Basudha Data Paper No. **7**

Diversity and Environmental Correlates of Flower Opening Time in Rice (*Oryza sativa* ssp. *indica*) Landraces of South and Southeast Asia

Prepared by

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Abstract

We present here the first records of flower opening time and flower exposure duration, and examine the influences of cultivation season, sunrise time, and day maximum temperature on the anthesis behavior, of 996 winter rice and 77 summer rice landraces of South and Southeast Asia.

Keywords: Rice, Landrace, Flower opening time, Flower opening duration, Season, Temperature

Centre for Interdisciplinary Studies Kolkata

Basudha
Laboratory for Conservation

2022

Introduction

The flower opening time (FOT) and the duration of the flowers remaining open (= flower exposure duration, FED) are crucially important for the success of pollination and fertilization in rice plants. If the flowers of the ovary parent (OP) close even a second before the FOT of the pollen parent (PP), the FED overlap between the two parents is zero, and consequently, there woud be no cross pollination. In spite of this crucial importance of FOT and FED overlap between the OP and the PP, reports of cross pollination experiments, published over the past century (Beachell et al. 1938; Coste 1969; da Silva et al. 2005; Endo et al. 2009; Jodon 1959; Messeguer,et al. 2001; OGTR 2004; Reaño and Pham 1998; Robert et al. 1961; Sahadevan et al. 1961; Somaratne et al. 2012) surprisingly do not mention FOT and flower closing time (FCT) of respective cultivar pairs slected in the experiments. (Deb and Bhattacharya 2021) surmised that in all the previous experiments (cited above), near-zero overlap of the FED between the PP and OP might be the only factor resulting in extremely low cross pollination frequency reported in those experiments.

The earliest record of FOT in cultivated rice was made by van der Stok (1910), informing that in Java, flowers of a large number of rice cultivars opeened between 0900 h and 1000 h, while some varieties opened between 1200 h to 1300 h. Pope (1916: p. 669) reported that in the US, rice florets fully opened at 1014 h, and closed at 1300 h. However, Jones (1924) reported that in California, most of the flowers of 12 rice cultivars opened between 1200 h and 1400 h. Hirabayashi et al. (2014) reported that the beginning of FOT of Nanjing 11 in temperate Japan was at ca.0900, and the FOT of IR64 in the Philippine tropics began at ca. 1100. After incorporation of a QTL (*qEMF3*) from wild rice, the FOT of both the cultivars was shifted 1.5 – 2 hr earlier (0700 h for Nanjing 11, 0930 h in IR64) in response to elevated ambient temperatures.

There is paucity of FOT and FED data of a majority of *Indica* rice landraces, of which the first record of FOT is found in Sharngapani (1924), who noted that Aus rice varieties (flowering in April-May) opens at ca. 0700 h, while the winter rice cultivars, flowering in October, opened at 0900 h. Bheemanahalli et al. (2017) recorded the variation of FOT of the largest number (289) of Asian cultivars till date, including some landraces from South and Southeast Asia, and showed that these cultivars open their florets netween 2.35 h and 5.08 h after sunrise during the dry season, compared to 3.05 h and 5.50 h after sunrise during the wet season. However, the exact time of FOT is not available from their data. Kobayashi et al. (2009) examined FOT and FCT of 93 cultivars, including 17 South Asian cultivars (12 from India, 2 from Nepal and 1 each from Bangladesh,

Bhutan and Sri Lanka); and reported that the FOT of the Indian cultivars, all grown in Japan, ranges between 0953 h and 1116 h.

Table 1. Published Records of Earliest and Last FOT for Rice Cultivars from Different Countries.

	Indica		**Japonica**		
Country	**Earliest FOT**	**Last FOT**	**Earliest FOT**	**Last FOT**	**Reference**
India	07:00	12:00			Sharngapani (1924)
	09:53		11:16		Kobayasi et al. (2009)
Nepal			10:51	11:30	Kobayasi et al. (2009)
Myanmar	07:00 10:38	09:00	 11:31		Thompstone (1915); Kobayasi et al. (2009)
China	09:01	10:47	11:44	12:02	Kobayasi et al. (2009)
Japan	10:08	11:42	10:19	12:35	Kobayasi et al. (2009)
The Philippines	09:55	11:15	09:00	11:30	Torres (1923); Kobayasi et al. (2009)
Indonesia	09:00 10:44	13:00	11:01 12:00	-	Van der Stok (1910); Kobayasi et al. (2009)
USA	08:00	17:00	10:10	11:42	Jones (1924); Kobayasi et al. (2009)

A range of FOT and FED data, gathered from published literature (**Table 1**) indicates that flowers of *Indica* varieties tends to open earlier than *Japonica* varieties (Table 1). However, as daylength and diurnal temperature are often interrelated, the rice plant may respond to temperature and photoperiod simultaneously, but the response varies according to the cultivar genotype (Vergara and Chang 1985). The FOT of a cultivar native to lower latitudes (e.g. southern India) is apt to be delayed in northern latitudes (in California), due to lower temperature and shorter day length. As Vergara and Chang (1985: 16) surmised, "a rice cultivar that must have less than 12 h of daylight to flower will obviously flower too late at the northern latitudes because frost will set in before harvest". This is corroborated by Jones (1924), who recorded that a majority of flowers of 12 rice cultivars of Asian origin opened between 1200 h and 1400 h in California, while a small number (0.53%) opened between 4 p.m. and 5 p.m. Three of these varieties in Jones' experiment are late

maturing *Japonica* cultivars Omachi, Shinriki and Wataribune, which open their flowers in Japan no later than 1125 h.

Here we contribute to expandig the database of rice flowering time. This paper constitutes the first comprehensive report of FOT and FED of 996 *Indica*-type landraces cultivated in South and Southeast Asia.

Materials and Methods

Our recording of flowering dates and times began with 985 *aman* varieties, planted in June 2020. After the harvest of *aman* rice, 31 *boro* varieties were planted in January 2021, 124 *aman* varieties in June 2021, and 49 *boro* and 5 *aush* varieties in January 2022. Most of these cultivars were repeatedly grown in the three years of study, totalling 994 landraces. These landraces were originally collected from different districts of Bangladesh, India, Myanmar, Nepal, Pakistan and Sri Lanka, in addition to 17 landraces from Southeast Asia (**Table 2**),and grown on Basudha conservation farm, located in Bissam Cuttack block, Rayagada district of southern Odisha (19° 42′ 32.0″N, 83° 28′ 8.4″E). Young (14-16 day-old) seedlings of each landrace were transplanted from the nursery to the main rice farm plots, where the soil had been prepared following standard organic method, with no synthetic agrochemical inputs. Each varietal plot contained 64 plants till maturity.

Table 2: Countries of Origin of the Landraces Examined for FOT and FED.

Country	**No. of Landraces**	
	Winter Harvest	**Summer Harvest**
Bangladesh	31	2
India	915	79
Myanmar	3	0
Nepal	2	0
Pakistan	1	1
Sri Lanka	28	2
The Philippines	14	0
Thailand	3	0

The steps of our method for recording the flower opening (FOT) and closing time (FCT) of the rice landraces is in order.

a) We, sometimes assisted by a few volunteers, gleaned the approximate day of the first panicle emergence of a variety from our observation of the booting stage.

b) On the expected day of panicle emergence of the plants of a variety, one of us stood up in front of the rice plant in the plot of that variety; while the other colleagues stood in the discrete plots of other varieties. Because none of us had known exactly when the flowering would begin, we stood ready from 8:30 am on the first few days.

c) Soon we learned that the flowering of the 'earliest' varieties would not begin until about 9:30 am. We observed the onset of panicle emergence and anthesis, and recorded the time of each event, before moving on to another plot that was also expected to open on the same date.

d) We often missed the first emergence date and time of several cultivars, because the anthesis date and time of them were coincident. However, we made an effort to recapture the missed FOT of a landrace on the following day from a newly emerged panicle in the same plot, because the FOT of all the flowers would be almost identical (unless the day is cloudy, in which case we also record the daylight condition). Despite our efforts, we were able to record the FOT and FCT of only 996 winter rice and 77 summer rice landraces.

e) We recorded the 50% flowering date of each variety, and return to the same plot repeatedly 2-3 days after the 50% flowering date, until we observe the opening and closure of the last florets of the same panicle on which we had recorded the first FOT.

f) The length of time between the FOT and the FCT of the florets indicates the exposure duration (FED) of a variety's florets. Considering a slight (ca. 1 min) delay of the FCT of the last 10 florets on the same panicle, we calculated the maximum possible FED as the time interval between the FOT of the first floret and the FCT of the last floret.

g) If the florets of a selected panicle opens and/ or closes on a cloudy day, we recorded both the FOT and FCT of other florets on a different panicle of the same cultivar on a subsequent sunny day.

This was not possible for every cultivar, so the number of observations of FOT and FCT on sunny and cloudy days were not equal.

h) We recorded the Max and Min temperatures of each day using a mercury thermometer on our farm campus.

i) The exact sunrise time on each day of anthesis was obtained from https://www.timeanddate.com/sun/

j) The procedure was repeated in the Aman season (harvested in winter) of 2020, Boro season (harvested in early summer) of 2021, Aman of 2021, Boro of 2022, and Aus season (harvested in late summer) of 2022.

Annexure 1 shows the FOT and FED of the winter and summer rice accessions. Because anthesis is delayed on cloudy and rainy days (the flowers do not open until the sun appears), FOT and FED of all the cultivars were recorded on sunny as well as cloudy days at the time of anthesis, generating a total of 1231 data points (sunny and cloudy days/ summer and winter). This is the first database of the range of FOT and FED, and the length of time after sunrise until anthesis, of 996 rice landraces of South Asia.

Results: Influences of Season, Day-Maximum Temperature, and Sunrise on FOT and FED

Our data reveal that in summer, when the day-max temperatures are often above 30 ºC, FED is inversely related to the length of time of anthesis after sunrise (TAS), on sunny days as well as cloudy days (**Fig. 1**). This inverse relationship is held for all landraces in the winter, too, on sunny days ($p < 0.0001$). However, on cloudy days, this relationship turns to be slightly positive, albeit statistically not significant ($p > 0.9$) (**Fig. 2**).

For both summer and winter rice landraces, FED is directly related to FOT on sunny days (**Fig. 3** and **Fig. 4**). However, on cloudy days, this relationship is reversed for winter rice (**Fig. 4**). It appears that summer, FOT and TAS are important drivers of FED on both cloudy and sunny days, presumably due to higher day temperatures. This importance of TAS is lost in the winter months, on cloudy days, when, as the temperature data indicate, day-maximum temperature has a strong negative influence on FED.

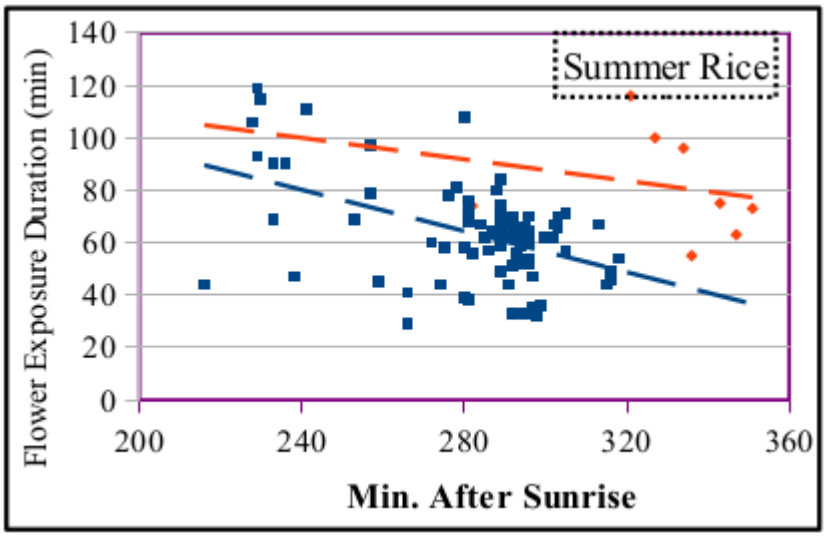

Fig. 1. Regression of FED on TAS of Summer Rice Landraces on Sunny (Blue) and Cloudy Days (Red).

Slopes of regression $b = -0.393$ ($R^2 = 0.226$) and -0.204 ($R^2 = 0.047$), respectively.

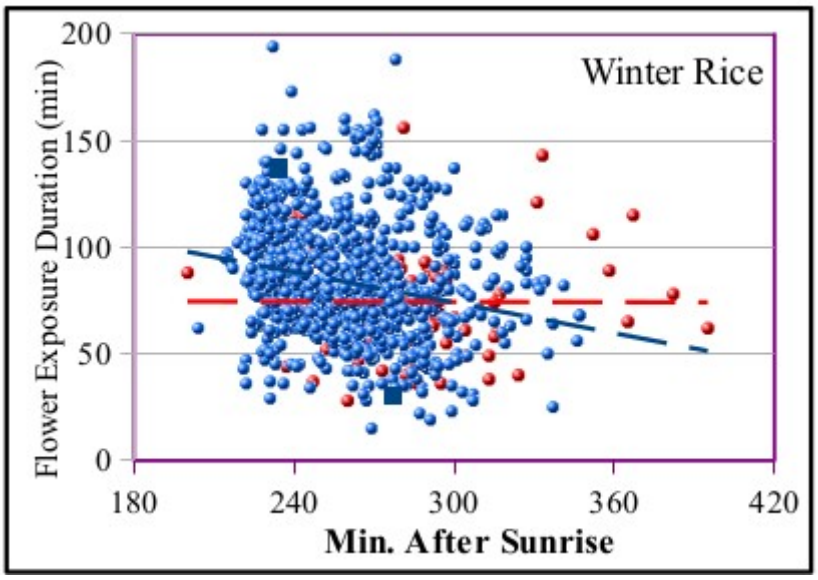

Fig. 2. Regression of FED on TAS of Winter Rice Landraces on Sunny (Blue) and Cloudy Days (Red).

Slopes of regression $b = -0.239$ ($R^2 = 0.053$) and -0.002 ($R^2 = 0.000008$), respectively.

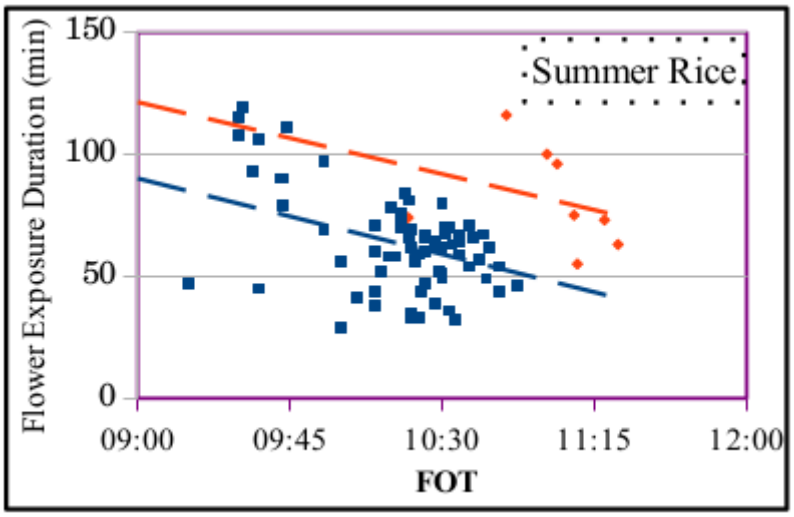

Fig. 3. Regression of FED on FOT of Summer Rice Landraces on Sunny (Blue) and Cloudy Days (Red). Slopes of regression $b = -496.98$ ($R^2 = 0.166$) and –471.77.002 ($R^2 = 0.098$), respectively.

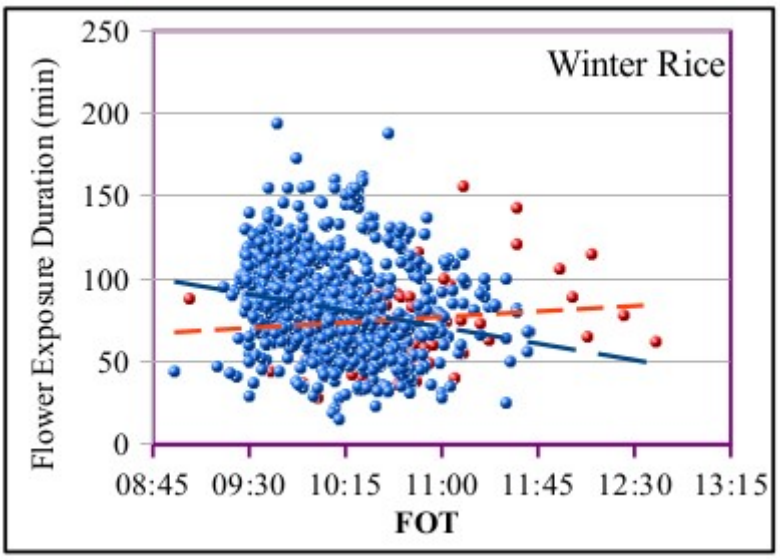

Fig. 4. Regression of FED on FOT of Winter Rice Landraces on Sunny (Blue) and Cloudy Days (Red). Slopes of regression $b = -317.61$ ($R^2 = 0.051$) and 106.59 ($R^2 = 0.014$), respectively.

Our data further show a strong positive relationhip between the day-maximum temperature and FOT for summer rice landraces, whereas this relationship reverses in the winter months of anthesis (**Fig. 5** and **Fig. 6**). Sunny days in summer seem to have little difference from cloudy days in either

hotter or colder months in influencing FED (**Fig. 7** and **Fig. 8**). A summary of the relationships of day maximum temperatures with FOT and FED on sunny and cloudy days is given in **Table 4**.

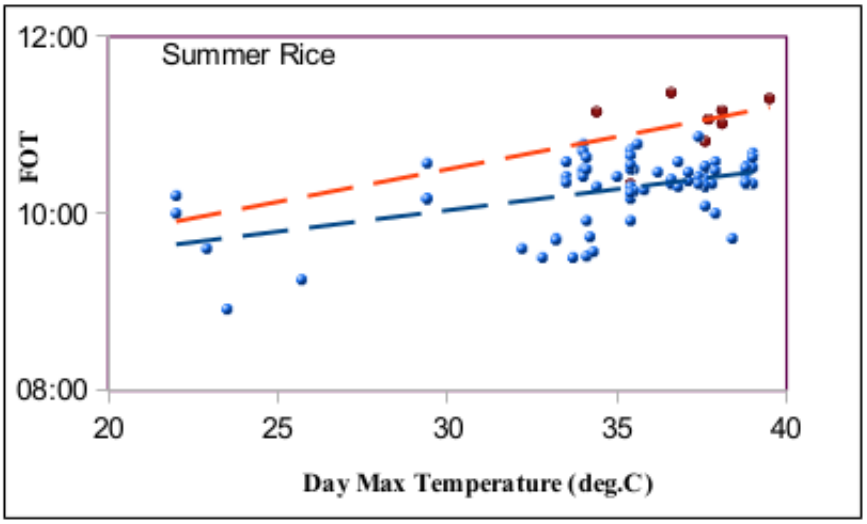

Fig. 5. Regression of FOT on Day Maximum Temperature of Summer Rice Landraces on Sunny (Blue) and Cloudy Days (Red). Slopes of regression $b = 0.002$ ($R^2 = 0.243$) and 0.00009 ($R^2 = 0.025$), respectively.

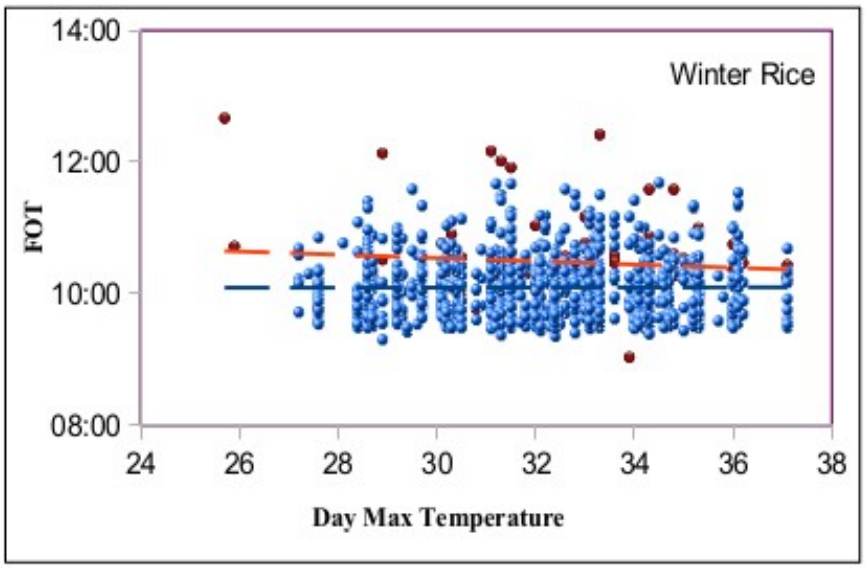

Fig. 6. Regression of FED on Day Maximum Temperature of Winter Rice Landraces on Sunny (Blue) and Cloudy Days (Red). Slopes of regression $b = 2.437$ ($R^2 = 0.000009$) and –0.001 ($R^2 = 0.009$), respectively.

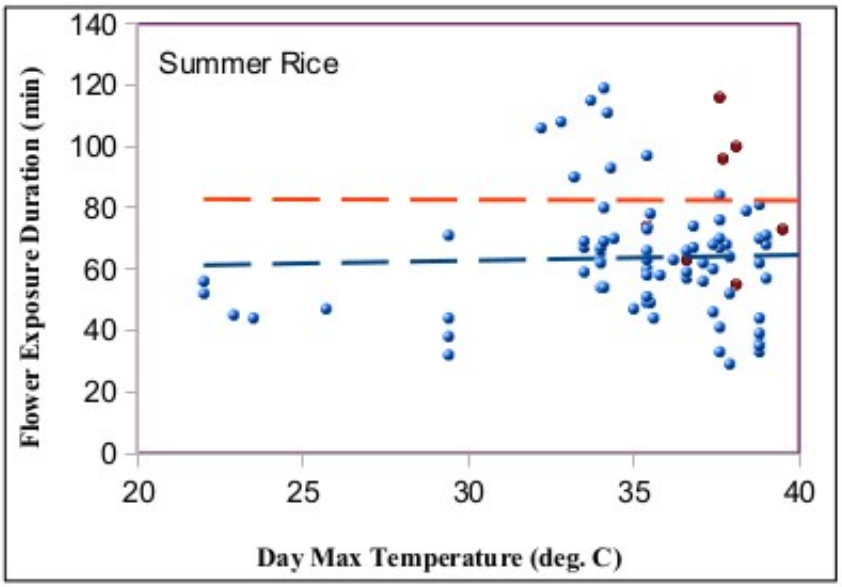

Fig. 7. Regression of FED on Day Maximum Temperature of Summer Rice Landraces on Sunny (Blue) and Cloudy Days (Red). Slopes of regression $b = 0.184$ ($R^2 = 0.001$) and –0.024 ($R^2 = 0.016$), respectively.

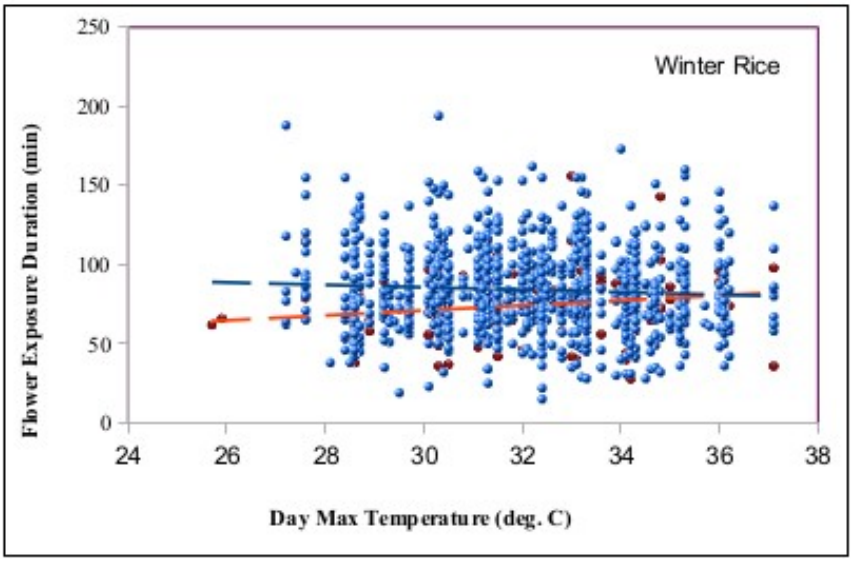

Fig. 8. Regression of FED on Day Maximum Temperature of Winter Rice Landraces on Sunny (Blue) and Cloudy Days (Red). Slopes of regression $b = –0.771$ ($R^2 = 0.004$) and 1.57 ($R^2 = 0.026$), respectively.

Table 4: Student's *t* value of the regression slope of FOT and FED on sunny and cloudy days on day maximum temperatures in summer and winter months of cultivation. (*See* **Figures 5 – 8**)

Weather Variables	*df*	FOT	FED
Winter- Sunny Day	1145	0.03 *	0.59 ns
Summer- Sunny Day	84	5.15 §	0.34 ns
Winter- Cloudy Day	1145	0.87 ns	1.48 ns
Summer- Cloudy Day	84	3.59 **	1.16 ns

[*Legend*: ns = Not significant * $p < 0.05$; ** $p = 0.005$ § $p < 0.0001$]

The influence of day maximum temperatuer on the length of time (in min) of anthesis after sunrise (TAS) seems to be no different from that on FOT. During summer months, TAS is strongly influenced by day temperature (**Fig. 9**), while in the colder months, the relationship disappears, both on sunny and cloudy days (**Fig. 10**).

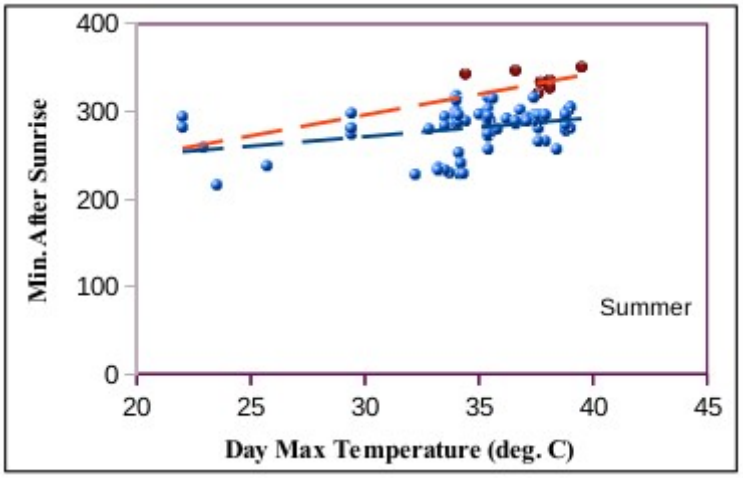

Fig. 9. Regression of Time of Anthesis before Sunrise on Day Maximum Temperature of Summer Rice Landraces on Sunny (Blue) and Cloudy Days (Red). Slopes of regression $b = 2.148$ ($R^2 = 0.128$) and 4.757 ($R^2 = 0.127$), respectively.

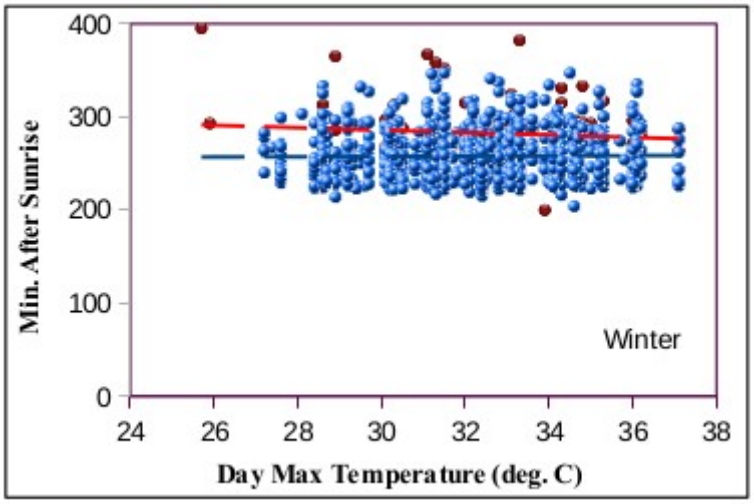

Fig. 10. Regression of Time of Anthesis before Sunrise on Day Maximum Temperature of Winter Rice Landraces on Sunny (Blue) and Cloudy Days (Red). Slopes of regression $b = 0.153$ ($R^2 = 0.0002$) and –1.30 ($R^2 = 0.0009$), respectively.

Researchers hypothesize that anthesis early in the day provides for escape from heat stress-indced spikelet sterility at anthesis by shedding viable pollen on to a receptive stigma during the cooler hours in the morning,during the day (Jagadish et al., 2007; Bheemanahalli et al. 2017, and citations there). "The adaptive value of anthesis happening early in the day is thus an established fact" (Julia and Dinkuhn 2012: 173). However, such assertions are based on studies in *Japonica* cultivars and modern breeding lines derived from *Japonica-Indica* hybrids such as IR64 and IR72. Our study contradicts the conjecture of early anthesis in response to heat stress in the South and Southeast Asian landraes. In our study, anthesis tends to be delayed on hotter days in summer both on sunny and cloudy days (**Fig. 5** and **Fig. 9**). In winter months, FOT and TAS seem to be unaffectd by day maximum temperature, either on sunny or cloudy days (**Fig. 6** and **Fig. 10**). Day maximum termperature has no effect on FED, whose slope of regression is no different from zero either on sunny or cloudy days. The positive relationship between day temperature and anthesis time appears to lie in the evolutionary history of *Indica* rice landraces, which were primarily selected over millennia to adapt to high day tempertures in tropical summer. Sunlight intensity, rather than day temperature may be a more important factor in eliciting anthesis in South Asian landraces. Rice flowers appear to wait for stronger light intensity, and therefore, TAS tends to lengthen when the sun rises higher.

Acknowledgements

We received no funding support from any institution for this work. We are deeply grateful to Sri Aniket Aga, Sri Shaliesh Awate, Ms Chitrangada Chowdhury, Sri Ms Shikha Kansagara, Sri Raghuveer Nandam, Sri Sahith Ravindra, and Sri Karan Sarin for devoting their time and labour of love for weeks to recording of FOT and FCT of a large number of rice varieties on Basudha farm.

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Annexures

(Excel Data Sheets)

Annexure 1: FOT and FED Data (2020-2022)

https://cintdis.org/wp-content/uploads/2023/07/FOT-FED-Data-2020-22.xlsx