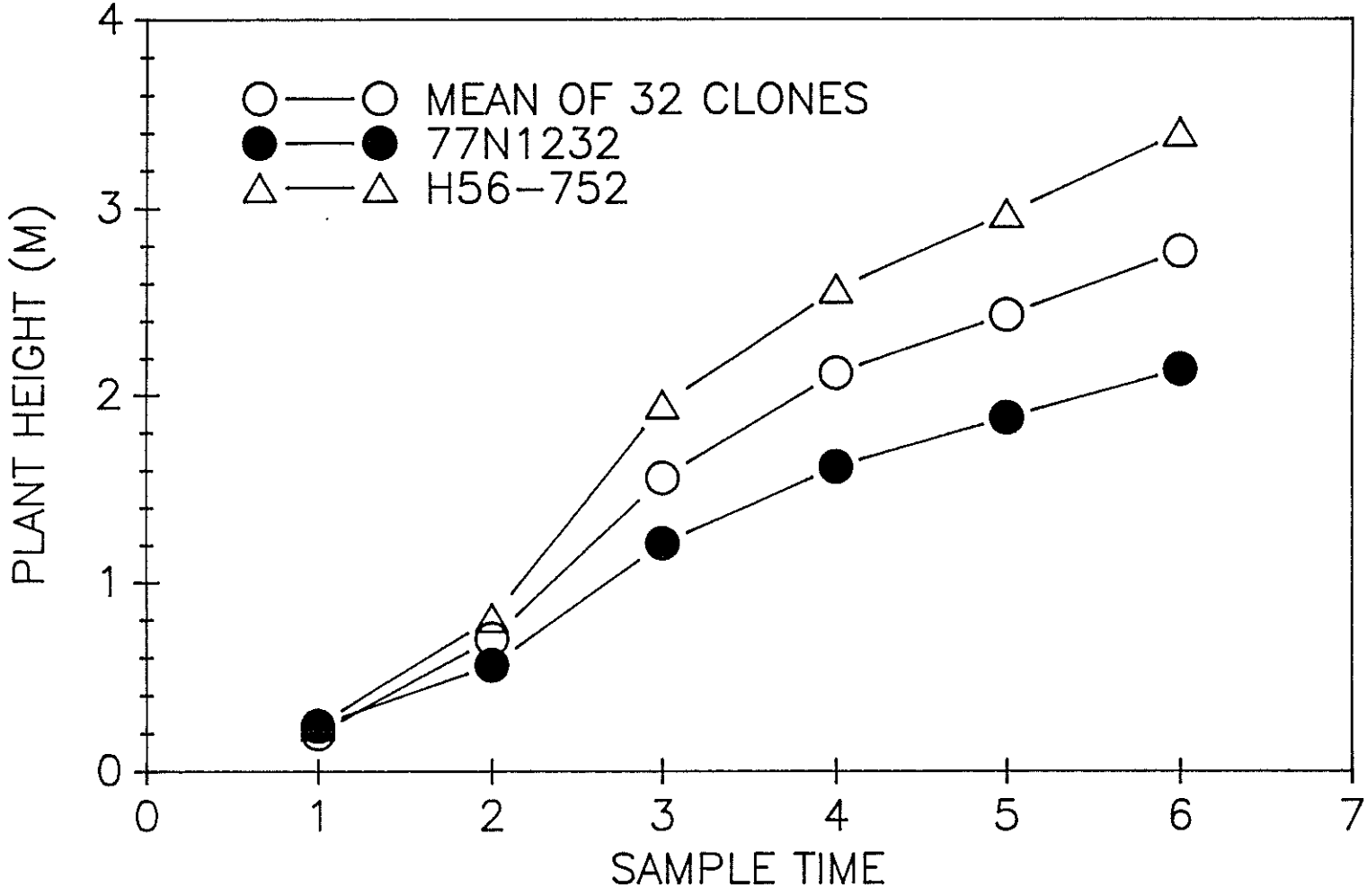

FIG. 1. STALK GROWTH OF PHOTOPERIOD FACILITY ENTRIES, NOVEMBER 1, 1988 TO APRIL 1. 1989.

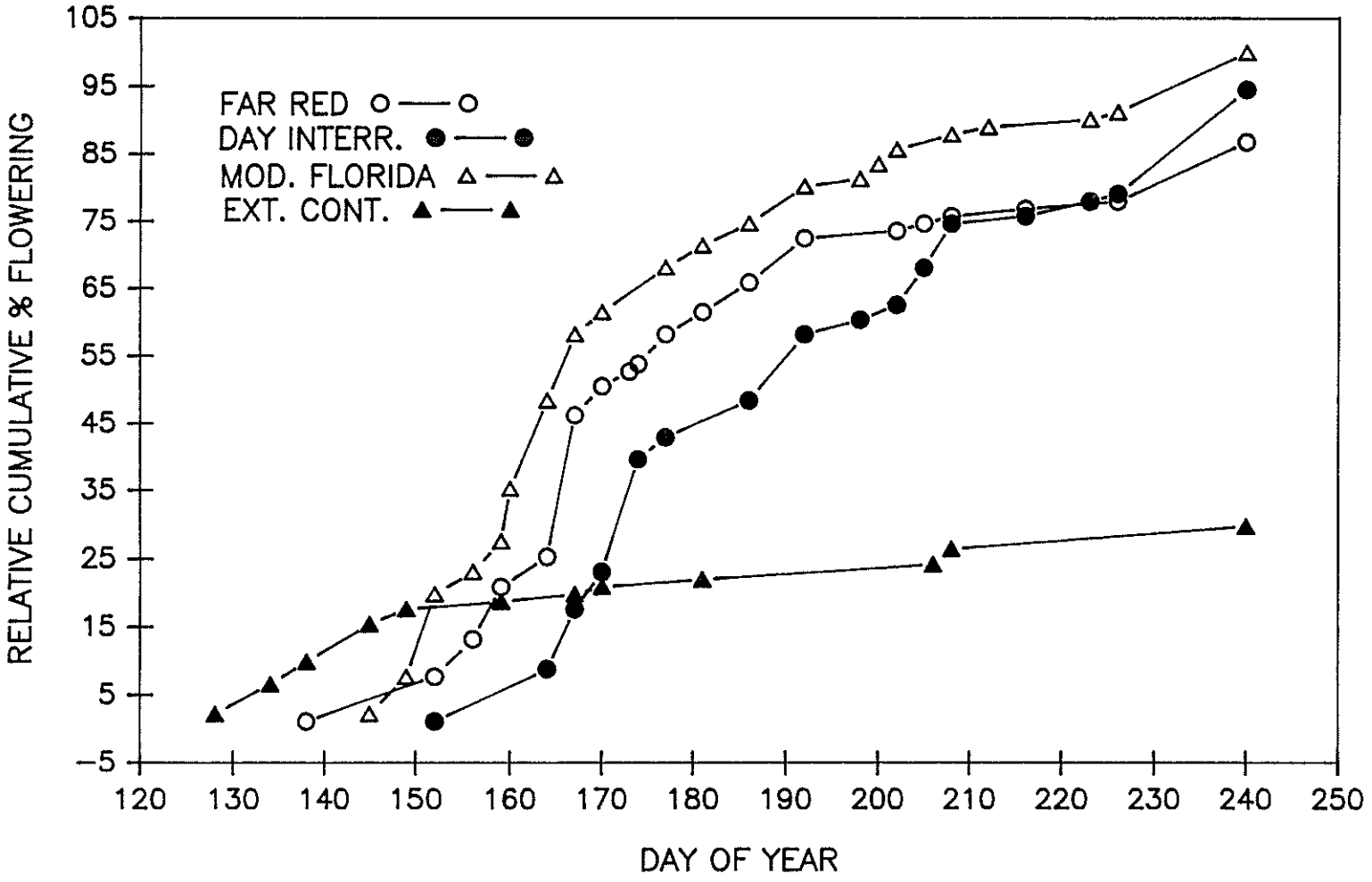

FIG. 2. RELATIVE CUMULATIVE FLOWERING IN THE PHOTOPERIOD FACILITY IN 1989.

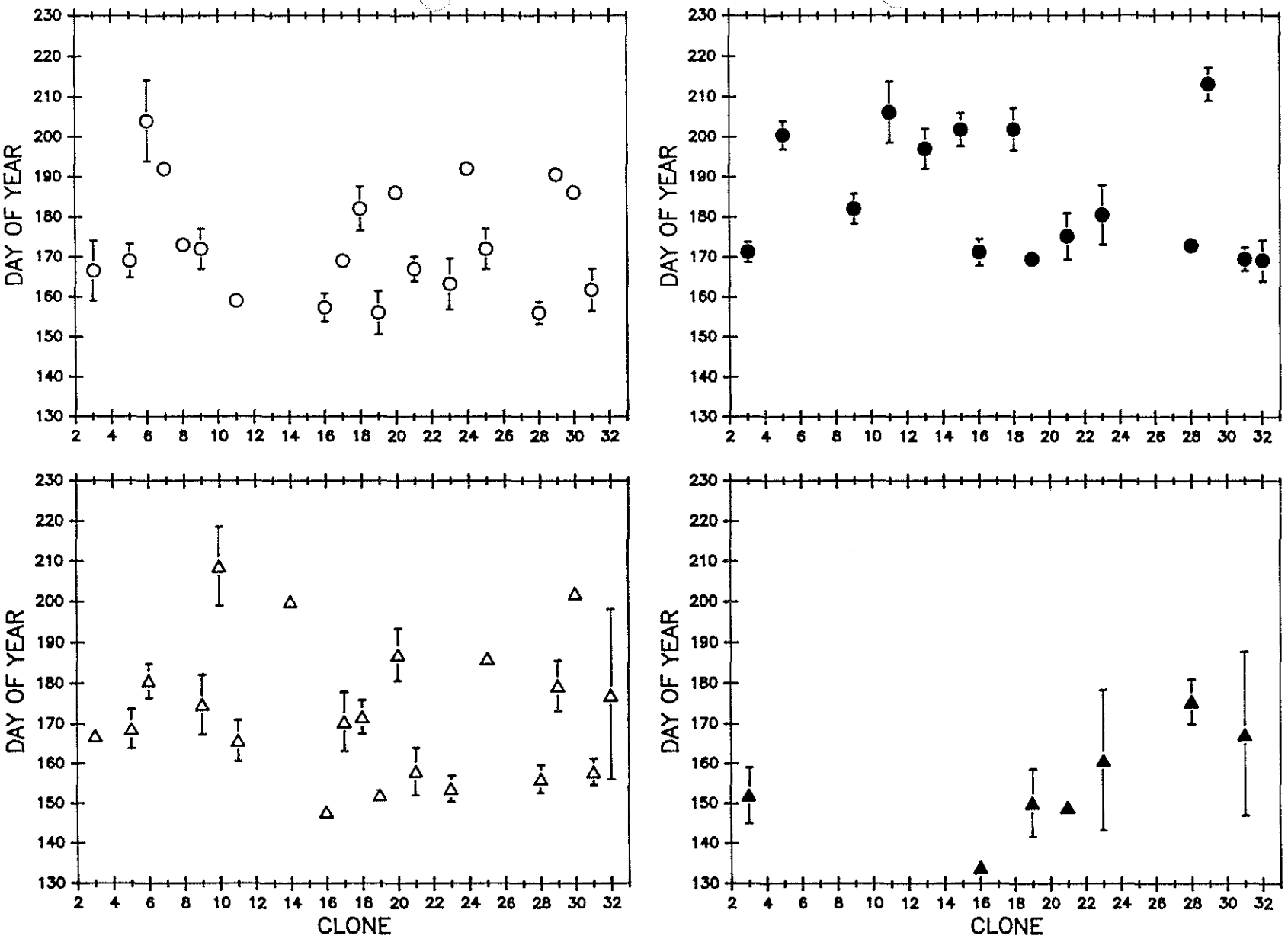

FIG. 3. MEAN EMERGENCE DAY, AND ITS STANDARD DEVIATION, FOR THIRTY TWO CLONES SUBJECTED TO FOUR PHOTOPERIOD REGIMES IN 1989: ○ FAR RED; ● DAY INTERRUPT; △ MODIFIED FLORIDA; ▲ EXTERNAL CONTROL.

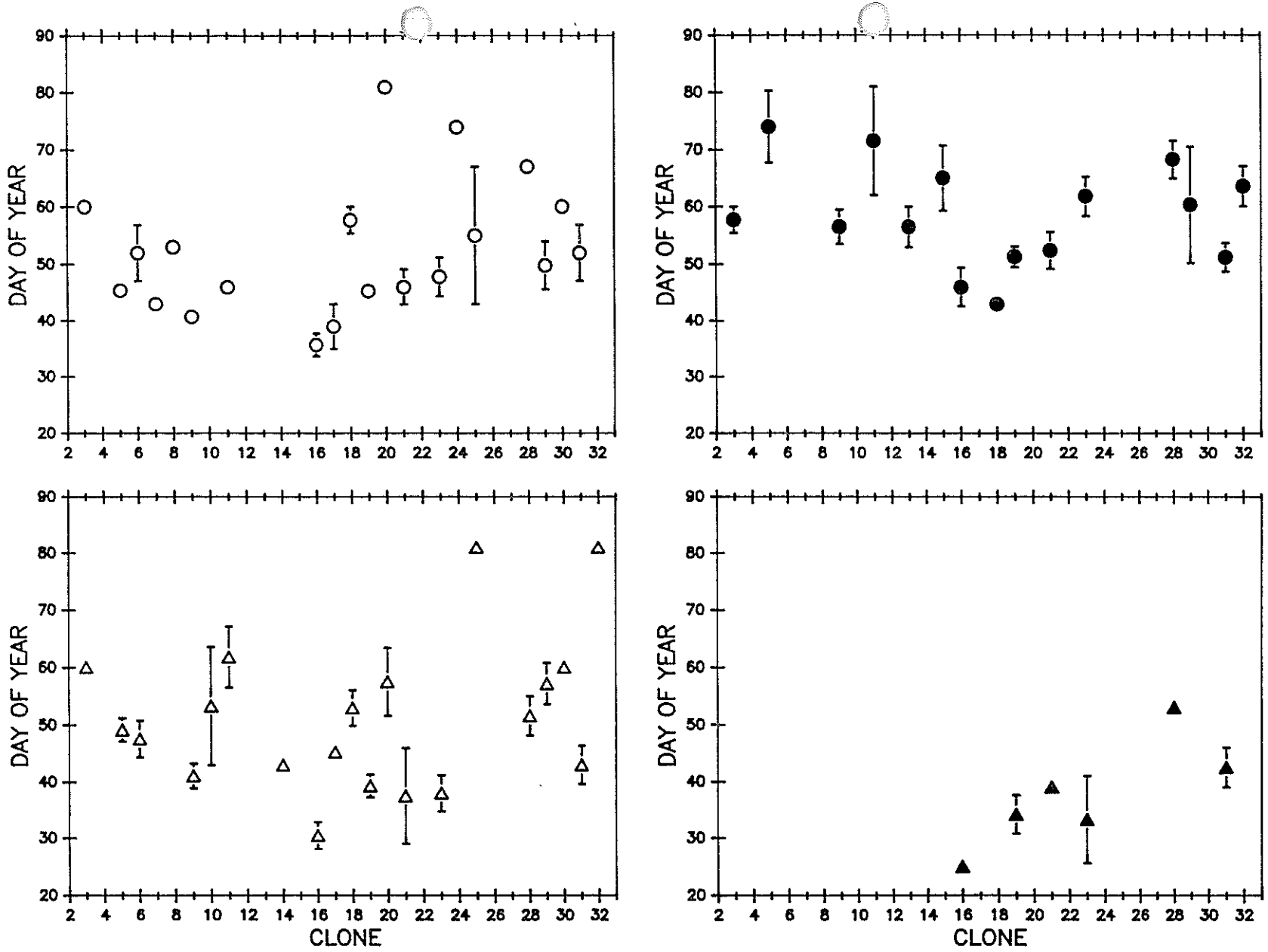

FIG. 4. MEAN INITIATION DAY, AND ITS STANDARD DEVIATION, FOR THIRTY TWO CLONES SUBJECTED TO FOUR PHOTOPERIOD REGIMES IN 1989: ○ FAR RED; ● DAY INTERRUPT; △ MODIFIED FLORIDA; ▲ EXTERNAL CONTROL.

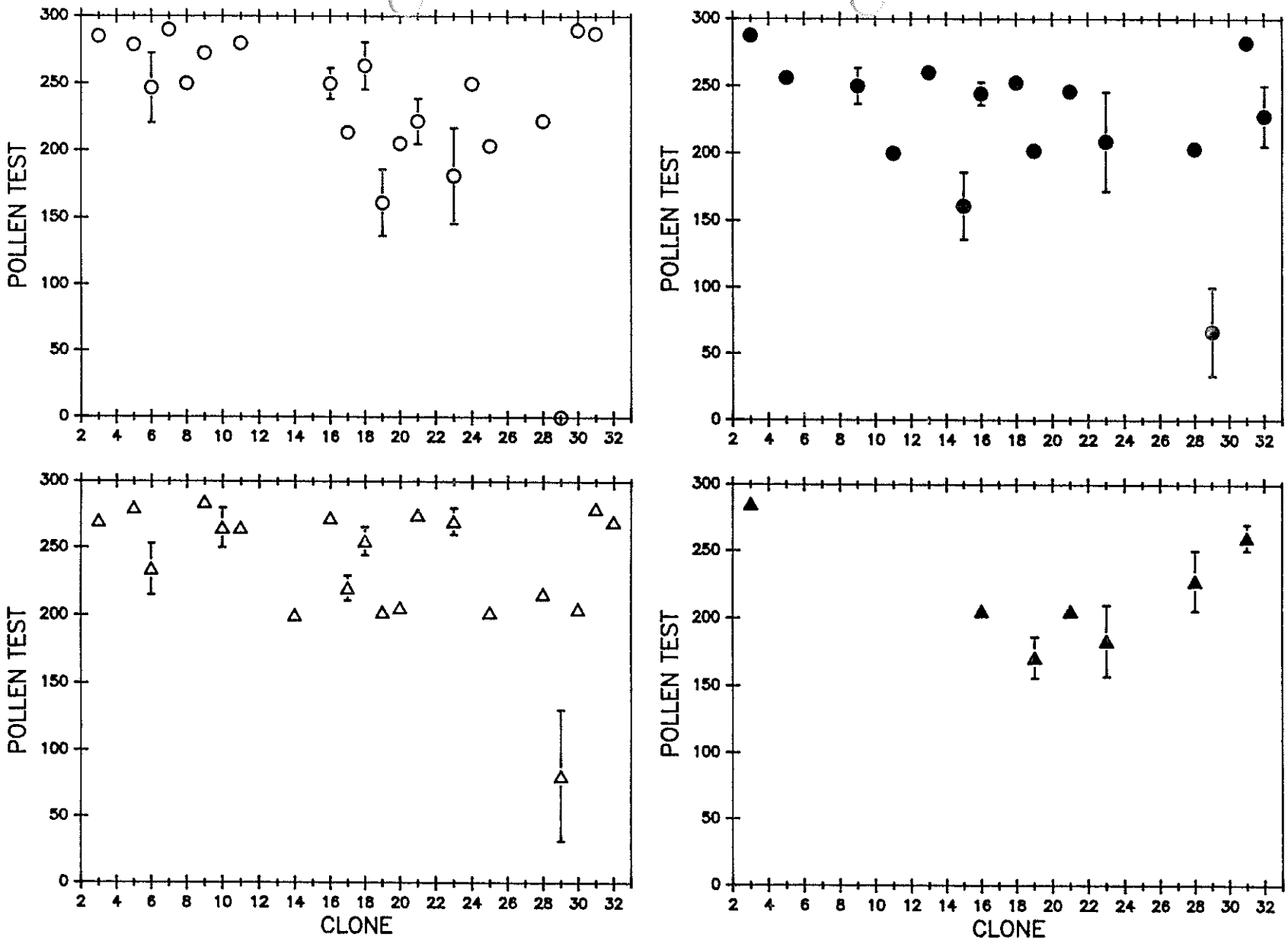

FIG. 6. MEAN POLLEN TEST, AND ITS STANDARD DEVIATION, FOR THIRTY TWO CLONES SUBJECTED TO FOUR PHOTOPERIOD REGIMES FOR 1989: ○ FAR RED; ● DAY INTERRUPT; △ MODIFIED FLORIDA; ▲ EXTERNAL CONTROL.