CROP BREEDING, GENETICS & CYTOLOGY

Photoperiod Effects on Seed Quality Traits in Peanut

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ABSTRACT

Peanut (*Arachis hypogaea* L.) is a rich source of oil, protein, minerals, and vitamins. The chemical and physical seed quality aspects are gaining importance because of increased use of peanut as a food crop; however, little or no investigation has been carried out on the effect of photoperiod on these traits. The objective of this study was to determine the effect of photoperiod on seed quality traits. The experiment was conducted for three seasons in a three replicate split-plot randomized complete block design with three photoperiods (ND = Normal day, 12 h; SD = Short day, 8 h; LD = Long day, 16 h) as main plots and 10 genotypes as subplots. The SD and LD conditions were created artificially. Pooled analysis of variance, based on a mixed linear model with season (S) as random and photoperiod (Ph) and genotype (G) as fixed effects, indicated significant S and G differences for most of the traits studied. Ph differences were significant only for shelling percentage and palmitic and eicosenoic fatty acids. The interactions S × Ph, S × G, Ph × G, and S × Ph × G were significant for several traits. When SD and LD treatments were compared with ND, shelling percentage increased under SD. Oil content, oleic (O) and linolenic (L) fatty acids, and O/L ratio were not affected due to variation in photoperiod. However, palmitic acid increased and eicosenoic acid decreased under SD. The SD conditions were more interactive with seasons and genotypes for fatty acids. High performing and photoperiod insensitive genotypes were identified for various seed quality traits. These genotypes would be useful in breeding programs aimed at developing high yielding genotypes with improved seed quality for edible purposes.

Photoperiod insensitivity plays a significant role in adaptation of crop genotypes across diverse environments. Unlike other crops, the photoperiod effect in peanut is manifested during the post-flowering reproductive development and phenology. Long days increase crop growth rate and decrease partitioning of photosynthate to pods and the duration of effective pod filling phase (Ketring, 1979; Witzenberger et al., 1988; Bagnal and King, 1991; Bell et al., 1991; Nigam et al., 1994 and 1998). Temperature also has a significant influence on plant and pod growth rates in peanut (Leong and Ong, 1983; Bagnall and King, 1991; Cox, 1979; Nigam et al., 1994). Photoperiod and temperature interact in influencing the partitioning of photosynthate to pods. At low temperature, photoperiod does not effect partitioning; however, at higher temperature it significantly increases the partitioning of photosynthate to pods under short days. Genotypes respond to photoperiod × temperature interactions differentially (Nigam et al., 1994 and 1998).

Chemical composition of seed in soybean [*Glycine max* (L.) Merr.] is influenced by photoperiod. Pre-flowering short-day treatment increases protein, oil, and oleic fatty acid but decreases linolenic fatty acid (Han-TianFu et al., 1995). When the short-day treatment is imposed post-flowering, it results in higher protein and palmitic and oleic fatty acids but oil and linolenic and linolenic fatty acids are lowered (Han-TianFu et al., 1997). There is little information available in the literature on the effect of photoperiod on seed quality traits in peanut. The seed quality aspects are gaining importance because of increased use of peanut as a food crop in developing countries. Peanut seed contains 44 to 56% oil and 22 to 30% protein on a dry seed basis and is a rich source of minerals (phosphorus, calcium, magnesium, and potassium) and vitamins (E, K, and B group) (Savage and Keenan, 1994). Seed size, shape, color, oil and protein content, fatty acid and amino acid composition, taste, and flavor are the major quality traits of peanut. Oleic (O), linolenic (L), and palmitic fatty acids, together, account for over 80% of the total fat in peanut seed (Dwivedi et al., 1993). Peanut seed with a high O/L ratio have long product stability and shelf-life (James and Young, 1983; Branch et al., 1990). Large genetic variation for seed size, oil content, and fatty acid composition is reported in peanut germplasm (Treadwell et al., 1983; Norden et al., 1987; Dwivedi et al., 1989, 1998; Branch et al, 1990). Photoperiod has a significant influence on shelling percentage and the large seed size fraction in a seed lot of sensitive genotypes. Photoperiod × genotype interaction for these traits is also significant (Witzenberger et al., 1988). Information on the influence of photoperiod on chemical quality of the seed in peanut has not been reported.

The present experiment was conducted to study the effect of photoperiod on shelling percentage, sound mature seeds (SMS) percentage, 100-seed weight, and oil and fatty acid contents among 10 diverse peanut genotypes grown under three photoperiod treatments during three seasons.

MATERIALS AND METHODS

Ten peanut genotypes, belonging to subsp *fastigiata* (ICGV 96235, ICGV 96239, JL 24, Gangapuri, and ICG 7227) and subsp hypogaea (TMV 10, Chalimbana, GP NC 343, ICGV

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Table 1. Pooled analysis of variance for shelling%, SMS%, 100-seed weight (g), and oil and fatty acid contents (%) of 10 peanut genotypes grown in nine environments (three seasons and three photoperiods), ICRISAT Center, Patancheru, India.

Source	df	Shelling %	SMS %†	100-seed weight	Oil	Palmetic	Stearic	Oleic
Season (S)	2	264.6**	122.1**	2935.3**	21.98*	11.847**	3.617**	160.661**
Error (a)	6	5.4	8.3	43.9	3.25	0.166	0.169	9.017
Photoperiod (Ph)‡	2	125.5*	20.7	497.3	1.61	3.144*	1.757	22.149
ND vs. SD	1	126.7*	4.7	522.2	1.04	6.160**	1.900	0.720
ND vs. LD	1	124.2	36.8	472.3	2.18	0.130	1.610	43.580
S × Ph	4	13.3	80.8	949.2**	14.93*	0.276	0.365	14.517*
(ND vs. SD) × S	2	2.6	153.3	114.5	25.66**	0.370*	0.230	24.790**
(ND vs. LD) × S	2	23.9	8.2	1783.9**	4.20	0.180	0.500	4.240
Error (b)	12	10.6	72.7	68.5	2.91	0.088	0.312	2.921
Genotype (G)	9	76.0*	123.9*	4773.6**	73.49	25.678**	3.673**	1069.637**
S × G	18	25.7*	41.2	554.2**	41.94**	0.407*	0.491**	12.439**
Ph × G	18	7.9	66.4**	238.4	2.78	0.491*	0.309*	12.789*
(ND vs. SD) × G	9	7.3	65.5*	116.5	4.53	0.600	0.480*	19.620*
(ND vs. LD) × G	9	8.5	67.3*	360.3	1.02	0.380*	0.130	5.950
S × Ph × G	36	11.8	22.9	161.9**	5.11**	0.199**	0.152	5.529**
(ND vs. SD) × S × G	18	7.6	21.6	140.3	3.07	0.250**	0.160	6.880**
(ND vs. LD) × S × G	18	15.9	24.2	183.5*	7.16**	0.140	0.140	4.170
Error (c)	162	11.5	26.6	76.2	1.89	0.102	0.106	2.299

Source	df	Linoleic	Arachidic	Eicosenoic	Behenic	Lignoceric	O/L ratio§
Season (S)	2	17.053	0.334**	0.025	7.946**	0.023	0.533*
Error (a)	6	5.176	0.010	0.011	0.114	0.017	0.049
Photoperiod (Ph)‡	2	18.619	0.030	0.375*	2.337	0.229	0.176
ND vs. SD	1	6.420	0.047	0.526*	1.233	0.364	0.040
ND vs. LD	1	30.820	0.013	0.224	3.440*	0.093	0.312
S × Ph	4	10.844*	0.016	0.025	0.396**	0.049	0.092
(ND vs. SD) × S	2	17.630**	0.006	0.019	0.647**	0.074*	0.159*
(ND vs. LD) × S	2	4.050	0.026	0.031	0.146	0.025	0.025
Error (b)	12	2.898	0.018	0.015	0.070	0.017	0.026
Genotype (G)	9	805.916**	0.756**	0.135**	1.524**	0.527**	6.246**
S × G	18	8.758**	0.059**	0.026**	0.271**	0.048*	0.085*
Ph × G	18	8.421*	0.030	0.012	0.098	0.018	0.068
(ND vs. SD) × G	9	12.870*	0.041	0.015	0.157**	0.016	0.096
(ND vs. LD) × G	9	3.970	0.018	0.008	0.039	0.019	0.039
S × Ph × G	36	3.606**	0.020	0.008	0.084	0.019	0.037**
(ND vs. SD) × S × G	18	4.920**	0.018	0.008	0.042	0.012	0.045*
(ND vs. LD) × S × G	18	2.290	0.022	0.009	0.126	0.025	0.028
Error (c)	162	1.567	0.015	0.008	0.075	0.012	0.017

*, ** Significant at 0.05 and 0.01 levels, respectively.
† SMS = Sound mature seeds.
‡ ND = Normal day (12 h), SD = Short day (8 h), LD = Long day (16 h).
§ O/L ratio = Oleic/linoleic fatty acid ratio.

94218, and ICGV 96234) were selected for the study. While JL 24, TMV 10, and Gangapuri are released cultivars in India, Chalimbana is a large-seeded released cultivar in Malawi and Zambia. GP NC 343 is a large-seeded germplasm from North Carolina State University with multiple resistance to insect pests (Campbell et al., 1971). ICGVs 96234, 96235, and 96239 are chemically induced mutants developed at ICRISAT with an O/L ratio between 0.94 to 3.51. The former two originated from ICGV 88448 and the latter from J L 24 (Dwivedi et al., 1998). ICGV 88448 is a large-seeded breeding line, derived from a cross between *A. hypogaea* and *A. cardenasii*, developed at North Carolina State University. ICGV 94218 is a high yielding breeding line with large seed size. ICG 7227 is a germplasm line with low oil and high protein contents. It originated from PI 275734 in Zimbabwe.

Table 2. Effect of photoperiod on mean shelling%, SMS%, 100-seed weight (g), and oil and fatty acids contents (%) in peanut, ICRISAT Center, Patancheru, India.

	Photoperiod (Ph)†			
Character	ND (Control)	SD	LD	SEd
Shelling %	65.64	67.32*	65.04	±0.543
SMS %‡	68.17	68.49	67.54	±1.413
100-seed weight	56.15	52.75	57.26	±4.593
Oil	48.31	48.46	48.20	±0.576
Palmitic	11.13	11.50*	11.27	±0.078
Stearic	2.66	2.87	2.60	±0.090
Oleic	45.42	45.54	44.63	±0.568
Linoleic	32.60	32.22	33.13	±0.491
Arachidic	1.41	1.44	1.44	±0.021
Eicosenoic	1.15	1.04*	1.15	±0.024
Behenic	3.97	3.80	4.12	±0.094
Lignoceric	1.66	1.57	1.66	±0.033
O/L ratio§	1.47	1.50	1.42	±0.045

* Significant at 0.05 level.
† ND = Normal day (12 h), SD = Short day (8 h), LD = Long day (16 h).
‡ SMS = Sound mature seeds.
§ O/L ratio = Oleic/linoleic fatty acid ratio.

These genotypes were evaluated in Alfisol (clayey-skeltel, mixed, isohypertheric family of Udic Rhodustalfs) fields under normal day (ND), short day (SD), and long day (LD) conditions at Patancheru (18°N, 78°E) for three seasons (E 1 = postrainy season 1996–1997; E 2 = rainy season 1997; E 3 = postrainy season 1997–1998). The field was prepared in broad beds of 1.5 m width with furrows of 30 cm on either side of the bed. The experiment was conducted in a three-replicate split plot randomized complete block design with photoperiod as main plot, and genotype as subplots. The plot size consisted of 1.2 m^2 (4 rows of 1 m) with an inter- and intra-row spacing of 30 and 15 cm, respectively. The crop received a basal dose of single super phosphate of 375 kg ha^{-1}, and 400 kg gypsum ha^{-1} at peak flowering. It was irrigated during the crop period 13 times in E 1, six times in E 2, and 15 times in E 3 (50 mm each irrigation). The crop was protected against rust (*Puccinia arachidis* Speg.), late leaf spot (*Phaeoisariopsis personata* Berk. & Curtis), thrips (*Thrips palmi* Karny), aphids (*Aphis crassivora* Koch), leaf miner (*Aproaerema modicella* Deventer), and Spodoptera (*Spodoptera litura* Fabricius). Foliar

Table 3. Ph × G interaction and genotype means over nine environments for shelling%, SMS%, 100-seed weight (g), oil, and palmetic, oleic, and linoleic fatty acid contents (%), and O/L ratio of 10 peanut genotypes at ICRISAT Center, Patancheru, India.

	Shelling%				SMS%†				100-seed weight				Oil			
Genotype	ND‡	SD§	LD¶	Average	ND	SD	LD	Average	ND	SD	LD	Average	ND	SD	LD	Average
ICGV 94218	65.10	66.60	66.30	66.00	62.80	65.40	63.90	64.00	78.10	79.90	72.80	73.60	50.09	50.90	50.14	50.40
ICGV 96234	67.00	68.90	66.60	67.50	58.80	65.10*	66.30*	66.70	75.20	62.90	80.30	72.80	47.73	47.00	47.49	47.40
ICGV 96235	68.30	69.30	67.20	68.30	72.90	69.40	67.40	69.90	53.00	46.80	63.20	54.30	46.48	48.41	46.64	47.20
ICGV 96239	68.40	70.30	66.60	68.40	67.60	67.20	73.30	69.40	43.60	44.00	40.70	42.80	51.28	49.88	49.94	50.40
ICG 2271	63.90	66.70	62.20	64.30	66.30	66.30	63.20	65.30	52.30	57.50	53.70	54.50	48.90	49.30	48.71	49.00
ICG 7227	65.60	68.30	64.90	66.30	70.80	71.90	68.10	70.30	41.70	40.50	56.80	46.30	47.89	48.04	47.59	47.80
Gangapuri	64.60	67.20	65.00	65.60	66.20	73.90*	69.80	70.00	42.20	38.10	38.60	39.70	46.68	46.76	46.78	46.70
JL 24	65.00	67.90	64.00	65.60	64.90	69.70	69.30	68.00	48.90	43.80	41.40	44.70	45.32	46.59	46.51	46.10
TMV 10	64.60	65.10	64.30	64.70	72.30	70.30	65.70*	69.40	52.30	48.20	54.10	51.50	50.88	50.62	50.47	50.70
Chalimbana	64.00	62.90	63.30	63.40	69.10	65.60	68.30	67.70	74.30	75.90	71.00	73.70	47.87	47.13	47.69	47.60
SEd		±1.941		±1.394		±3.058		±1.868		±9.219		±6.482		±2.020		±1.763
	Palmetic				Oleic†				Linoleic				O/L ratio#			
Genotype	ND‡	SD§	LD¶	Average	ND	SD	LD	Average	ND	SD	LD	Average	ND	SD	LD	Average
ICGV 94218	10.57	10.44	10.74	10.58	48.89	49.93	47.76	48.86	29.00	27.34*	29.21	28.52	1.69	1.83	1.64	1.72
ICGV 96234	9.16	9.52	9.61	9.43	57.57	57.42	56.13	57.04	22.81	22.56	23.60	22.99	2.54	2.58	2.41	2.51
ICGV 96235	12.27	12.89*	12.27	12.47	37.17	37.69	37.13	37.33	40.01	39.12	39.87	39.67	0.93	0.97	0.93	0.94
ICGV 96239	10.99	12.01**	11.19	11.39	50.21	45.10**	48.34	47.88	27.97	31.81**	29.22	29.67	1.80	1.47**	1.66	1.65
ICG 2271	11.41	11.27	11.26	11.31	45.11	48.13*	45.66	46.30	32.76	30.54	32.59	31.96	1.38	1.59	1.40	1.46
ICG 7227	11.51	12.02*	11.70	11.74	40.11	40.16	39.23	39.83	38.03	37.66	38.33	38.01	1.06	1.07	1.03	1.05
Gangapuri	11.22	11.42	11.40	11.35	39.80	40.32	39.77	39.96	37.72	37.32	38.17	37.74	1.06	1.08	1.04	1.06
JL 24	12.82	13.29	12.59	12.90	37.78	37.48	38.12	37.79	38.32	38.06	37.94	38.11	0.99	0.99	1.00	0.99
TMV 10	10.30	10.97*	10.80	10.69	49.16	49.28	47.14	48.53	28.74	29.03	30.68	29.48	1.71	1.71	1.54	1.65
Chalimbana	11.07	11.18	11.14	11.13	48.38	49.92	46.99	48.43	30.63	28.78	31.67	30.36	1.59	1.76	1.49	1.61
SEd		±0.248		±0.174		±1.393		±0.960		±1.159		±0.806		±0.114		±0.08

*, ** Significant at 0.05 and 0.01 levels, respectively.
† SMS, sound mature seeds
‡ ND, Normal day (12 h)
§ SD, Short day (8 h)
¶ LD, Long day (16 h)
# O/L ratio, oleic/linoleic fatty acid ratio

diseases were controlled by spraying chlorothalonil at the rate of 1.2 kg ha^{-1}, and insect pests by applying dimethoate at the rate of 1.0 L ha^{-1}, monocrotophos at the rate of 1.0 L ha^{-1}, methomyl at the rate of 3.5 L ha^{-1}, and quinalphos at the rate of 2 l ha^{-1}. The number of insecticide sprays were five in E 1, four in E 2, and six in E 3. Chlorothalonil (tetrachloroisophthalonitrile) was sprayed twice in E 2.

The photoperiod treatments were imposed soon after seedling emergence and continued up to the last harvest. The ND treatment consisted of exposing the genotypes to natural day length of 12 h that prevailed during the season. The day length in SD (8 h) and LD (16 h) was adjusted depending on ND length including civil twilight at dawn and dusk. Daily sunrise and sunset times were collected from the meteorological observatory situated within a radius of 1 km from the experimental site, and the timings of SD and LD were adjusted for a period of 15 d. The portable rain out shelter (ROS), designed and fabricated at ICRISAT (Chauhan et al., 1997), was used to create SD by covering the ROS with black polythene. The ROS were moved over to SD plots every day at 1630 h and its side curtains pulled down and tied to achieve 100% darkness under SD plots. The ROS were then moved out from SD plots at 0830 h. The side curtains of ROS were lifted up and left as such for 15 min before moving them to their parking place. LD treatment was established by extending the normal day length by another 4 h in the evening soon after the natural light intensity fell to around 576 J m^{-2}. The artificial illumination was supplied by 100 W incandescent tungsten filament lamps suspended 0.75 m above the crop and arranged in a grid spacing of 3 by 3 m. The bulbs were attached to an automatic timer and programmed to switch on and off at specified times.

After harvest, 500 randomly selected dried pods (moisture less than 100 g kg^{-1}) from each plot were shelled to determine shelling and SMS percentages. All seed was weighted in determining shelling percentage, whereas for SMS percentage, only fully mature seeds irrespective of their size were considered. The SMS were taken to record 100-seed weight (in grams), and the same seed was later analyzed for total oil and fatty acid contents. Oil content was determined by a nuclear magnetic resonance procedure (Jambunathan et al., 1985). The fatty acid methyl esters (FAME) of triglycerides were prepared (Hovis et al., 1979) and FAME were analyzed as per the procedure described earlier (Dwivedi et al., 1993). The O/L ratio was determined for each genotype.

Pooled analysis of variance over three seasons (S) and three photoperiods (Ph), based on a mixed linear model with S as random and Ph and genotypes (G) as fixed effects, was performed, on plot means, to separate S, Ph, G, and their interaction effects for all the characters. The statistical significance of S was tested against pooled error (a), of Ph against S × Ph, of S × Ph against pooled error (b), of G against S × G, of S × G and S × Ph × G against pooled error (c), and that of Ph × G against S × Ph × G following the last column in Table 4 of McIntosh (1983).

RESULTS AND DISCUSSION

Except for the oil content, the genotypes showed significant differences for all traits (Table 1). Seasons also had a significant effect on all traits except for linolenic, eicosenoic, and lignoceric fatty acids. Photoperiod affected only shelling percentage, and palmitic and eicosenoic fatty acids, which are of minor importance. Witzenberger et al. (1988) also reported significant photo-period effect and photoperiod × genotype interaction for shelling percentage in a seed lot of sensitive genotypes. The S ×

G interaction was significant for all traits except SMS percentage. This indicated the stability of SMS percentage over seasons among the genotypes included in the study. The S × Ph interaction was significant for 100-seed weight, oil, and oleic, linolenic, and behenic fatty acids. These interactions for oil and fatty acids arose mainly because of significant (ND vs. SD) × S interaction. For 100-seed weight, (ND vs. LD) × S interaction was significant. These interactions can result because of differences in temperature, natural day length, humidity among seasons, and the sensitivity of the genotypes to these parameters. Partitioning of photosynthate to pods in peanut is affected by both photoperiod and temperature and their interaction is significant (Bagnall and King, 1991; Bell et al., 1991; Nigam et al., 1994; Nigam et al., 1998). The Ph × G interaction was significant for SMS percentage, and palmitic, stearic, oleic, and linolenic fatty acids. Oleic and linolenic fatty acids constitute 80% of the total fatty acids in peanut. They strongly influence shelf-life (as determined by O/L ratio) and nutritional quality of the peanut and its products. However, the Ph × G interaction for O/L ratio was nonsignificant. Like S × Ph, the Ph × G interaction arose because of significance of (ND vs. SD) × G for stearic, oleic, and linolenic fatty acids. Both (ND vs. SD) × G and (ND vs. LD) × G interactions affected SMS percentage. Palmitic acid was influenced by (ND vs. LD) × G interaction only.

Normal day (ND) was used as a control for comparison with SD and LD treatments (Table 2). Of the three physical seed quality characteristics, SMS percentage and 100-seed weight remained unaffected with the change in photoperiod. However, shelling percentage increased under SD conditions. Nigam et al. (1998) also reported a nonsignificant effect of photoperiod on 100-seed weight. Unlike soybean (Han-TianFu et al., 1995 and 1997), the oil content in peanut remained unaffected due to photoperiod. Except for the palmitic and eicosenoic acids, the remaining fatty acids were not affected due to variation in photoperiod. Palmitic acid increased but eicosenoic acid decreased under SD conditions. The short-day conditions were more interactive with seasons and genotypes for fatty acids. In soybean, oleic, linolenic, palmitic, and linolenic fatty acids were affected either negatively or positively by pre- and post-flowering short-day treatment (Han-TianFu et al., 1995 and 1997).

Among the physical seed characteristics, high shelling percentage, SMS percentage, and 100-seed weight are desirable in confectionery genotypes. Equally important is the photoperiodic insensitivity of genotypes for these traits for their stable performance across locations. ICG 7227, ICGV 96235, and ICGV 96239 for SMS percentage, ICGVs 96239, 96235, and 96234 for shelling percentage, and Chalimbana, ICGVs 94218, and 96234 for 100-seed weight were high performers and insensitive to photoperiod (Table 3). All the genotypes for oil content and O/L ratio (except ICGV 96239) were insensitive to photoperiod. Among the oil characteristics, low oil and a high O/L ratio are desirable traits in confectionery genotypes. JL 24, Gangapuri, ICGV 96234, and ICGV 96235 for low oil and ICGV 96234 for high O/L ratio would be useful parents in a confectionery breeding program.

In spite of a strong effect of photoperiod on partitioning of photosynthate to pods in peanut (Bagnall and King, 1991; Bell et al., 1991; Nigam et al., 1994; Nigam et al., 1998), the major seed quality traits such as SMS percentage, 100-seed weight, oil content, and oleic and linolenic fatty acid contents, in general, remained unaffected by variation in photoperiod. However, the effect of growing season is more pronounced on these seed quality traits.

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Field Response to Selection in Alfalfa for Germination Rate and Seedling Vigor at Low Temperatures

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ABSTRACT

Successful establishment of alfalfa (*Medicago sativa* L.) stands in early spring may require emergence and seedling growth at soil temperatures below 10°C. The objectives of this experiment were to evaluate changes in emergence and seedling height after laboratory selection in six cultivars at suboptimal temperature for (i) early germination (EG), (ii) high seedling vigor (HSV), (iii) EG + HSV, or (iv) late germination and low seedling vigor (LG + LSV). Cycles (C) 0 to 2 were evaluated for emergence 8 d after planting, seedling height (SH) 27 d after planting, forage dry matter yield, and other agronomic traits in field trials at Ames and Nashua, IA, in early spring 1998. Emergence was improved in all selected populations at Ames but not at Nashua; HSV and EG + HSV selection were most effective at improving emergence. After two cycles, seedling height was increased 21% by HSV selection and 9% by EG selection; however, the response among cultivars was highly variable. Combined EG + HSV selection was less effective than HSV alone at increasing height. Selection for LG + LSV did not reduce seedling height in the field even though large decreases were previously observed in the laboratory. Most gain from selection was realized with C1, possibly because the variable seed production environment in the greenhouse may have limited more consistent responses in C2. Seedling height selection at suboptimal temperatures in the laboratory successfully improved seedling height in the field in some alfalfa populations without changing other agronomic characteristics.

Most alfalfa is planted in the north-central USA during the spring to take advantage of available moisture and to allow harvest in the seeding year (Barnes and Sheaffer, 1995; Vough et al., 1995). Alfalfa seed planted under optimum conditions emerges rapidly, usually within 17 d after planting, but spring soil temperatures in this region are often suboptimal for alfalfa germination and growth (Brar et al., 1991; McElgunn, 1973; Vough et al., 1995; Weihing, 1941). At suboptimal temperatures, alfalfa cultivars differ in germination and root growth rates, and some cultivars may have better potential for good stand establishment than others (Brar et al., 1990, 1991; Klos, 1999).

Field emergence of alfalfa 8 d after planting is positively correlated with radicle growth rate and negatively correlated with germination time (GT) measured in the laboratory (Klos, 1999). Germination time was defined at the average days from planting to germination for a population of seeds (Klos, 1999). Germination rate assessed at low temperatures in the laboratory has been reported to be a good test for field tolerance to temperatures suboptimal for germination and growth in other legumes, including soybean, *Glycine max* (L.) Merr., and common bean, *Phaseolus vulgaris* L. (Dickson and Boettger, 1984; Littlejohns and Tanner, 1976; Szyrmer and Szczepanska, 1981).

Selection under laboratory conditions for GT and seedling vigor under low temperatures was conducted in six alfalfa cultivars (Klos and Brummer, 2000). Two cycles of selection for early germination at 5°C decreased the average GT in the laboratory by 29%. Improvement was also observed for seedling vigor as estimated by SH measured at a fixed period after germination. Seedling height increased by 15% after two cycles of selection at 10°C. McConnell and Gardner (1979) used phenotypic recurrent selection on two maize populations to increase germination percentage under laboratory conditions at 7.2°C by 8.8 and 9.9% per cycle, but field emergence and seedling vigor (on a scale of 1–9) of these populations were unchanged, possibly because of warm weather during testing.

The objectives of this study were to assess changes in emergence and seedling height in the field after two cycles of phenotypic recurrent selection for GT and seedling vigor at suboptimal temperatures under laboratory conditions and to compare these results with those observed in laboratory evaluations (Klos and Brummer, 2000).

MATERIALS AND METHODS

The six populations chosen for recurrent selection represent commonly available cultivars in the midwestern USA in Fall Dormancy Groups 2 through 4 (Table 1). Untreated seed was obtained either from commercial sources or from Dr. T.A. Campbell, USDA-ARS.

Selection Methods

Two cycles of phenotypic recurrent selection were conducted within each cultivar using the following four methods (Klos and Brummer, 2000):

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Abbreviations: C, cycle; EG, early germination; GT, germination time; HSV, high seedling vigor; LG, late germination; LSV, low seedling vigor; SH, seedling height.