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A Farmer's Approach to Detecting Photoperiod Sensitivity in Rice (*Oryza sativa* ssp. *indica*) Landraces

Debal Deb

Centre for Interdisciplinary Studies, Kolkata, 700075, India

ABSTRACT

Most indigenous rice landraces are sensitive to photoperiod during short day seasons, and this sensitivity is more pronounced in *indica* than in *japonica* landraces. Attempts to identify photoperiod sensitive (PPS) cultivars based on the life history stages of the rice plant, and several models and indices based on phenology and day length have not been precise, and in some cases yield counterfactual inferences. Following the empirical method of traditional Asian rice farmers, the author has developed a robust index, based on the sowing and flowering dates of a large number of landraces grown in different seasons from 2020 to 2023, to contradistinguish PPS from photoperiod insensitive cultivars. Unlike other indices and models of photoperiod sensitivity, the index does not require the presumed duration of different life history stages of the rice plant but relies only on the flowering dates and the number of days till flowering of a rice cultivar sown on different dates to consistently identify photoperiod sensitive cultivars.

Keywords*:* *Aman*; *Aus*; *Boro*; Flowering; Landraces; Photoperiod sensitivity; Rice (*Oryza sativa* L.)

1. Introduction

Flowering in most indigenous rice (*Oryza sativa* L.) landraces is sensitive to seasonal photoperiod during the short day season. Among the cultivated rice, *japonica* cultivars tend to be more sensitive to temperature and less sensitive to photoperiod than *indica* cultivars [1]. South Asian rice landrace that flower during short, cooler days and are harvested in winter, are termed *aman* and *sali* in eastern India and Bangladesh, *samba* in southern India [2], *mayin* in Myanmar and *na bi* in Thailand [3]. Most of the short-day rice landraces are strongly photoperiod sensitive (PPS), flowering on about the same date every year

*CORRESPONDING AUTHOR:
Debal Deb, Centre for Interdisciplinary Studies, Kolkata, 700075, India; Email: debdebal@gmail.com

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during the short-day season, regardless of the date of sowing. Some of the *aman* landraces that can also flower during the hotter long-day (termed *boro* and *aus*) seasons are insensitive to photoperiod [4].

Traditional farmers used to identify the degree of photoperiod sensitivity of their landraces by the invariance of either the date of anthesis or the date of 50% flowering. However, the precision of sensitivity to photoperiod is also variable in many landraces, and Yoshida (p. 44) [5] observed that "there is no sharp dividing line between the photoperiod-sensitive and photoperiod-insensitive varieties, and any definition would be based on arbitrary criteria"—accounting for an amorphous classification of strong, moderate and weak photoperiod sensitivity [5,6]. Rice biologists [5-7] have constructed a schema of growth phases of the rice plant, showing changes in the basic vegetative phase (BVP) and photoperiod sensitive phase (PSP) of the rice plant at short-day and long-day (> 11 h) seasons. **Figure 1** describes the growth phases of rice cultivars in the short day condition (*aman* season in South Asia), but sown on different days (e.g. 1 May and 20 May). If the cultivar flowers on about the same date despite considerably different sowing dates, the cultivar is PPS. If the flowering date is delayed proportionately by delayed sowing, the cultivar is photoperiod insensitive (PPI).

Several authors have developed a few indices to identify photoperiod-sensitive rice cultivars by considering the duration of the reproductive phase (RP) and vegetative growth phase [8-10], but "these models are only valid at the latitude where they have been calibrated" [10,11]. However, the actual anthesis date of many cultivars does not seem to match exactly with that predicted by the indices. We examine here the limitations of a most cited photoperiod-sensitivity index, and propose an alternative, simpler index, which takes into account only the degree of invariance of the date of anthesis in different years.

2. Materials and methods

Over 3 years from 2020 to 2022, we recorded the dates of sowing and the first flowering dates (FD) of 1114 rice landraces [12], among which we examine here 92 landraces that were repeat-sown in different years either in the same season or in different seasons. Eighty-one of these landraces were cultivated in the short-day season in different years, while 23 were cultivated in the long-day season, among which 12 were sown in both long-day and short-day seasons (detailed in Supplementary Material [13]). All these landraces were cultivated on the Basudha conservation farm (http://cintdis.org/basudha), located in Bissam Cuttack block, Rayagada district of Odisha. India (19°42'32.0" N, 83°28'8.4" E).

The deviation of the FD of each landrace grown during the short day season in different years was recorded. This difference in FD of a landrace between years (dFD) would indicate the degree of photoperiod sensitivity of that landrace, because an ideal, strongly PPS cultivars ought to show dFD ≈ 0 d. Conversely, a PPI cultivar would not only show a wide range of dFD (> 6 d) between years, but also flower in both short- and long-day seasons.

Using the flowering data of the landraces summarised in Supplementary Material [13], we develop an index of photoperiod sensitivity based on the relative invariance of FD:

$$PPSI = dFD / |dFD - dDTF| \quad (1)$$

where dFD is the actual seasonal difference in flowering dates = $|FDi - FDE|$;

DTF = Days till flowering, is the number of days from the sowing date (SD) till FD, or (FD – SD);

dDTF = $|(DTF - DTFE)|$;

FDi is the flowering date observed for the ith sowing date;

FDE is the earliest flowering date in a short day season of a given year;

DTFE is the number of days from the sowing of a cultivar to FDE, or (FDE – SD).

The index is zero if FD_i = FDE. To illustrate, if the FD1 of a cultivar is 10 Sep 2020, and FD2 of the same cultivar is 01 Sep 2021, then FDE is 01 Sep 2021; thus, dFD = 10 Sep – 01 Sep = 9 d.

The difference (in days) between $|DTFi - DTFE|$ and $|FDi - FDE|$ informs whether anthesis is delayed in response to a delay in the sowing date—a feature characteristic of PPI cultivars. This difference would approximate zero for a purely PPI cultivar that comes to flowering exactly according to the sowing date, without changing the growth phase duration till maturity. Conversely, |FD*i* – FDE| is zero for strongly PPS cultivars. Based on this understanding, we estimate the range of PPSI values for all the landraces examined, based on the actual DTF, DTFE and dFD of all the landraces.

For an accurate estimation of the effective interval of one or more years ($Y > 0$) between the dates of anthesis, the following procedure was undertaken. For a cultivar flowering during the same season in different years, a factor of $365Y$ must be subtracted from the dFD, to calculate the *actual seasonal difference* (in days), because the interval between two successive *aman* (or *boro*) seasons is 365 d (except leap years, in which case the interval is 366 d). An *aman* cultivar, for instance, that flowers in September are likely to flower also on the same date in succeeding years (dFD = 0), exactly $365Y$ d later. If its anthesis occurs during the *boro* (long day) season, we calculate the difference between this interval and $365Y$. For example, the FD1 (= FDE) of cultivar DD01, sown during *aman* season, was 03 September 2020, and FD2 was 16 September 2021 when sown in July 2021 (**Table 1** and Supplementary Material). In this instance, $Y = (2021 – 2020) = 1$, and dFD between the two *aman* seasons = |FDE – FD2| = (378 – 365 x 1) d = 13 d. The same cultivar was sown during *boro* season, and its flowering date FD3 was 28 April 2022; so the actual seasonal difference between the short-day and long-day flowering dates is |FDE – FD3| = |602 – 2 x 365| d = 128 d. All the calculations are shown in Supplementary Material [13].

3. Results

An illustrative data set presented in **Table 1**, drawn on the data of flowering of 91 rice landraces [13] shows that for the cultivar DD01, the earliest flowering date (FDE), marked during the short day season of any year, is 03 September, corresponding to its sowing date on 17 June. For cultivar N03, the FDE is 06 September, corresponding to its sowing date on 20 June.

The data of 92 landraces with their SD, FD, dFD and DTF, and the corresponding calculations of PPSI are presented in Supplementary Material [13]. It is common knowledge that strong photoperiod sensitivity is found in most short-day (*aman*) rice, and they do not flower beyond a "critical" photoperiod, usually > 11 h [6]. Thus, we identify the PPI landraces as those that flowered both during short- and long-day seasons, and their anthesis occurs after a fixed

Table 1. Identification of photo-period sensitivity based on sowing dates and flowering dates of illustrative rice cultivars (Excerpted from Supplementary Material [13]).

Cultivar & Year	SD	FD	DTF (d)	Factor to subtract from dFD	dFD (d)	|dFD – dDTF|	PPSI
***C04* (2020)**	17 JUN	22 SEP	97	0	8	17	0.47
C04 (2021)	04 JUL	14 SEP*	72	365 x 1			
C04 (2022)	03 FEB	11 APR	67	365 x 1	156	51	1.03
DD01 (2020)	17 JUN	03 SEP*	78	0			
DD01 (2021)	07 JUL	16 SEP	71	365 x 1	13	6	2.17
DD01 (2022)	03 FEB	28 APR	84	365 x 2	128	122	1.05
DD01 (2022)	29 MAR	21 JUN	84	365 x 2	74	68	1.09
S90 (2020)	17 JUN	18 SEP*	93	0	0		
S90 (2021)	08 JUL	18 SEP*	72	365 x 1	0	21	0
S90 (2022)	29 JUN	19 SEP	82	365 x 2	1	10	0.10

DTF = Days till flowering; DTFE = Days till earliest flowering during the short-day season; FD = Flowering date; FDE = Earliest date of flowering during the short-day season; dDTF = DTFi – dTFE; dFD = FDi – FDE; PPSI = Photoperiod sensitivity index. An asterisk (*) corresponds to the FDE of respective cultivars.

vegetative growth phase of the rice plant [6]. For these landraces in our dataset, PPSI is always found to exceed the value of 0.33. Conversely, many of the landraces that flowered only during the short-day season showed largely invariant FD, and were identified as strongly PPS. The PPSI for these landraces is seen to never exceed the value of 0.33.

4. Discussion

Previous analyses of photoperiod sensitivity in rice emphasized the different growth phases of the rice plant. In South Asia, most of the PPS winter (*aman*) landraces do not anthese in the long-day season, when the critical day PP exceeds 11 h. For example, the strong PPS landrace Latisail never flower in long day condition beyond 12 h of daylight [5]. However, if a cultivar can flowers in both seasons, its photoperiod sensitivity can be estimated as follows.

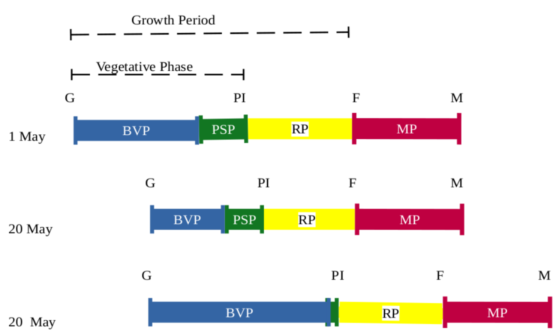

Figure 1. Schema of rice growth phase [7]: A vegetative period begins from germination (G) of the seedling until panicle initiation (PI), followed by a Reproductive Phase (RP) of a fixed duration (35 d) until flowering (F). The vegetative period consists of a Basic Vegetative Phase (BVP) and a photoperiod sensitive period (PSP), which ends at PI. The RP is followed by the grain Maturation Phase (MP) ranging from 30 d to 35 d, terminated at grain maturation (M). Different sowing dates are shown on the left.

"Maximum differences in growth duration can be obtained in the May and November plantings if temperatures are not too low for growth. If a rice's growth duration changes more than 30 d, agronomists usually consider it photoperiod sensitive or a seasonal cultivar." [6]. For instance, the PPS landrace Peta has DTF = 70 d at 10 h (winter) photoperiod, and DTF = 145 d at 16 h (summer) photoperiod [5]. With this data, the photoperiod sensitive phase (PSP) of the cultivar is calculated, assuming RP = 35 d:

$$\begin{aligned} PSP &= \text{Longest DTF} - \text{Shortest DTF} \\ &= 145 - 70 = 75 \text{ d} \end{aligned} \quad (2)$$

These calculations presuppose that Peta's PSP = 0 d in the short-day optimal photoperiod (as graphically shown in the study by Dinkhun and Asch [7], 1999, **Figure 1**):

Shortest DTF = BVP (35 d) + PSP (0 d) + RP (35 d) = 70 d

Longest DTF = BVP (35 d) + PSP (75 d) + RP (35 d) = 145 d

This assumption of PSP = 0 in short day condition implies that a strong PPS cultivar responds to the optimal photoperiod after PI. However, this contradicts the fact that only PPI cultivars can have a very short PSP, according to the "practical grouping" [6] (V&C) of rice varieties based on rice phenology (**Table 2**).

Table 2. Rice growth phases and corresponding phenological features (Vergara and Chang, 1985).

Response to day length	**Phenological features**
Photoperiod insensitive	Very short PSP (< 30 d) and BVP varying from short to long.
Weakly photoperiod-sensitive	Marked increase in growth duration when photoperiod is longer than 12 h; PSP may exceed 30 d, but flowering occurs under any long photoperiod.
Strongly photoperiod sensitive	Sharp increase in growth duration with increase in photoperiod; no flowering beyond critical photoperiod; BVP usually short (< 41 d).

4.1 Dissents to the schema

Collinson et al. [14] disagreed with the procedure of estimation of PSP. "The PSP [is] calculated as the difference between the duration from sowing to panicle emergence in short and long days, such that in optimal photoperiods (at which progress to panicle emergence is most rapid) the end of the BVP is assumed to coincide with the end of the vegetative phase; the duration of the reproductive phase is assumed to be 35 d, and so the BVP is assumed to be 35 d less than the duration from sowing to panicle emergence in optimal photoperiods. It would be remarkable if this arbitrary 35 d period proved to be not only insensitive to temperature but also identical for different cultivars." (p. 340). They [14] further showed that RP may range from 30.2 to 52.9 d at different temperatures. However, the contention of a significant effect of post-PI photoperiod on the RP duration [6] was confirmed by other studies [15,16].

An alternative division of rice growth duration was also proposed [7], in which (i) a constant duration (30 d) of a reproductive phase (RP) is followed by a constant grain ripening phase (35 d); and (ii) BVP is "estimated by subtracting [RP =] 30 d from the duration to flowering at the sowing date associated with the shortest duration" [7] (p. 112). When measured as degree-days at a given temperature, the BVP appears to show a constant duration, regardless of the sowing date, and is measured following Equation (2), with RP = 30 d, instead of 35 d.

BVP = Shortest DTF – RP [= 30 d] (3)

Dinkhun and Asch [7] calculated photoperiod sensitivity "as the difference in duration of the photoperiod-sensitive phase (PSP) between 12.0 h and 12.5 h mean astronomic day length during PSP" (p. 116).

4.2 Conformity and confusion

Despite the "somewhat arbitrary" measurement of BVP and assumed length of PSP, the same method is followed in determining the degree of phoroperiod sensitivity in rice cultivars in various models of photoperiodism in rice [8,9]. This approach to determining phoroperiod sensitivity, based on the duration of BVP and PSP, instead of more direct proximity of the exact flowering date of a cultivar with different sowing dates, leads to some confusion. For all *aman* cultivars that do not flower in the long day (summer) season, PSP cannot be calculated from a difference in a cultivar's growth duration between short-day and long-day seasons, and therefore the extent of photoperiod sensitivity cannot be quantified.

This constitutes a conundrum, which makes an attempt to detect the degree of photoperiod sensitivity in different rice landraces with recourse to different life history stages and their phenological durations of the rice plant. This conundrum is built summarily on:

(i) The arbitrary choice of a constant 35 d [6] or 30 d [7] for RP, overlooking the wide variability (30 to 52.9 d) of the RP, already documented [7];

(ii) The assumption that PSP = 0 in the calculation of the shortest DTF of a PPS cultivar (Equation (2)), directly contradicting the "practical" consideration [6] (**Table 2**) that PPI cultivars have very short PSP;

(iii) The thumb rule that *boro* and *aus* landraces (flowering in long day periods of April and early June, respectively) are PPI, is vitiated by the fact that some of the PPS cultivars described by those authors (such as Peta) flower both during short and long day seasons; implying that either this classification or the identification of PPS based on estimation of PSP, is incorrect.

It is impossible to determine if a cultivar is PPS or PPI when the FD during the short-day season is unavailable. Therefore, the criterion of the difference between PSP of the cultivar sown on different dates may not give a reliable indication of the degree of photoperiod sensitivity. An index of photoperiod sensitivity, based on flowering dates during at least 1 short day season is required to contradistinguish the PPI from PPS cultivars, regardless of the availability of the data pertaining to PVP and RP durations.

4.3 A misleading index in vogue

Immark et al. [8] and Khotasena et al. [9] considered two flowering dates of the same cultivar sown on two different dates, and employed the ratio of the difference between two DTFs and the interval between two sowing dates (SD) as an index of photoperiod sensitivity:

$$PSI = |DTF1 - DTF2| / |SD1 - SD2|, \quad (4)$$

and classified the cultivars with PSI < 0.3 as PPI, and PSI > 0.7 as strongly PPS [9].

This index poses two kinds of problems. Firstly, in the trivial case of SD1 = SD2 during the same season [8], the PSI is indeterminately large (division by zero). Secondly, if a cultivar is sown in *aman* and

DTF1 = DTF2, but FD1 and FD2 are wide apart, the Equation (4) would always yield PSI < 0.3, leading to the exactly opposite, counterfactual inference that cultivars flowering on widely different dates are all PPS!

4.4 Resolving the conundrum with Occam's razor

Previous attempts at indexing the PPS cultivars seem to be inaccurate, primarily because they counted on various *durations*, namely, DTF, BVP, RP and PSP, which in turn are calculated by indirect means, based on certain assumptions, some of which are disputable. We contend here that a more parsimonious approach of reliance on the exact sowing and flowering dates, rather than any estimated duration of PSP and RP, maybe more fruitful—the approach taken by indigenous farmers over centuries. The PPSI threshold of 0.33 developed here is not arbitrarily determined based on any *a priori* assumptions, but empirically derived from the values obtained from the invariant flowering dates of cultivars that do not flower in the long day season (see calculations in Supplementary Material [13]).

5. Conclusions

The basic characteristic of a strongly PPS cultivar is that its flowering date would ideally not deviate from a fixed date in a given season, regardless of different sowing dates. Rice farmers do not sow their *aman* crop more than 2 months later, unlike experimental agronomists, and are reasonably confident of the relatively invariant flowering date, especially for rice grown during the short-day season. Traditional farmers of South Asia sow the same cultivar in successive years on different dates, contingent on the arrival of the monsoon rain. Thus, *aman* cultivars are sown usually in May-June, but the sowing date may sometimes be delayed in some years by a month. The farmers used to recognize that if an *aman* cultivar flowers every year on the same date (with a few days' deviation), despite widely different sowing dates, it is PPS. Conversely, if the flowering dates are widely (> 10 d) different from the mean FD, it is PPI. Our experience with more than 1400 PPS landraces cultivated on our conservation farm Basudha (http://cintdis.org/basudha) over 25 years indicates that BVP, RP and PSP seem to be irrelevant, from the farmer's perspective, to detect the photoperiod sensitivity of a cultivar, regardless of their physiological importance in orchestrating the plant's photoperiod response at the molecular level. We demonstrate this using our record [12] of actual sowing and flowering dates of PPS and PPI cultivars in different seasons and years.

Our index of photoperiod sensitivity PPSI simulates this traditional procedure, and relies only on the date of flowering and the DTF, rather than on any presumption of the length of PSP or constancy of duration of life history stages (BVP, RP), and is therefore independent of latitudinal differences in day length. This parsimony of factors for adequate explanation is an application of Occam's Razor. For all strongly PPS cultivars, PPSI < 0.33, such as S90, despite altered days of sowing. Conversely, all cultivars (e.g. AA03, C04, DD01, G32, and N03) with PPSI > 0.33 are PPI, and they all bloomed during both short day and long day seasons (**Table 1**). This categorical consistency of the index is its most reliable property.

Supplementary Material

Supplementary Material contains the author's original data and calculations, and is freely available from Harvard Dataverse, DOI: https://doi.org/10.7910/DVN/QRCNMD [13].

Conflict of Interest

There is no conflict of interest.

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