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PHOTOPERIODIC RESPONSE AND ACCELERATED GENERATION TURNOVER IN CHICKPEA

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ABSTRACT

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Rapid generation advancement enables the breeder to produce and test near homozygous lines in a shorter period of time. Chickpea is a quantitative long-day plant. Three experiments were conducted, two at ICRISAT Center Hyderabad and one at Bangalore, from December 1978 to August 1979 to assess potential of extended daylength to shorten the life cycle by early flower induction. The studies involved cultivars of different maturity groups. Twenty-four hour daylength treatment by using incandescent lights induced early flowering. All cultivars flowered simultaneously and took 32 to 35 days after sowing, in contrast to 32 to 74 days taken for 50% flowering under normal daylengths. Plants exposed to 24-h daylength had slightly increased plant height, more pods and larger seeds in one of the experiments. Physiologically mature pods could be harvested as early as 62 days after sowing from plants induced to flower early by 24-h treatment. Once flowering was induced, continuation of the extended daylength treatment had no effect on maturity. This technique will allow harvesting of more than one generation per year.

INTRODUCTION

Techniques that accelerate generation turnover allow more rapid development of fixed lines and earlier determination of the value of breeding lines, and make breeding programs more responsive to contemporary demand. Usually, reducing the length of a breeding cycle involves a compromise; for example, some techniques of rapid generation turnover are labor-intensive or require modified environments in expensive facilities, and also negate the use of early-generation selection where it is a feasible proposition.

Procedures for, and use of, accelerated generation turnover have not been reported in chickpeas (*Cicer arietinum* L.). The chickpea improvement program at ICRISAT has been restricted largely to one generation per year for various reasons. Off-season nurseries during the summer in the drier, high altitude Himalayan region of India and Lebanon have been moderately successful, but their use is inhibited by cost and inaccessability in the Himalayan region of India and by quarantine problems in Lebanon.

Chickpeas have been variously reported to be long-day (Nanda and Chinoy, 1960a, b; Eshel, 1968; Mathon, 1965; Pandey et al., 1977), quantitative long-day (Sandhu and Hodges, 1971; Van der Maesen, 1972), day-neutral (Allard and Zaumayer, 1944), and short-day plants (Bhardwaj, 1955). In a study in controlled environments of three cultivars that ranged from early to late in flowering and maturity under field conditions, Summerfield et al. (1979) found that flowering occurred more rapidly in long (15-h) daylengths than in short (11- and 12-h) daylengths of PAR lighting, and that there was marked photoperiod × temperature interaction.

This study was initiated as a preliminary investigation of the influence of artificially extended daylengths on flowering of chickpea cultivars in the field during different seasons of the year in southern India. The primary objective was to determine the extent to which accelerated generation turnover could be attained for a range of chickpea ecotypes using long daylengths.

MATERIAL AND METHODS

Three experiments were conducted. All were grown under normal field conditions, with natural daylength alone and natural daylength extended artificially to 24 h. Light extension was by 200-watt incandescent bulbs on a grid of 1.5 m × 1.5 m maintained approximately 60 cm above the canopy (experiment I); 60-watt incandescent bulbs on a grid of 1.5 m × 1.5 m maintained approximately 30 cm above the canopy (experiment II); and by 60-watt incandescent bulbs on a grid 2.0 m × 1.5 m maintained at a fixed height of 1.2 m above the soil surface (experiment III). A transect across the middle of the grid of lights revealed an average illuminance of approximately 110 lux for experiment I and slightly less than 10 lux for experiments II and III.

Experiment I was conducted with an early *desi* cultivar, CPS-1, sown on 15 December 1978 at Hyderabad (17° 27′N, 545 m), India, in a vertisol using 30-cm rows with plants 10 cm apart within the row. Four treatments were imposed, viz., natural and 24-h daylengths as main plots, with and without foliar application of nutrients as subplots. The blocks were not replicated. The extended daylength was imposed 20 days after sowing (approximately 10 to 12 days after emergence). The foliar spray contained nitrogen and phosphorus at a rate equivalent to 25 kg ha^{-1} of N (as urea) and 20 kg ha^{-1} of P_2O_5 (as superphosphate). The first spray was applied 21 days after sowing and was repeated three times at 6-day intervals. Each subplot contained approximately 675 plants, and the time of opening of the first flower was recorded for each plant. Ten plants were sampled at random from each treatment at maturity, and yield components were measured.

Experiment II included 18 cultivars ranging from early to late flowering under normal field sowing in October at Hyderabad. The trial was sown on 17 January 1979 in a vertisol using 60-cm rows and 10-cm spacings within the row. The design was a split plot with daylength as main plots and culti-

TABLE I

Some climatological data for the three experiments (weekly means)

	Weeks after sowing 1	2	3	4	5	6	7	8	9	10	11
Experiment I, Hyderabad — sown 15 Dec. 1978											
Daylength + CT[1]	11.32	11.32	11.33	11.33	11.36	11.39	—	—	—	—	—
Daylength + AT[1]	12.27	12.27	12.28	12.28	12.29	12.32	—	—	—	—	—
Mean max. temp. (°C)	26.5	27.5	27.5	28.0	27.5	28.5	—	—	—	—	—
Mean min. temp. (°C)	13.5	15.0	16.0	14.5	15.0	18.5	—	—	—	—	—
Experiment II, Hyderabad — sown 17 Jan. 1979											
Daylength + CT[1]	11.37	11.41	11.45	11.52	11.58	12.06	12.11	12.17	12.24	—	—
Daylength + AT[1]	12.31	12.34	12.40	12.45	12.50	12.57	13.02	13.08	13.16	—	—
Mean max. temp. (°C)	30.5	29.5	29.0	30.0	31.5	32.0	33.5	36.5	36.5	—	—
Mean min. temp. (°C)	17.0	18.0	19.0	18.5	19.0	18.0	14.5	20.0	21.5	—	—
Experiment III, Bangalore — sown 17 April 1979											
Daylength + CT[1]	12.50	12.54	12.59	13.03	13.06	13.09	13.12	13.15	13.15	13.16	13.16
Daylength + AT[1]	13.40	13.45	13.51	13.55	13.59	14.03	14.06	14.09	14.09	14.11	14.11
Mean max. temp. (°C)	←	34.3[2] →	←		33.8	→	←		30.1		→
Mean min. temp. (°C)		21.4			22.5				28.0		

[1] CT = Civil twilight; AT = Astronomical twilight; hours and minutes.
[2] Monthly means.

vars as subplots. There were four replications within each main plot. The subplot was a single 3-m row containing 30 plants. The 24-h daylength was imposed at emergence and continued for 24 days, by which time all cultivars had begun flowering in that treatment. The extended daylength was continued for 32 additional days in two of the replications, the other two replications being exposed to normal daylengths commencing 25 days after emergence. The trial was terminated 62 days after sowing.

Each subplot was observed for appearance of the first flower and for 50% flowering (50% of plants having open flowers). At maturity, plant height and number of pods per plant were recorded for 10 plants per subplot, and the entire plot was harvested for seed yield (g/plant at constant air-dry weight) and seed weight (g/100 clean whole unshrivelled seed regardless of size). On day 52, 57 and 62 after sowing, 10 pods were sampled at random from the lowest fruiting nodes of plants in different sections of each subplot, and 10 seeds (one from each pod) were tested for germination under laboratory bench conditions after being dried at 40°C for 24 h.

Experiment III was conducted at Bangalore (12°58′N, 899 m), India, using an off-season summer sowing, on 17 April 1979, of a bulk F_3 population of a cross of an early (P-436) × late (G-130) cultivar. The plants were grown in plastic tunnels to avoid waterlogging and incidence of foliar diseases. Separate unreplicated blocks were exposed to the natural daylength and 24-h days, and each block contained 320 plants established in 75-cm rows with plants 10 cm apart in the row. The plants emerged on 22 April, and the extended daylength was not imposed until 14 May, i.e., 22 days after emergence. Each block was observed for the date of first flower, and for the date of maturity for the entire population.

No significant problems due to weeds, insects or disease occurred in the three experiments. There was no visible moisture stress in any of the experiments. Moderate basal fertilizers were applied, i.e., approximately 60 kg ha^{-1} P_2O_5 and 40 kg ha^{-1} N for experiments I and II, and 40 kg ha^{-1} N as a side-dressing in experiment III.

The natural daylengths (including civil and astronomical twilight) and maximum and minimum temperatures on a weekly mean basis for each of the experiments are presented in Table I.

RESULTS

Experiment I

The cumulative percentage of plants of cv. CPS-1 that had flowered is plotted against days after sowing in Fig. 1. Flowering begun on day 40 under 24-h days versus day 52 under normal daylengths, and all plants had flowered by day 54 and day 62, respectively, in these treatments. Foliar fertilization resulted in accelerated flowering, particularly in the 24-h days. The combination of extended daylength and foliar fertilization re-

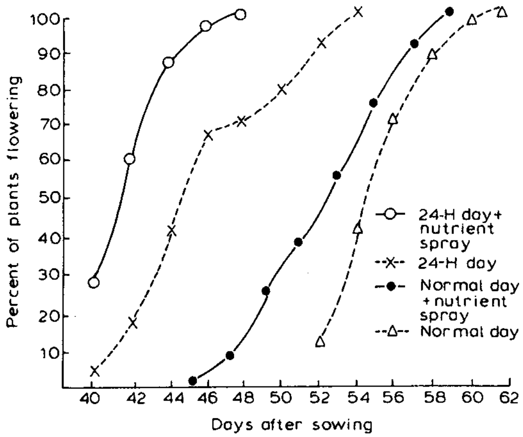

Fig. 1. Effect of 24-h daylength and foliar fertilization on flowering in chickpea cv. CPS-1; Experiment I.

duced the time to first flower, 50% flowering, and 100% flowering by 12 days, 13 days, and 14 days, respectively.

There was a small but significant increase in plant height due to extension of daylength, particularly in the absence of foliar fertilization (Table II). Foliar fertilization resulted in an increase in plant height only under the normal daylength. Daylength and foliar fertilization had no significant influence on number of seeds per pod. However, the number of pods and

TABLE II

Effect of daylength and foliar fertilization (NS) on vegetative and reproductive development of cv. CPS-1; Experiment I

Character	Normal day		24-h day	
	+ NS	−NS	+ NS	−NS
Plant height (cm)	29.4 (0.31)[1]	26.3 (0.62)	31.4 (0.75)	29.4 (0.52)
Pods per plant	24.7 (2.22)	8.7 (0.82)	22.7 (1.90)	5.5 (0.27)
Seeds per plant	27.3 (2.57)	9.6 (0.73)	27.3 (2.72)	7.0 (0.54)
Seeds per pod	1.11 (0.048)	1.12 (0.054)	1.19 (0.042)	1.26 (0.059)

[1] Standard error of the mean.

seeds per plant was greatly increased by foliar fertilization and was slightly lower in the 24-h than in the normal daylength treatment in the absence of foliar fertilization.

Experiment II

The results for various phenological and plant characters are summarized in Table III, in which the cultivars are ordered from early to late flowering on the basis of normal field performance for October sowings at Hyderabad. Only seven of the earliest flowering cultivars attained 50% flowering and completed normal reproductive growth in all replications of the normal daylength treatment prior to termination of the trial on 20 March (62 days after sowing). Most of the later flowering cultivars failed to flower, and all of them failed to reproduce, under normal daylengths for the 17 January sowing, and most plants of these cultivars died by the end of the experiment, possibly owing to high temperatures (Table I). In contrast, all 18 cultivars flowered and reproduced successfully under the 24-h daylength, with 50% flowering occurring virtually simultaneously in all cultivars 32 to 35 days after sowing.

Despite the small size of the plants, all cultivars matured normally under the 24-h daylength and produced reasonable numbers of seed (Table III), which tended to be slightly smaller in size than seed produced by plants grown using the normal October-sowing date. Averaged over the seven cultivars that reproduced in both daylength regimes, the 24-h daylength resulted in substantially earlier flowering, slightly increased plant height, and the production of greater numbers of pods and larger seed. The coefficients of variation for seed yield and pod number per plant were considerably smaller under the 24-h daylength, indicating that these plants were more uniform in reproductive development than those exposed to normal daylengths.

For plants exposed to the 24-h daylength prior to flowering, continuation of the extended daylength during the reproductive phase had no significant influence on any plant character measured, except seed weight. There was no interaction between cultivars and daylength during the reproductive phase for any character. Averaged over the 18 cultivars, seed weight was greater for plants exposed to normal daylengths during the reproductive phase, but the effect was relatively small, e.g. 20.7 vs. 18.6 g/100 seeds.

Averaged over cultivars, germination of seed harvested from the 24-h daylength treatment 52, 57, and 62 days after sowing was 30, 75, and 95%, respectively, for the plots exposed only until flowering, and 21, 72 and 88%, respectively, for the plots exposed until maturity. The reason for lower viability of seeds from the latter treatment is unknown. The data suggest that seed may be harvested successfully before maturity in order to further shorten the crop cycle. However, the lower germination may impose a selective bias, particularly in populations undergoing single-seed descent. More detailed study of the relationship between seed development and germinability is required.

TABLE III

Some phenological, growth, and yield characteristics of 18 cultivars grown under normal (N) and 24-h daylengths when sown at Hyderabad on 17 January 1979, and days to flowering for normal October field sowings.

Cultivar	Type	Days to flowering					Plant height (cm)		Seed yield per plant (g)		Pods per plant		Seed weight (g/100)	
		50F[1] October sowing	FF[2]		50 F[1]									
			N day	24-h day	N day	24-h day	N day	24-h day	N day	24-h day	N day	24-h day	N day	24-h day
Chafa	desi	32	42	29	46	33	18.7	21.4	2.1	3.7	14.7	18.9	11.1	14.2
Annigeri	desi	32	44	30	47	33	20.3	20.7	1.7	3.1	13.2	16.9	16.2	17.0
P-436	desi	36	45	32	49	35	20.0	20.0	1.4	2.4	9.4	14.2	13.3	15.3
NEC-143	kabuli	42	44	29	48	33	23.2	24.0	2.1	3.2	15.2	19.7	10.9	12.8
CPS-1	desi	47	45	32	49	35	23.1	27.6	1.7	3.7	10.5	15.4	13.1	18.0
PRR-1	desi	49	44	31	49	34	22.6	26.6	0.9	2.8	2.8	6.2	29.3	35.7
P-2591	kabuli	50	48	29	53	32	22.6	23.5	0.8	3.7	4.5	14.5	14.0	18.2
850-3/27	desi	54	52	31	(58)[3]	34	ND[4]	22.4	ND	4.5	ND	14.7	ND	26.9
Radhey	desi	55	49	30	(53)	34	ND	25.2	ND	3.1	ND	10.4	ND	23.2
L-550	kabuli	60	(52)	29	ND	32	ND	20.9	ND	3.6	ND	14.8	ND	20.7
K-1189	kabuli	62	(49)	30	(53)	34	ND	40.6	ND	4.3	ND	20.0	ND	21.1
G-130	desi	62	ND	31	ND	34	ND	21.0	ND	3.1	ND	16.5	ND	14.3
H-208	desi	62	ND	30	ND	34	ND	19.7	ND	2.9	ND	17.0	ND	12.5
K-468	desi	62	ND	30	ND	32	ND	21.9	ND	4.2	ND	21.9	ND	12.8
L-532	kabuli	68	ND	32	ND	35	ND	24.8	ND	3.7	ND	15.3	ND	21.4
Rabat	kabuli	68	(53)	29	ND	33	ND	24.9	ND	3.2	ND	9.8	ND	27.6
No. 501	kabuli	68	ND	30	ND	33	ND	26.7	ND	4.8	ND	14.0	ND	28.7
F-496	desi	74	ND	31	ND	33	ND	22.0	ND	4.2	ND	24.0	ND	12.9
Mean all cvs.		54.6	ND	30.3	ND	33.5	ND	23.9	ND	3.6	ND	15.8	ND	19.7
C.V.% all cvs.				3.5		3.6		11.1		37.8		35.4		6.9
Mean 1st 7 cvs.			44.6	30.3	48.7	33.6	21.5	23.4	1.5	3.2	10.0	15.1	15.4	18.7
Difference betw. means			14.3*		15.1*		1.9*		1.7*		5.1*		3.3*	
C.V.% 1st 7 cvs.			3.2	4.0	2.8	4.0	8.9	8.4	56.9	24.5	54.6	24.8	8.5	7.4

[1] 50F = 50% of plant bear open flowers. [2] FF = First flower recorded in plot. [3] Figures in parentheses indicate flowering occurred in only one or two replications. [4] ND = No data recorded. Plants succumbed to high temperatures. *Significant at 0.01 level of probability.

Experiment III

First flowering of plants within the segregating population under normal daylengths at Bangalore was observed on 21 June, i.e., 66 days after sowing. Under the 24-h daylength, first flowering occurred on 28 May, 42 days after sowing and 15 days after the extended light regime was commenced. It was not possible to document the distribution of flowering over time for these plots. However, daylength extension was terminated on 15 July (89 days after sowing), at which time all plants within the 24-h daylength plot were mature and those under the normal daylength were in the late podding stages. At maturity the plants grown under the 24-h daylength were approximately 50% taller than those grown under the normal daylength.

DISCUSSION

In the present studies and those of Summerfield et al. (1979), the duration of the pre-initiation and post-initiation phases were not determined separately, and this greatly reduces the usefulness of the data in determining the influence of environmental factors on floral behaviour. However, the uniformity and shortness of the pre-flowering phase under the 24-h daylength in Experiment II (32 to 35 days; Table III) suggests that all cultivars were approaching a minimum threshold; that is, initiation probably occurred soon after emergence in those conditions. This indicates that the juvenile phase in chickpeas, if any, is probably of a short duration. The occurrence of flowering only 15 days after imposition of 24-h daylengths in Experiment III suggests that the response to long days is very rapid in chickpeas, and probably also involves the post-initiation period.

CPS-1 was included in Experiments I and II, and cultivars Chafa, Rabat, and G-130 were common to Experiment II and the trials of Summerfield et al. (1979). The flowering responses of these cultivars in these trials are summarized in Table IV, the data from Summerfield et al. (1979) being estimated from his graphical representations. Under normal daylengths, first flowering and 50% flowering of CPS-1 occurred earlier in Experiment II than in Experiment I, and this may be related to the longer and increasing daylengths and the higher night and day temperatures during Experiment II (Table I). Under 24-h daylengths, flowering of CPS-1 occurred much more rapidly in Experiment II. This may be associated with the higher temperature regime, but the comparison between experiments is confounded since the long days on Experiment I were not imposed until 20 days after sowing. There is some evidence that foliar fertilization resulted in earlier flowering under normal daylengths and more synchronized flowering in 24-h daylength (Table IV).

In their study of growth and development in chickpeas, Summerfield et al. (1979) considered three daylengths (11, 12, 15 h) and four day/night temperatures (30/18, 30/10, 22/18, 22/10°C). The weekly mean maximum

TABLE IV

Days to first flowering (FF) and 50% flowering (50 F) for certain cultivars common to different experiments

Experiment and treatment	Cultivar and character							
	CPS-1		Chafa		Rabat		G-130	
	FF	50 F	FF	50 F	FF	50 F	FF	50 F
Experiment I								
24 h[1] + NS[2]	40	41	CNE[3]	CNE	CNE	CNE	CNE	CNE
24 h – NS	40	45	CNE	CNE	CNE	CNE	CNE	CNE
Normal + NS	45	53	CNE	CNE	CNE	CNE	CNE	CNE
Normal – NS	52	55	CNE	CNE	CNE	CNE	CNE	CNE
Experiment II								
24 h	32	35	29	33	29	33	31	34
Normal	45	49	42	46	(53)[4]			
Summerfield et al. (1979)								
11 h/30–18°C[5]	CNE	CNE	41	CNE	78	CNE	71	CNE
12 h/30–18°C	CNE	CNE	36	CNE	71	CNE	80	CNE
15 h/30–18°C	CNE	CNE	27	CNE	57	CNE	51	CNE

[1] Length of day (light) period. [2] NS = Nutrient spray. [3] CNE = Cultivar not entered in trial. [4] Indicates flowering in some replicates only. [5] Day temperature—night temperature.

and mean minimum temperatures for Experiment II (Table I) were reasonably consistent during the first 5 to 7 weeks of growth, and approximated the maximum day and night temperature combination (30/18°C) used by Summerfield et al. (1979). Depending on whether the effective daylength for chickpeas is considered to include civil or astronomical twilight, the natural daylength regime for Experiment II (Table I) was intermediate between the 11- and 12-h treatments or was somewhat longer than the 12-h treatment of Summerfield et al. (1979), respectively. For cv. Chafa, the number of days to flowering in the 11-h/30—18°C regime of Summerfield et al. (1979) was a close simulation of the response in the field to natural daylengths in Experiment II (Table IV), and the days to flowering for their 15 h/30—18°C treatment was similar to that in 24-h daylength treatment of Experiment II. A similar comparison is not possible for Rabat and G-130 since both these cultivars died without flowering within 62 days of sowing under normal daylengths in Experiment II. However, they flowered as early as Chafa under the 24-h daylength in the field (29 and 31 days, respectively; Table III), whereas Summerfield et al. (1979) observed flowering only after 57 and 51 days, respectively, in their 15-h/30—18°C treatment. These data suggest that onset of flowering in all three cultivars is sensitive to photoperiod, but that they differ in the photoperiodic range to which they can respond; that is, at these temperatures Chafa was induced to flower at the earliest possible time by 15-h daylengths, whereas flowering time in Rabat and G-130 was responsive to daylengths longer than 15 h.

The results of the field studies reported here support certain of the conclusions of Summerfield et al. (1979) from controlled environment experiments. The flowering in chickpeas is accelerated in long days and warm temperature regimes. In the subtropics, sophisticated and complex environmental modification is not required to induce early flowering and pod set in chickpea, and therefore a detailed physiological understanding of the ontogeny is not necessary.

Simply, artificial extension of daylength to 24 h was effective and adequate for cultivars ranging virtually from the earliest to the latest ones available with respect to flowering and maturity. The data suggested that it was unnecessary to maintain the extended daylength during the reproductive phase.

There is nothing published on the minimum illuminance required to elicit photoperiodic response in chickpeas and on its response to spectral change. In these studies, illuminance as low as 10 lux from incandescent bulbs proved effective, but further information is required on these aspects to develop efficient procedures for extension of daylengths in the field. For example, in view of the responses obtained to extended daylength in these studies, a form of night-break may be effective in inducing early flowering of chickpeas and the intensity/spectral/logistic implications require investigation.

The response of cultivar CPS-1 to foliar fertilization was substantial, particularly in advancing the time of flowering and increasing the number of pods per plant. Response to foliar fertilization in increasing yield of chickpeas has been reported by Saxena and Sheldrake (1980).

Using the methods applied in these studies, it should be possible to grow four generations of chickpeas annually at Hyderabad, i.e., two generations in the field during autumn—winter (September and January sowings), and two generations in spring—summer, possibly in a glasshouse or similar facility in which temperature can be controlled and the plants protected from disease. This would allow accelerated turnover of breeding generations with or without selection, with field testing of near-homozygous F_5-derived lines in the F_6 generation being possible only 2 years after making the initial cross. The importance of attaining accelerated turnover of generations in chickpea improvement cannot be overemphasized.

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