An easy way to assess photoperiod sensitivity in sorghum: Relationships of the vegetative-phase duration and photoperiod sensitivity

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Introduction

Sorghum (*Sorghum bicolor*) landrace varieties show very large variation for the duration of their vegetative phase, ranging from 50 to 300 days depending on the sowing date (Miller et al. 1968). This variation is linked with the duration of the rainy season in their place of origin (Curtis 1968). Late sorghum varieties are known to be highly photoperiod-sensitive and, for a given variety, the flowering date remains more or less constant independent of sowing dates, which in the tropical areas of the northern hemisphere occur anytime between May and July. Even though the importance of matching sorghum flowering date to the end of the rainy season has long been known, relatively little has been done to improve these photoperiod-sensitive varieties until the past decade. The lack of new, improved sorghum varieties able to respond to the increased soil fertility in cotton (*Gossypium* spp) systems of Burkina Faso and Mali has most recently raised the need for this type of research, and breeding programs are currently addressing this objective (Bazile et al. 2003).

Among the many questions regarding methods for improving photoperiod-sensitive sorghums, the most urgent include: (i) How can the photoperiod sensitivity of large numbers of germplasm accessions be efficiently characterized so as to facilitate their use in breeding programs? (ii) What is the relationship between photoperiod sensitivity and the duration of the crop life cycle? The experimental results reported in this article give some clear indications to these questions.

Materials and methods

International Cooperation Centre for Agronomic Research for Development (CIRAD), France maintains a mini-core collection of 210 sorghum accessions, comprising nearly 1% of the World Sorghum Collection conserved by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) in Patancheru, India. Accessions in this core collection were chosen to maximize the representation of the total diversity of this collection. The majority of accessions were derived from a logarithmic sampling "L sorghum core" of 2247 accessions representing 10% of the landraces maintained at ICRISAT (Grenier et al. 2001). Details are given by Deu et al. (2006) that explain how the 210 accessions were drawn from the L core collection and other sources to establish the mini-core collection studied in this article. The mini-core collection was sown on 8 June and 9 July 2002 at ICRISAT, Samanko, Mali (12°32' N, 8°04' W). The experiment was irrigated in June to establish the first sowing date and again during October and November to avoid water shortage during flowering and grain filling of later maturing accessions after the rains had ended. An alpha lattice design was used with the 210 test entries plus six variety checks sown in two replications, with incomplete blocks consisting of four plots within each replication. Plots consisted of a single row with three hills at 0.25-m intervals and 0.80 m between rows. Hills were thinned to 3 plants, 2 weeks after sowing. Dates of flag-leaf exsertion, heading and flowering were recorded when 50% of the plants in a plot had reached the respective stages.

Given that for each variety there is a linear relationship between the duration of vegetative phase and the sowing date (for sowings between mid-May and mid-July in the northern tropics), with the slope corresponding to the level of photoperiod sensitivity, an index of photoperiod sensitivity based on the decrease of the duration of the vegetative phase between two sowing dates was computed as:

$$Kp = \frac{DurH1 - DurH2}{DatS2 - DatS1}$$

with *DurH1* and *DurH2* the duration in days from sowing to heading for the first and second sowing dates, respectively, and *DatS1* and *DatS2* the first and second sowing dates in Julian days (Kouressy et al. 1998). *Kp* is expected to vary from 0 for photoperiod-insensitive varieties, which do not change the duration of their vegetative phase with the sowing date, to 1.0 for the most strongly photoperiod-sensitive varieties which reduce their vegetative phase to the same extent as the delay in sowing, keeping the calendar date of flowering constant.

Kp was plotted against the number of days from sowing to heading of the June (*DurH1*) and July (*DurH2*) sowings. A non-linear regression calculated as a broken linear function was chosen to fit the data for the June sowing (Table 1), where

$Kp = a,$ for $DurH1 < D1,$
$Kp = a+b*DurH1,$ for $D1 \leq DurH1 \leq D2,$
$Kp = a+b*D2,$ for $D2 < DurH1,$

where a = intercept, b = slope, $D1$ and $D2$ = minimum and maximum thresholds in days from sowing to heading between which the regression slope is positive. This broken linear function was chosen based on the following: for the initial segment, non-photoperiod-sensitive varieties could exhibit genotypic variation for the duration of their vegetative phase while having a common index value of 0.0; the second and third segments correspond to the visually observed pattern of data points as well as the expectation that very late photoperiod-sensitive varieties show genotypic variation for vegetative phase duration while having a common index value of 1.0 (Curtis 1968).

The model was iteratively fitted using the procedure SAS-NLIN. The confidence intervals calculated for each parameter were used to compute a maximal confidence interval to the predictions given by the model.

Regression was conducted on the 194 accessions for which data was available of sufficient reliability. The regression for the July sowing was derived from the regression on the June data under the assumptions that the values of a and $D1$ are stable for non-photoperiod-sensitive varieties and $D2_{July} = D2_{June} - (DatS1 - DatS2)$.

Results and discussion

Heading occurred between 18 July and 13 November for the first sowing and between 17 August and 1 December for the second. There was no difference between early and late maturing varieties for the duration between flag-leaf extension and heading, indicating that serious water shortage was not experienced by the later varieties. The experiment clearly shows that lateness and photoperiod sensitivity are strongly related ($P = 6.6.10^{-70}$) (Fig. 1) in sorghum, with the earliest flowering varieties exhibiting *Kp* values near 0, and the latest flowering varieties with *Kp* values approximating 1.0. Some *Kp* values are small and negative, which is due to the lower temperatures in July. These negative values disappear however when *Kp* is calculated using thermal time – the "time" that plants perceive (data not shown). However, calculations based on days is used in this study to facilitate the extended use of this method. The strong relationship between time to flowering at a single date and the photoperiod sensitivity, as measured by *Kp*, indicates that all late maturing sorghums are photoperiod-sensitive, and the degree of lateness is proportional to the degree of photoperiod sensitivity. This suggests that the system conferring photoperiod sensitivity primarily determines the length of the vegetative phase in cultivated sorghums. These results, based on a mini-core collection representing the variation in cultivated sorghum worldwide, suggest that this is a general phenomenon. Only 11 varieties with intermediate maturities were consistently outside the confidence interval and may express physiological responses that differ from the 183 other varieties by lengthening their vegetative phase without a corresponding increase of photoperiod sensitivity. Among these 11 varieties, 6 were classified as *Durra*, 4 *Bicolor* and 1 *Guinea* race (*roxburghii* in Snowden classification) (Table 2).

Table 1. Parameters of the non-linear regression $Kp = a + b * min(max(0,DurH1-S1),S2-S1)$ fitted for the sowing done on 8 June and estimated for later dates.

	Sowing date		
	8 June	9 July	8 June + n days
a	–0.063	–0.063	–0.063
b	0.013	0.020	$(Kp_{max} - a) / (D2_n - D1)$
$D1$	49.5	49.5	49.5
$D2$	127.8	98.6	$127.8 - n*Kp_{max}$
Kp_{max}	0.941		

Table 2. Sorghum accessions showing *Kp* values deviating beyond the confidence intervals of Figure 1.

Race	Identification
Durra	IS 929, IS 4821, IS 6351, IS 11026, IS 11827, IS 19453
Bicolor	IS 5430, IS 12169, IS 20706, SSM 1049
Guinea roxburghii	IS 19466

Thus, the results showed that all the accessions from the other three races (*Caudatum*, *Kafir* and *Guinea* except *Guinea roxburghii*) and their intermediate forms share the same strong relationship between the duration of their vegetative phase and their level of photoperiod sensitivity.

The important practical consequence of this observation is that it is possible to obtain a rapid and quite accurate estimate of the photoperiod sensitivity of a large number of sorghum varieties by simply observing the duration of their vegetative phase from a single date of sowing. Indeed, the relationship between *Kp* and the duration of the vegetative phase can be estimated from the relationship fitted for data from the sowing done on 8 June (Fig. 2). The initial parameters of the regression, *a* and *D1*, are assumed to be stable and are used as

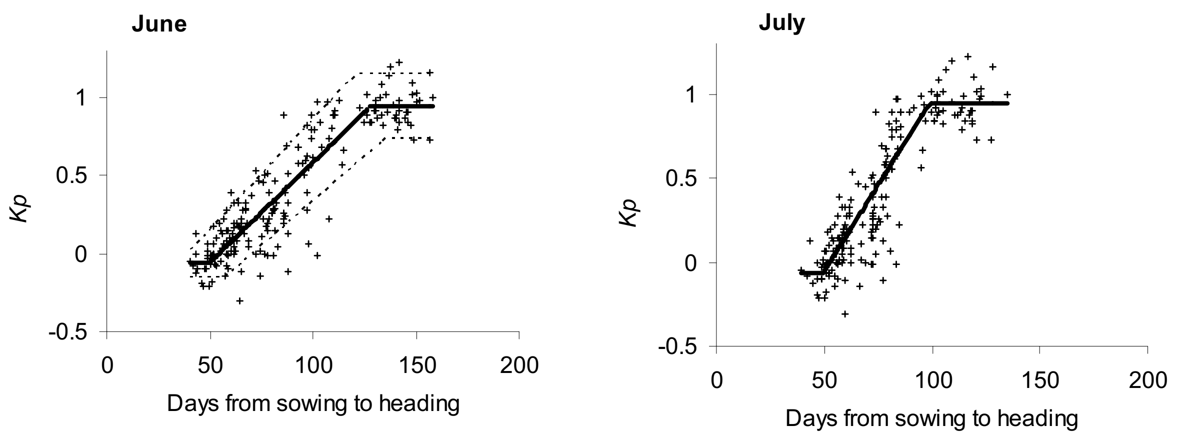

Figure 1. Relationships between the duration of the vegetative phase (days from sowing to heading) for June and July sowings and the photoperiod sensitivity index *Kp*. Solid lines represent the non-linear regression and dotted lines the confidence intervals, iteratively fitted for the June sowing and extrapolated for the July sowing.

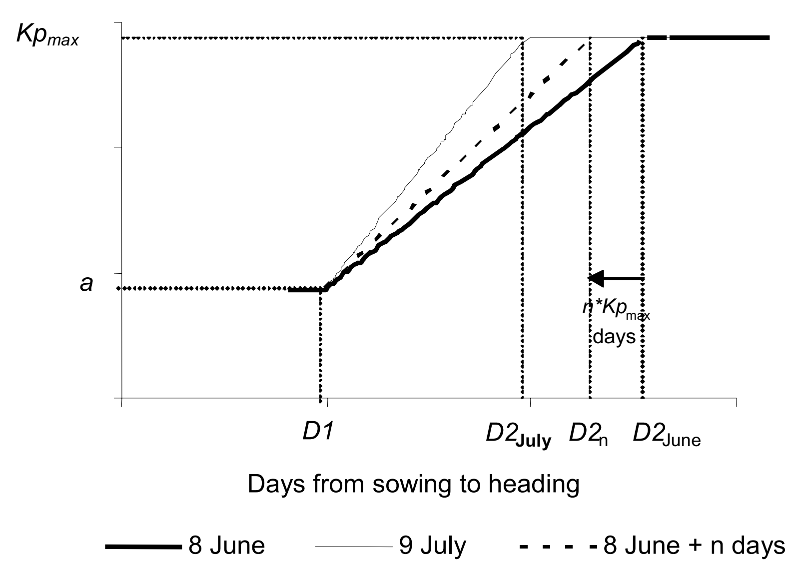

Figure 2. Extrapolation of the relationship between the photoperiod sensitivity index *Kp* and the duration of the vegetative phase (in days) for any sowing date between 8 June and 9 July.

constants, whereas *D2* and the slope *b* are linearly extrapolated using the formulae in Table 1. Once the relationship between *Kp* and the observed length of the vegetative phase is estimated for the specific date of sowing of a given experiment using calculations from Table 1, *Kp* can be predicted. These predictions should be reliable for sowing dates between 8 June and 9 July for locations with similar latitudes to that of this study, ie, between 10° and 14° latitude.

Figure 1 clearly shows that the range of vegetative phase durations is much greater with the June sowing. Earlier sowing dates therefore should provide more precise estimates of photoperiod sensitivity. Further study of the *Durra* and *Bicolor* races would be necessary to predict photoperiod sensitivity with similar confidence as obtained for the other races.

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