Chickpea (Cicer arietinum L.) is an important grain legume crop worldwide and is cultivated for its protein rich seeds in ~82 countries on 12.65 million ha with production of 12.09 Tg and productivity of 956 kg ha$^{-1}$ (FAOSTAT, 2018). The crop is affected by a number of biotic (pod borer [Helicoverpa armigera (Hübner)], Fusarium wilt [Fusarium oxysporum Schlechtend.], botrytis gray mold [Botrytis cinerea Pers.:Fr.], dry root rot [Macrophomina phaseolina (Tassi) Goidanich], Ascochyta blight [Ascochyta rabiei (Pass.) Labr.]), and abiotic (drought, heat and cold) stresses resulting in low productivity. Chickpea has a narrow genetic base that hinders its genetic improvement by using cultivated genepools, especially for high levels of resistance against important biotic and/or abiotic stresses. In contrast, the genus Cicer, containing 43 wild species comprising eight annual and 35 perennial species, provides sufficient genetic variability for use in chickpea improvement programs. Although the importance of wild species for crop improvement is well known, very few attempts have been made to introgress important traits from wild Cicer species into cultivated backgrounds (Jaiswal et al., 1986; Singh and Ocampo, 1997; Malhotra et al., 2002; Singh et al., 2005; Knights et al., 2008; Upadhyaya, 2008).

As chickpea is an annual crop, annual wild Cicer species are of particular interest to breeders for introgressing useful alleles into cultivated backgrounds. However, the difference in phenology of cultivated and wild species (Summerfield et al., 1989; Robertson et al., 1997; Abbo et al., 2002; Berger et al., 2005) poses serious concern for their utilization in hybridization programs. Chickpea is adapted to diverse environments in tropical, subtropical, and...
warm–temperate zones, whereas annual wild *Cicer* species are mostly found in western and central Asia above 34.5° N, as well as along the coastal eastern Mediterranean and in isolated populations adjacent to the African Red Sea coast (Berger et al., 2003), and exhibit vernalization and photoperiod response (Sharma and Upadhyaya, 2015). In subtropical regions such as southern India, the vernalization and photoperiod requirements of wild *Cicer* species are not fulfilled under natural field conditions. Under such environments, wild *Cicer* species are generally late in phenology and therefore cannot be used frequently in crossing programs.

Studies have shown the response of wild *Cicer* species to vernalization (Abbo et al., 2002; Berger et al., 2005; Sharma and Upadhyaya, 2015) and extended photoperiod (Sethi et al., 1981; Sharma and Upadhyaya, 2015). Our recent studies revealed that annual wild *Cicer* species are responsive both to vernalization and 24-h extended photoperiod treatments. However, compared with vernalization, the response of most of these species to 24-h photoperiod treatment was greater (Sharma and Upadhyaya, 2015). In a similar study, long-day (16/8 h day/night) and short-day (10/14 h day/night) photoperiods were used to study the flowering response in cultivated chickpea accessions (Daba et al., 2016). Nevertheless, none of the studies was aimed at determining the critical daylength required by the wild *Cicer* species for flowering. The present investigation is the first attempt to study the response of annual wild *Cicer* species and cultivated chickpea to different photoperiod treatments on days to first flowering and yield-contributing traits with an aim to appraise critical daylength for desired days to first flowering.

**MATERIALS AND METHODS**

**Plant Material**

Germplasm accessions of seven annual wild *Cicer* species [*C. reticulatum* Ladjiz., *C. judaicum* Boiss., *C. bijugum* K.H. Rech., *C. pinnatifidum* Jaub. & Sp., *C. chrorassanicum* (Bunge) M. Pop., *C. cuneatum* Hochst. ex A. Rich., and *C. yamashitae* Kitamura] and cultivated *C. arietinum* were used in this investigation. These germplasm accessions were collected or originated from Afghanistan, Ethiopia, Syria, and Turkey (Table 1). *Cicer arietinum* was represented by late-maturing desi-type chickpea variety G 130, cultivated in India (Singh, 1987) (Table 1).

**Methodology**

The study was performed under controlled greenhouse conditions maintained at 25°C in 2012 and 2013. In both years, all eight *Cicer* species were evaluated under five photoperiods by extending the natural daylength artificially to 15, 18, 21, and 24 h. Natural daylength of 11 to 12 h of exposure at 25°C was the control.

To initiate germination, seeds of wild *Cicer* species were scarified by incising the hard seed coat. Scarified seeds of wild *Cicer* accessions and nonscarified seeds of *C. arietinum* ’G 130’ were placed on wet filter paper in Petri dishes for germination at room temperature for 3 d. After 3 d, the germinated seedlings were transplanted in pots (one seedling per pot) containing a 2:1:1 mixture of black soil, farmyard manure, and sand. Each light exposure treatment was performed in separate chambers in the greenhouse maintained at 25°C. In each chamber, the natural daylength was extended by using 60-W incandescent lights 15 d after transplanting through maturity (Sethi et al., 1981). Each of the eight species were randomly allotted to three pots, with one plant per pot, and kept under each chamber. These 24 pots were randomized within each chamber. For the control treatment, seedlings were transplanted in pots and maintained under natural daylength (11–12 h) at 25°C in the greenhouse. In both years, data were recorded for each plant on number of days to first flowering starting from the day of transplanting, and yield-contributing traits such as plant height, canopy width, number of pods per plant, number of seeds per plant, seed weight per plant, and 100-seed weight.

**Statistical Methods**

Response of wild and cultivated *Cicer* species to different treatments was based on a reduction in number of days to first flowering under different treatments compared to the control. To assess variation due to accessions and interactions between accession and extended photoperiods and years, ANOVA was performed on the data where accession effects were modeled under the completely randomized design and combined over the photoperiods, incorporating the interaction between accession and photoperiod. The means for accessions and their combinations with the photoperiods were obtained for each response variable, along with their SEs. Significant differences between species were detected by comparing means with respective LSDs. The patterns of differential responses of accessions to treatments were estimated by partitioning accession × treatment interaction in polynomial components in exposure length. For each species, the relationship of days to first flowering with length of photoperiod was evaluated by fitting linear, quadratic, and cubic regressions, selecting the best of the three regressions that accounted for the highest percentage variance, and estimating regression coefficients for the best regression. There are other types of nonlinear curves that could support days to first flowering and photoperiod relationships and are available in Genstat software (VSN International, 2015, p. 312–321). Left exponential, exponential, and linear divided by linear curves were tested and the one that accounted for the highest percentage variance was chosen. Although many of these forms can be used for estimating days to first flowering for a given photoperiod, some,

<table>
<thead>
<tr>
<th>Species</th>
<th>Accession identity</th>
<th>Country of origin or pedigree</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>C. reticulatum</em></td>
<td>ICC 17123</td>
<td>Turkey</td>
</tr>
<tr>
<td><em>C. judaicum</em></td>
<td>ICC 17188</td>
<td>Syria</td>
</tr>
<tr>
<td><em>C. pinnatifidum</em></td>
<td>ICC 17126</td>
<td>Turkey</td>
</tr>
<tr>
<td><em>C. bijugum</em></td>
<td>ICC 17289</td>
<td>Turkey</td>
</tr>
<tr>
<td><em>C. yamashitae</em></td>
<td>ICC 17117</td>
<td>Afghanistan</td>
</tr>
<tr>
<td><em>C. chrorassanicum</em></td>
<td>ICC 17141</td>
<td>Afghanistan</td>
</tr>
<tr>
<td><em>C. cuneatum</em></td>
<td>ICC 20176</td>
<td>Ethiopia</td>
</tr>
<tr>
<td><em>C. arietinum</em></td>
<td>G 130 (Desi late)</td>
<td>India/708 × C 235</td>
</tr>
</tbody>
</table>

Table 1. List of annual wild and cultivated *Cicer* species used in study at ICRISAT, Patancheru, India.
such as an exponential curve, could be more suited for estimation of daylength required to achieve a given number of days to first flowering. The exponential form, expressed as days to first flowering = \( A + BR^t \), was used for estimating days to first flowering for a given photoperiod \((b)\). The parameter \( R \) \((R < 1)\) is an indicator of nonlinear rate of decline in \( h \), whereas \( B \) is the slope or linear decline with the nonlinear variable \( R^t \). The parameter \( A \) measures the potential as an asymptotic value of days to first flowering that can be achieved after an infinite or practically the longest possible exposure. Thus, days to first flowering would vary between \( A \) and \( A + B \). Such an equation was fitted using the FITCURVE directive in Genstat software. The exposure times required to achieve a low value of days to first flowering expressed as 10% > \( A \) were also estimated. Standard errors of estimated hours were determined using the results for inverse estimation for a general nonlinear function given in Singh et al. (1992). Genstat statistical software (VSN International, 2015) was used for all the calculations.

**RESULTS**

Year-wise and pooled analysis showed significant differences among species and photoperiod treatment \( \times \) species interaction \((p \leq 0.001)\) for all the traits. Pooled analysis (Table 2) indicated that different photoperiod treatments significantly affected days to first flowering and 100-seed weight \((p \leq 0.001)\) with significant linear and quadratic trends in treatments; plant height \((p \leq 0.05)\) with a significant linear trend; number of pods and seeds per plant \((p \leq 0.001)\) with significant quadratic and cubic trends and deviations; and seed weight per plant \((p \leq 0.05)\) with significant quadratic and cubic trends. Further, partitioning of the total sum of squares showed that different photoperiod treatments explained \(\approx 58\%\) of the variation in days to first flowering, with the linear trend being much stronger \((78\%\) variation) than the quadratic trend \((21\%\) variation) (Table 2). However, in treatment \( \times \) species interaction, the linear trend was much stronger \((51\%\) variation) than the quadratic trend \((24\%\) for days to first flowering. Similarly, the linear trend was most important in explaining variation \((\approx 66\%)\) for plant height, linear \((40\%)\), cubic \((28\%)\) and quadratic \((22\%)\) trends for canopy width, cubic \((\approx 40\%)\) and linear \((24\%)\) trends for number of pods and seeds per plant, linear \((37\%)\) and cubic \((30\%)\) trends for seed weight per plant, and linear \((49\%)\) and quadratic \((31\%)\) trends for 100-seed weight (Table 2). Although deviations from cubic polynomials were found to be statistically significant, the cubic polynomials in daylength explained a large part of variability, exceeding 89% for days to first flowering, plant height, 100-seed weight, and canopy width, and exceeding 80% for number of pods and seeds per plant, implying that response to the exposure time can be well described by cubic polynomials.

### Response to Treatments

All the treatments reduced the number of days to first flowering compared with the control (12 d to first flowering, such as an exponential curve, could be more suited for estimation of daylength required to achieve a given number of days to first flowering. The exponential form, expressed as days to first flowering = \( A + BR^t \), was used for estimating days to first flowering for a given photoperiod \((b)\). The parameter \( R \) \((R < 1)\) is an indicator of nonlinear rate of decline in \( h \), whereas \( B \) is the slope or linear decline with the nonlinear variable \( R^t \). The parameter \( A \) measures the potential as an asymptotic value of days to first flowering that can be achieved after an infinite or practically the longest possible exposure. Thus, days to first flowering would vary between \( A \) and \( A + B \). Such an equation was fitted using the FITCURVE directive in Genstat software. The exposure times required to achieve a low value of days to first flowering expressed as 10% > \( A \) were also estimated. Standard errors of estimated hours were determined using the results for inverse estimation for a general nonlinear function given in Singh et al. (1992). Genstat statistical software (VSN International, 2015) was used for all the calculations.

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### Response to Treatments

All the treatments reduced the number of days to first flowering compared with the control (12 d to first flowering,
Fig. 1). Overall, the three highest exposure treatments, 24, 21, and 18 h were similar and significantly better than 15 h at reducing the number of days to first flowering in wild and cultivated Cicer species. On average, the number of days to first flowering varied from 41 to 45 d under these three treatments, 70 d under 15 h and 111 d for the control. Therefore, the number of days to first flowering was reduced by 60 to 63% under three treatments (24, 21, and 18 h), followed by a 37% reduction under 15 h compared with the control. Similar patterns were observed in two groups separately: in wild Cicer species, where days to first flowering were reduced by ∼61 to 65% under 24, 21, and 18 h, followed by a ∼38% reduction under 15 h, and in cultivated chickpea cultivar G 130, where days to first flowering was reduced by ∼44% under 24 h, ∼42% under 21 h, ∼39% under 18 h, and 28% under 15 h. Further, the effect of these treatments on days to first flowering varied significantly between Cicer species, and different responses were observed in different species (Fig. 1).

Species Response

All four treatments were similarly effective in reducing the number of days to first flowering in tertiary genepool species, C. judaicum and C. yamashitiae (∼70–77% reduction under 21, 24, 18, and 15 h) and cultivated chickpea compared with the control (Fig. 1). The reduction in number of days to first flowering observed at 18, 21, and 24 h was similar but significantly greater than the reduction observed in the 15-h treatment in the primary gene pool species C. reticulatum and tertiary gene pool species C. pinnatifidum and C. bijugum (Fig. 1). Two treatments, 24 and 21 h, were similar and significantly better than other treatments in reducing the number of days to first flowering in tertiary genepool species C. cuneatum (∼38–39% reduction under 21 and 24 h, ∼23% under 18 h, and ∼16% under 15 h) and C. chorassanicum (∼22–27% reduction under 21 and 24 h, ∼16% under 18 h, and ∼10% under 15 h) (Fig. 1).

The regression models for days to first flowering in terms of photoperiods are given in Table 3. The best model that accounted for the highest percent variance was quadratic for three species (C. reticulatum, C. pinnatifidum, and C. cuneatum) and cubic for the other species. Not only did the relationship of days to first flowering and photoperiod vary with the species in terms of the coefficients, but also in its form. These equations (Table 3) can be used to estimate days to first flowering for a given photoperiod.

Although the polynomial equations described the response well (Table 3), these can also be used to predict the response within the observed photoperiod. However, estimation of the daylength from polynomials may result in invalid or multiple estimates. Examination of the days to first flowering and photoperiod graphs supported the fitting of an exponential curve (days to first flowering = $A + DR^{h}$; Fig. 2), and the estimates of $A$, $B$, and $R$ parameters are given in Table 4, along with estimate of exposure $h = \log[(\text{days to first flowering} - A)/B]/\log(R)$ when days to first flowering = 1.1A (10% above the lower limit). The relationship between days to first flowering and exposure hours varied with species (Fig. 2, Table 4). The exponential decline rate ($R$) in days to first flowering with exposure was slowest for C. yamashitiae followed by C. judaicum. The lowest potential flowering earliness that can be reached among the species studied among the species studied is in C. reticulatum ($A$ = 6.2 d), followed by C. pinnatifidum ($A$ = 10.3 d). The higher side of potential earliness lies in C. cuneatum ($A$ = 44.9 d). The exposure hours for days to first flowering to reach within 10% of the potential was found to go beyond the experimental period of 24 h for the four species C. reticulatum, C. chorassanicum, C. pinnatifidum, and C. cuneatum (exceeding 36.6 h), where
for the remaining species, such a potential was seen to be observed within 14 to 21 h.

**Effect on Yield-Contributing Traits**

Different daylength treatments had different effects on yield-contributing traits in different wild and cultivated *Cicer* species. At the species level, there was no significant effect of extended photoperiod treatments on plant height in *C. reticulatum*, *C. bijugum*, and *C. arietinum* (Fig. 3). In *C. judaicum*, treatments $\geq 18$ h resulted in significant reduction in plant height (63.3 cm under 18 h, 47.2 cm under 21 h, and 34.7 cm under 24 h) compared with the control (97.0 cm) and 15 h (100.7 cm). In *C. pinnatifidum*, plant height was significantly increased under 15 h (80.7 cm) compared with the control (62.8 cm) but was significantly reduced under treatments $\geq 18$ h (44.3 cm under 18 h, 34.8 cm under 21 h, and 27.7 cm under 24 h). Treatments $\geq 15$ h were similar and resulted in 54% reduction in plant height compared with the control (50.5 cm) in *C. yamashitae* (23.8 cm under 15 h, 23.0 cm under 18 h, 28.3 cm under 21 h, and 26.2 cm under 24 h), whereas treatments $\geq 15$ h were similar and resulted in 23 to 37% increases in plant height compared with the control (49.8 cm) in *C. chorassanicum* (62.8 cm under 15 h, 68.0 cm under 18 h, 61.5 cm under 21 h, and 64.3 cm under 24 h). In *C. cuneatum*, 15- and 18-h treatments were similar and both resulted in 18% increase in plant height, whereas 21- (145.3 cm) and 24-h (140.3 cm) treatments had no effect on plant height compared with the control (141.8 cm) (Fig. 3).

Treatments effects on canopy width were not consistent across species. Overall, as well as in individual

![Fig. 2. Observed (points) and fitted exponential curves for days to first flowering in terms of exposure hours for eight wild and cultivated *Cicer* species.](image)

Table 3. Regression relationships between days to first flowering and photoperiod.

<table>
<thead>
<tr>
<th>No.</th>
<th>Species</th>
<th>Best of the three models</th>
<th>Adjusted $R^2$ %</th>
<th>Coefficients of the regression model†</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td><em>C. reticulatum</em></td>
<td>Quadratic</td>
<td>85.1</td>
<td>$a = 624$ $b = -52.3$ $c = 1.153$</td>
</tr>
<tr>
<td>2</td>
<td><em>C. judaicum</em></td>
<td>Cubic</td>
<td>97.8</td>
<td>$a = 2249$ $b = -338.9$ $c = 17.08$ $d = -0.2834$</td>
</tr>
<tr>
<td>3</td>
<td><em>C. pinnatifidum</em></td>
<td>Quadratic</td>
<td>79.7</td>
<td>$a = 414$ $b = -33.5$ $c = 0.731$</td>
</tr>
<tr>
<td>4</td>
<td><em>C. bijugum</em></td>
<td>Cubic</td>
<td>99.5</td>
<td>$a = 927$ $b = -123.9$ $c = 7.47$</td>
</tr>
<tr>
<td>5</td>
<td><em>C. yamashitae</em></td>
<td>Cubic</td>
<td>92.5</td>
<td>$a = 2005$ $b = -309$ $c = 15.9$ $d = -0.269$</td>
</tr>
<tr>
<td>6</td>
<td><em>C. chorassanicum</em></td>
<td>Cubic</td>
<td>99.7</td>
<td>$a = 166$ $b = -12.22$ $c = 0.533$ $d = -0.00874$</td>
</tr>
<tr>
<td>7</td>
<td><em>C. cuneatum</em></td>
<td>Quadratic</td>
<td>95.7</td>
<td>$a = 197.7$ $b = -10.1$ $c = 0.185$</td>
</tr>
<tr>
<td>8</td>
<td><em>C. arietinum</em></td>
<td>Cubic</td>
<td>94.1</td>
<td>$a = 369$ $b = -48.2$ $c = 2.31$ $d = -0.0365$</td>
</tr>
</tbody>
</table>

† Quadratic regression: $DTFF = a + bh + ch^2$. Cubic regression: $DTFF = a + bh + ch^2 + dh^3$. $DTFF$ is days to first flowering; $h$ is daylength exposure in hours.

Table 4. Estimates of parameters of exponential curve fitted to days to first flowering in exposure (in hours) and estimated exposure hours to reach 10% above the potential value of days to first flowering.

<table>
<thead>
<tr>
<th>No.</th>
<th>Species</th>
<th>Adjusted $R^2$ %</th>
<th>$R$</th>
<th>$B$</th>
<th>$A$</th>
<th>DTFF observed at 24 h</th>
<th>DTFF1 (10% above $A$)</th>
<th>Estimated photoperiod for DTFF1</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td><em>C. reticulatum</em></td>
<td>80.4</td>
<td>0.8431</td>
<td>1,196</td>
<td>6.2</td>
<td>35.7</td>
<td>6.8</td>
<td>44.3</td>
</tr>
<tr>
<td>2</td>
<td><em>C. judaicum</em></td>
<td>99.9</td>
<td>0.475</td>
<td>892,149</td>
<td>34.93</td>
<td>35.8</td>
<td>38.4</td>
<td>16.7</td>
</tr>
<tr>
<td>3</td>
<td><em>C. pinnatifidum</em></td>
<td>74.9</td>
<td>0.8554</td>
<td>686</td>
<td>10.3</td>
<td>33.5</td>
<td>11.3</td>
<td>41.6</td>
</tr>
<tr>
<td>4</td>
<td><em>C. bijugum</em></td>
<td>99.1</td>
<td>0.698</td>
<td>6,055</td>
<td>31.6</td>
<td>33.5</td>
<td>34.8</td>
<td>21.0</td>
</tr>
<tr>
<td>5</td>
<td><em>C. yamashitae</em></td>
<td>100</td>
<td>0.2</td>
<td>1.92 x 10^9</td>
<td>31.6</td>
<td>31.5</td>
<td>34.8</td>
<td>14.0</td>
</tr>
<tr>
<td>6</td>
<td><em>C. chorassanicum</em></td>
<td>99.5</td>
<td>0.931</td>
<td>89</td>
<td>43</td>
<td>58.8</td>
<td>47.3</td>
<td>42.4</td>
</tr>
<tr>
<td>7</td>
<td><em>C. cuneatum</em></td>
<td>95.3</td>
<td>0.901</td>
<td>203</td>
<td>44.9</td>
<td>63.0</td>
<td>49.4</td>
<td>36.6</td>
</tr>
<tr>
<td>8</td>
<td><em>C. arietinum</em></td>
<td>94.4</td>
<td>0.653</td>
<td>4,123</td>
<td>34.16</td>
<td>34.7</td>
<td>37.6</td>
<td>16.6</td>
</tr>
</tbody>
</table>

When fitted jointly over all the species

† Exponential curve: $DTFF = A + B + 10^A$. $DTFF$ is days to first flowering; $h$ is daylength exposure in hours.
species *C. reticulatum*, *C. chorassanicum*, *C. cuneatum*, and *C. arietinum*, there was no effect of extended photoperiod treatments on canopy width compared with the control. Canopy width was minimal and similar under treatments ≥18 h compared with 15 h and the control in *C. judaicum*, *C. pinnatifidum*, and *C. bijugum*. In *C. yamashitae*, canopy width was reduced significantly under all treatments compared with the control (Fig. 3).

All treatments had similar effects on number of pods per plant and seeds per plant (Fig. 3). Overall, 15-h treatment resulted in the highest number of pods and seeds per plant compared with the control, followed by 18-, 21-, and 24-h treatments. However, different species showed distinct responses. No treatment had a significant effect on number of pods and seed per plant in *C. reticulatum* and *C. arietinum*. The 15-h treatment was the most effective at producing the highest number of pods and seeds per plant compared with the control and other treatments in *C. judaicum*, *C. bijugum*, *C. pinnatifidum*, and *C. yamashitae*. The 18-h treatment resulted in the highest number of pods and seeds per plant in *C. chorassanicum* and *C. cuneatum* and was similar to the 21- and 24-h treatments.

Overall, the 15-h treatment resulted in the greatest seed weight per plant, followed by the 18-, 21-, and 24-h treatments, compared with the control in wild and cultivated *Cicer* species (Fig. 3). However, differential responses were observed across species. In *C. reticulatum*, 18 h resulted in the greatest seed weight per plant (7.1 g), followed by 21 (3.1 g) and 24 h (3.2 g), then 15 h (2.2 g), and finally the control (1.3 g). The 15-h treatment resulted in the greatest seed weight per plant in *C. judaicum* (12.5 g), *C. pinnatifidum* (6.7 g), *C. bijugum* (11.6 g), and *C. yamashitae* (3.0 g). Daylengths ≥18 h resulted in the highest and similar seed weight per plant in *C. chorassanicum* and *C. cuneatum*. All treatments resulted in similar seed weight per plant, which was similar to the control in *C. arietinum* (Fig. 3).

For 100-seed weight, the 18-h treatment resulted in the highest 100-seed weight in *C. reticulatum*, whereas these treatments were similar to the control in *C. judaicum*, *C. pinnatifidum*, *C. yamashitae*, *C. chorassanicum*, and *C. cuneatum*. Daylengths ≥15 h were similar to and better than the control in yielding high 100-seed weight in *C. bijugum* and *C. arietinum* (Fig. 3).

**DISCUSSION**

The narrow genetic base of cultivated chickpea poses a serious threat for its improvement. Further, new biotic and abiotic stresses such as dry root rot and heat stress are emerging due to climate change and are causing huge yield losses in chickpea (Savary et al., 2011). Using the genetic variation present in wild species will facilitate the development of climate-resilient chickpea cultivars. Wild *Cicer* species harbor many useful genes and provide enormous genetic variation for use in chickpea improvement programs. Previous studies have reported enormous variability for morphological traits in wild annual *Cicer* species, with the largest variability in *C. reticulatum*, *C. echinospermum* P.H. Davis, and *C. bijugum* (Robertson et al., 1997; Talip et al., 2018). However, different phenology of wild *Cicer* species and cultivated chickpea (Summerfield and Roberts, 1987; Summerfield et al., 1989; Robertson et al., 1997; Abbo et al., 2002; Berger et al., 2005) hinders their frequent utilization in chickpea breeding programs, especially due to vernalization and extended photoperiod requirements for flowering (Abbo et al., 2002; Sharma and Upadhyaya, 2015). Vernalization and photoperiod sensitivity of wild *Cicer* species is also a serious matter of concern for their efficient regeneration and conservation in genebanks. In the previous study, we concluded...
that wild Cicer species carry both vernalization- and photoperiod-responsive genes, with the preponderance of photoperiod-responsive genes in C. reticulatum, C. echinospernum, C. judaicum, C. bijugum, C. pinnatifidum, and C. yamashitae, whereas vernalization-responsive genes were predominant in C. chorassanicum and C. cuneatum (Sharma and Upadhyaya, 2015).

The present study is an attempt to study the response of wild and cultivated Cicer species to different extended photoperiod treatments in terms of reduction in the vegetative phase, and to study the effect of these treatments on yield-contributing traits. The study revealed that all four photoperiod treatments were effective in reducing the vegetative phase in wild Cicer species (Fig. 1). It is evident from the study that a linear trend of different photoperiod treatments was the most correct for explaining variation for days to first flowering and plant height; linear, cubic, and quadratic trends were the most correct for canopy width; cubic and linear trends were the most correct for number of pods and seeds per plant; linear and cubic trends were the most correct for seed weight per plant; and linear and quadratic trends were the most correct for 100-seed weight (Table 2).

Given the extent of reduction in number of days to first flowering, daylengths ≥15 h were similar and effective at reducing the vegetative phase by ~70%, thereby resulting in a strong response in C. judaicum and C. yamashitae, whereas daylengths ≥18 h were effective at reducing the vegetative phase by 70% in C. reticulatum, C. pinnatifidum, and C. bijugum (Fig. 1). The earlier study also showed the preponderance of photoperiod-responsive genes in C. reticulatum, C. judaicum, C. bijugum, C. pinnatifidum, and C. yamashitae (Sharma and Upadhyaya, 2015), which was confirmed by the high response (~70% reduction in vegetative phase) of these species to extended photoperiod treatments compared with the control in the present study. The extended photoperiod treatments were less effective in reducing the vegetative phase in C. chorassanicum, wherein days to first flowering were reduced only by 10 to 27% under treatments ≥15 h. Similarly, in C. cuneatum, the vegetative phase was reduced only by ~38 to 39% under both 21- and 24-h treatments, 23% under 18-h treatments, and 16% under 15-h treatments, showing weak response to these treatments. These results are in accordance with the previous study, which indicated the preponderance of vernalization-responsive genes in C. chorassanicum and C. cuneatum (Sharma and Upadhyaya, 2015). Cultivated C. arietinum also exhibited a weak response to extended photoperiod treatments, as the vegetative phase was reduced only by 28 to 44% under treatments ≥15 h. These responses could be associated with the geographical origin and distribution of these species in different environments. Two species, C. chorassanicum and C. cuneatum, are found in areas >2400-m elevation with low temperatures (<4°C) during pod set and are therefore exposed to vernalization under natural field conditions (Berger et al., 2003). The remaining species, which are found at lower elevations, such as C. reticulatum (966-m mean elevation), C. judaicum (322-m mean elevation), C. bijugum (957-m mean elevation), and C. pinnatifidum (935-m mean elevation) were found to be more photoperiod sensitive (Sharma and Upadhyaya, 2015), which is evident from the high response of these species to extended photoperiod treatments compared with C. chorassanicum and C. cuneatum in the present study. Further, the present study suggests that within photoperiod responsive species, treatments ≥18 h were more effective at reducing the vegetative phase in species such as C. reticulatum, C. bijugum, and C. pinnatifidum, which are found at comparatively higher elevations, whereas treatments ≥15 h were effective at reducing the vegetative phase in C. judaicum, which is found at much lower elevation. The weak response to extended photoperiod treatments in cultivated C. arietinum could be associated with the origin and domestication of cultivated chickpea from the wild progenitor, C. reticulatum. Major genes and alleles controlling photoperiod sensitivity might have been lost during the evolution and domestication of cultivated chickpea.

Besides days to first flowering, other yield-contributing traits such as plant height, number of pods and seeds per plant, seed weight per plant, and 100-seed weight were also affected by different photoperiod treatments in wild and cultivated Cicer species. However, differential response was observed in each species (Fig. 3). These results have major implications for the utilization of wild Cicer species in hybridization programs for chickpea improvement by synchronizing flowering with cultivated chickpea, and for efficient regeneration and conservation in the genebanks.

In C. reticulatum, daylengths ≥18 h were similar and led to a strong response. As C. reticulatum yielded the highest number of pods and seeds per plant, seed weight per plant, and 100-seed weight at 18 h compared with other treatments (Fig. 3), 18 h may be regarded as the critical daylength required for synchronizing flowering and for efficient regeneration of this species.

In C. judaicum and C. yamashitae, daylengths ≥15 h resulted in strong responses, and plants yielded the highest number of pods, seeds per plant, and seed weight per plant under 15 h (Fig. 3). Thus, 15 h could be regarded as the critical daylength required for both synchronizing flowering with cultivated chickpea and for efficient regeneration of these two species.

In C. pinnatifidum and C. bijugum, although daylengths ≥18 h were equally effective in reducing the vegetative phases, plants yielded significantly highest number of pods and seeds per plant, seed weight per plant, and 100-seed weight under 15 h (Fig. 3). Thus, it can be concluded that 15 h is the most effective treatment for regeneration of this accession, whereas for a crossing program, 18-h treatment
should be used, as this treatment will help to synchronize the flowering of *C. pinnatifidum* with cultivated chickpea genotypes, which usually flower within 35 to 50 d.

In *C. chonassianum*, and *C. cuneatum*, which are mainly vernalization responsive (Sharma and Upadhyaya, 2015), and in cultivated *C. arietinum* with weak response to extended photoperiod treatments, the present study revealed that daylengths $\geq$15 h in *C. chonassianum* and *C. arietinum* and daylengths $\geq$18 h in *C. cuneatum* were effective at reducing the vegetative phase to some extent and yielding more pods and seeds per plant compared with the control (Fig. 3).

For each trait, the high percentage of variation explained by cubic polynomials indicated that the response could be modeled using the cubic polynomials in the exposure time, but further improvement became possible by exploring other nonlinear forms such as exponential.

The present study holds great potential for improving the understanding of mechanisms controlling the physiological behavior of wild and cultivated *Cicer* species. In this study, photoperiod sensitivity and critical daylengths in wild *Cicer* species clearly exhibited latitudinal clines, wherein the lower the latitude, the shorter the critical daylength. The results indicated the requirement of long photoperiods (varying from 15 to 18 h) in wild *Cicer* species for their transition from vegetative into reproductive phase. It is also evident from the study that optimum photoperiods improve agronomic traits such as pod and seed yield, which could be due to the better assimilation and translocation of photosynthates from source to sink. Overall, it can be concluded that critical photoperiods for transition from the vegetative to reproductive phase and for net assimilation rate varies across wild and cultivated *Cicer* species. The optimum daylength requirement for different *Cicer* species identified in this study will be helpful in utilizing the wild *Cicer* species in chickpea improvement programs, as well as in their efficient regeneration for conservation in genebanks.

Conflict of Interest
The authors declare that there is no conflict of interest.

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