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SEASONAL VARIATION IN FLOWERING TIME OF SRI LANKAN TRADITIONAL RICE

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Abstract

Growing season is a critical factor for both short and long-aged traditional rice cultivation in Sri Lanka, where natural photoperiod fluctuates in a range of less than one hour within a season. However, the effect of planting time during two main seasons on agronomic characters and the yield of traditional rice remains unknown. To address this, ten accessions were selected to represent the seasonal variation in days to flowering (DF) among traditional rice accessions of Sri Lanka. These accessions were grown in the field at a single location, with twelve planting dates spaced at one-month intervals from November 2018 to October 2019, to study the effect of the growing period on agronomic traits and yield. DF variations of accessions across 12 months of the year suggested three patterns. Both, the accession and the planting date affected the DF, plant height at flowering (PH) and number of spikelets per first panicle (SPP) significantly (p<0.05). The regression relationship between DF and SPP was quadratic for accessions 4132, 5530, 4387, 4290, 4145, 4772, 4731, 6412 and, 2170, while accession 4237 and improved variety Bg 300 showed a positive linear association. These findings provide valuable insights into manipulating DF in rice breeding programs to enhance adaptability to future adverse climatic conditions without compromising yield.

Key words: Flowering Time, Planting Date, Traditional Rice, Yield.

Introduction

Rice being the second most consumed staple food in the world, an increase in rice production is required in the future to feed the speculated population of ten billion in 2100. Rice is grown in a wide ecological range from 44^0N at North Korea to 35^0S at Australia (Pathak *et al*., 2021). Both rain-fed and irrigated cultivations of rice are dependent on climatic factors. Rice production will face serious challenges leading to decline in the yield under future climate change scenarios (Hussain *et al*., 2020). Breeding new rice varieties adaptable to future climates must be a key breeding objective. Rice grown in the tropics could be nominated as a versatile breeding resource for climate change adaptions as it mainly thrives under higher environmental temperatures and rainfall fluctuations. Accessions of Sri Lankan traditional rice germplasm exhibit a variety of desirable adaptations for floods, droughts, pests and diseases, and photoperiods. The above germplasm had been the foundation for surplus rice production for the export market in ancient Sri Lanka, earning the country the title of the Granary of the East. Exploiting Sri Lankan traditional rice germplasm for adverse climates should focus on the manipulation of flowering time. Natural selection of accessions to different ecologies contributes to the evolution of adaptable rice accessions. The distribution of *japonica* rice across Japan with date-fixed varieties in Hokkaido, Tohoku, and early varieties across the country indicates the effect of flowering time in ecological adaptation (Izawa, 2007). The interaction between genetic factors and environmental clues regulating rice flowering time is widely studied (Tsuji *et al*., 2008; Song *et al*., 2015; Sun *et al*., 2014). The mobile protein coded by *Heading Date 3a* (*Hd3a*), which is produced in the leaf, mediates flowering under short day conditions. On the other hand, *Ehd1*can mediate early-flowering in rice under long day conditions (Wei *et al*., 2016). Rice flowering time-specific mediators coordinate gene networks in response to shifts between short-day and long-day conditions (Nemoto *et al*., 2016; Zhang *et al*., 2022; Vincentini *et al*., 2023). The vegetative growth phase of rice is subdivided into the basic vegetative phase and the photoperiod-sensitive phase. The basic vegetative phase is characterized by insensitivity to the photoperiod. The photoperiod-sensitive phase is attained after a certain level of growth during the basic vegetative phase (Vergara & Chang, 1985). In Sri Lanka, there are two growing seasons (*Yala* from March to August) and *Maha* (from September to February) under rain-fed and irrigated conditions. According to the raw data from the Meteorological Department of Sri Lanka, the country in the tropics, experiences mild differences in photoperiod throughout the year. The highest photoperiod is 12 hours and 32 minutes in June, while the lowest photoperiod is 11 hours and 26 minutes in December. The response of Sri Lankan traditional rice to these subtle variations in photoperiod is reflected in the variation in DF. Short-day sensitive rice accessions do not flower during the non-inductive season (Rathnathunga *et al*., 2016a; Rathnathunga & Geekiyanage 2016; Rathnathunga *et al*., 2016b; Pushpakumari *et al*., 2017). Sri Lankan traditional rice is no more the choice of common commercial farmers due to the sensitivity to photoperiodic growing season associated long crop duration or non-flowering, tall plant height of even more than 2 m and less grain yield in some of the accessions (Rathnathunga *et al*., 2014; Padukkage *et al*., 2015;

Pushpakumari *et al*., 2016). Meanwhile new improved rice varieties with photoperiod insensitivity, desirable plant architecture, and responsiveness to inorganic fertilizer for higher yields are dominant in the extent of cultivation (Ginigaddara & Disanayake, 2018).

Information on the DF, plant architecture and yield components in 384 (Rathnathunga *et al*., 2014), 277 (Padukkage *et al*., 2015), and 43 accessions (Pushapakumari *et al*., 2016) of Sri Lankan traditional rice accessions exhibit wide variations. These variations may due to adaptive responses to mild variations in photoperiod under tropical condition in Sri Lanka suggesting valuable genetic factors for flowering manipulation. Sri Lankan traditional rice responds to extreme photoperiods under growth chamber conditions differently (Padukkage *et al*., 2017). When several accessions of one rice variety were grown under uniform management practices at one location, the variation of DF must relate to the variation in genetic factors: Positive correlations between DF and PH and a negative correlation between DF and panicle weight had been recorded in traditional rice variety *Hondarawala* and *Sudu wee* (Rathnathunga & Geekiyanage, 2016: Rathnathunga *et al*., 2016b), while, DF increased the yield in *Kalu heenati* accessions (Pushapkumari *et al*., 2015). *Sudu wee, Sulai, Kohu mawee* and *Deveraddili* varieties exhibited a positive relationship between DF and PH, while a negative relationship between DF and the yield (Geekiyanage *et al*., 2012). However, there are no reports on experiments investigating the effect of different planting dates of Sri Lankan traditional rice covering the entire year across both growing seasons to determine the DF and yield in response to the resulting growing period with natural variations in photoperiod, temperature, and other environmental factors. Therefore, the current study aimed to determine the effect of “planting date determined-growing season”, on two critical agronomic characteristics of traditional rice (DF and PH), as well as the yield component SPP. Our evaluation of selected accessions of traditional rice germplasm could be important in the future in elucidating the genetic basis for climate resilient breeding.

Material and Methods

Planting material: Ten traditional rice accessions and improved rice variety Bg 300 were selected for the study representing the flowering time variation (Table 1). Seeds were received from the Plant Genetic Resources Centre, Gannoruwa, Sri Lanka.

Field experiment: Two categorical explanatory variables of rice accession (11 levels) and planting date (12 levels) were tested. The experiment was conducted at a field in Gokarelle, Sri Lanka (6° 17' 0" of North and 81° 17' 0" of East). Meteorological data during the experimental period were recorded. Germinated seeds were transferred to pots filled with moist top soil. Two weeks old seedlings were planted in a randomized complete block design with ten replicates. The seedlings were planted with an inter-row spacing of 25 cm and an intra-row spacing of 45 cm (Fig. 1). Twelve monthly plantings were carried out from November 2018 to October 2019 on the 5th day of each month. Weeding and irrigation were regularly practiced.

Table 1. Rice accessions used for the experiment.

Variety name	Accession number	Days to flowering*
Masuran	4132	89
	5530	93
Banawee	4387	49
Hathe pas dawasewee	4237	52
Kuru mawee	4290	163
Mudu kiri al	4145	57
	4772	81
Hodarawala	4731	81
Heras	6412	71
Unknown	2170	66
Bg 300	New improved variety	60

* Source: Rathnathunga *et al*., 2014: Padukkage *et al*., 2015: Pushpakumari *et al*., 2016

Table 2. Variation of temperature and photoperiod during the experimental period at the site.

Planting date	Average temperature (°C)	Average photoperiod (hours)
November 2018	29.86	11.78
December 2018	30.32	11.68
January 2019	31.80	11.73
February 2019	33.10	11.88
March 2019	33.12	12.07
April 2019	32.90	12.28
May 2019	32.03	12.45
June 2019	31.13	12.55
July 2019	31.20	12.50
August 2019	30.09	12.35
September 2019	30.16	12.15
October 2019	30.12	11.95

Fig. 1. Rice plants in the field experiment layout.

Data collection: Days to flowering, PH and SPP were recorded from the plants of each monthly planting according to the modified descriptors of rice (Rathnathunga *et al*., 2014). Temperature and sunshine hours were recorded during the period at the experimental site (Table 2).

Statistical analysis

Analysis of means (ANOM), Turkey's test for mean separation and two-way ANOVA were performed using IBM SPSS statistical software 20.

The impact of levels in any of the variables on the outcome was obtained via the two-factor model as follows:

$$x_{ijk} = \mu + \alpha_i + \beta_j + \gamma_{ij} + \varepsilon_{ijk}$$

where, μ= Grand mean; α_i= Effect of Planting Date, $i = 1,2,\cdots,12.$; β_j= Effect of Accession, $j = 1,2,\cdots,10.$; γ_{ij}= Interaction Effect of Panting Date and Accession; ε_{ijk}= error term, $k = 1,2,\cdots,20.$

Regression analysis was carried out to develop models for each accession between DF and SPP using Minitab version 15.

Results and Discussion

Variation in days to flowering among rice accessions established at different planting dates: Days to flowering of the accessions varied from 52 to 90, 67 to 81, 58 to 79, 69 to 116, 48 to 84, 56 to 119, 81 to 130, 60 to 130, 71 to 122, 61 to 115, and 66 to 93 across the monthly planting dates from November 2018 to October 2019, respectively (Table 3). In November 2018, July 2019, August 2019, and September 2019, the highest days to flowering (DF) of 90 ± 1.6, 130 ± 4.1, 122 ± 0.32, and 115 ± 0.85 days, respectively, were recorded in the *Banawee* accession 4387. In December 2018, the highest DF of 81 ± 1.2 days was recorded in both *Mudukirial* accession 4145 and *Kuru mawee* accession 4290. Accession 4145 reported the highest DF of 79 ± 2.1 days and 84 ± 0.65 days in January and April 2019, respectively. *Kuru mawee* accession 4290 reported the highest DF of 79 ± 0.5 days and 116 ± 0.8 days in January and March 2019, respectively, among all accessions. The highest DF in September 2019 was recorded in both accessions 4387 and 4290. According to the analysis of variance (ANOVA), the accession, planting date, and the interaction between planting date and accession were significant at the 0.05 level of significance (R^2 = 0.948, Adjusted R^2 = 0.935).

Figure 2 depicts the flowering behavior of accessions in response to planting dates, proposing three distinct patterns. According to Fig. 2A, accessions 4132, 6412, and 4387 followed a pattern of increasing days to flowering (DF) in June and/or July 2019 during the *Yala* season. In Fig. 2B, planting dates in March, June, and July 2019 resulted in increased DF. Both Fig. 2B and 2C indicate that DF was drastically reduced in April 2019. The DF of accessions 4772, 2170, 5530, and Bg 300 followed a pattern where the peak DF occurred between March and May 2019.

The days to flowering (DF) of each accession at 12 monthly planting dates were subjected to simple main effect analysis using Analysis of Means (ANOM), as shown in Fig. 3. According to Fig. 3, accessions 4132 and 5530 of the *Masuran* variety responded differently to the planting dates. For accession 4132, DF in June and July 2019 were significantly higher than those at other planting dates, while for accession 5530, two distinct DF sets were observed: one from November 2018 to March 2019, and another from May to August 2019, indicating that *Yala* plantings resulted in delayed DF.

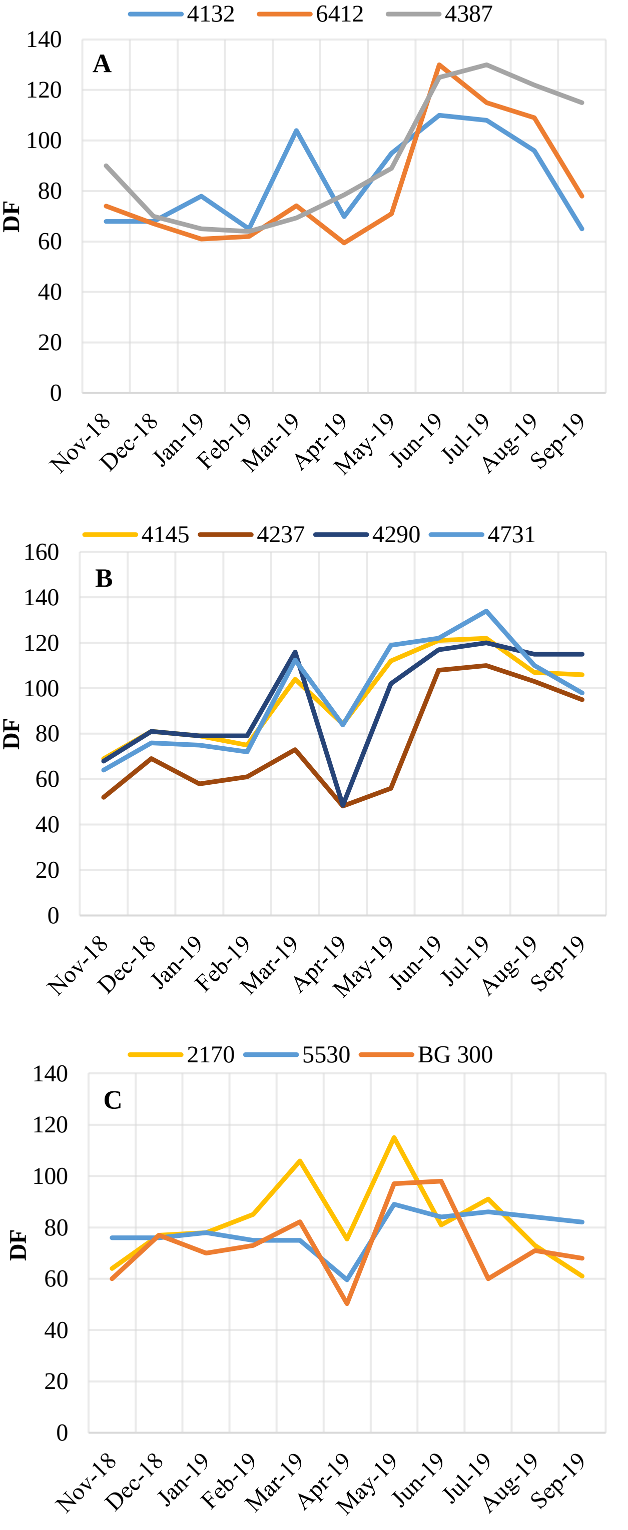

Fig. 2. Patterns of variation in days to flowering of traditional rice accessions across 12 monthly planting dates
(A): Type 1: Accessions 4132, 6412 and 4387, (B): Type 2: Accessions 4145, 4237, 4290 and 4731, (C): Type 3: Accessions 4772, 2170 and 5530

Table 3. Variation in the average number of days to flowering for accessions across different planting dates throughout the year.

Planting date	Days to flowering*										
	Rice accession/ variety										
	4132	**6412**	**4387**	**4145**	**4772**	**2170**	**5530**	**4237**	**4731**	**4290**	**Bg 300**
Nov. 2018	68 ±1.57^{cd}	74±1.32^{de}	90±5.20^{c}	69±1.70^{e}	74±2.80^{de}	64±0.90^{gh}	76±1.30^{cde}	52±1.65^{ef}	64±1.00^{g}	68 ± 1.30^{d}	60 ± 1.80^{de}
Dec. 2018	68±0.33^{cd}	67±0.35^{def}	70±0.28^{d}	81±0.36^{d}	73±0.37^{de}	77±0.28^{def}	76±1.30^{cde}	69±0.22^{cd}	76±0.38^{ef}	81±0.05^{c}	77±0.20^{bc}
Jan. 2019	78±0.26^{c}	61±0.30^{ef}	65 ± 0.20^{d}	79 ± 0.70^{d}	75 ± 027de	78±0.31^{def}	78±0.38^{cde}	58±0.6^{ef}	75±0.36^{fg}	79±0.21^{cd}	70±0.33^{cde}
Feb. 2019	65±4.23^{d}	62±1.30^{ef}	64 ± 1.30^{d}	75 ± 0.30^{cd}	73±0.50^{de}	85±0.39^{cd}	75±0.90^{de}	61±0.8^{de}	72±0.50^{fg}	79±0.60^{cd}	73±0.90^{bcd}
Mar. 2019	104±1.03^{ab}	74±1.88^{de}	69±2.60^{d}	104±2.15^{b}	95±0.76^{ab}	106±3.67^{b}	75±0.79^{de}	73±2.41^{c}	113±2.73^{bc}	116±2.00^{a}	82±1.65^{b}
Apr. 2019	70±0.95^{cd}	59±0.93^{f}	79±0.66^{cd}	84 ± 0.46^{c}	74±0.55^{de}	76±0.73^{ef}	60±0.32^{f}	48±4.12^{f}	84±0.22^{e}	49±0.51^{e}	50±0.26^{f}
May 2019	95±0.41^{b}	71±0.40^{def}	89±0.53^{c}	112±0.21^{ab}	82±0.89^{cd}	115±0.43^{a}	89±0.40^{a}	56±0.15^{ef}	119±0.35^{bc}	102±0.22^{b}	97±0.51^{a}
June 2019	110±1.25^{a}	130±0.44^{a}	125±0.39^{ab}	121±0.40^{a}	98 0.62^{a}	81±0.37^{de}	84±0.43^{abc}	108±0.36^{a}	122±0.79^{b}	117±0.50^{a}	98 ±0.52^{a}
July 2019	108±2.13^{a}	115±5.23^{b}	130±2.28^{a}	122±3.10^{a}	88±0.81^{abc}	91±4.50^{c}	86±4.23^{ab}	110±0.26^{a}	134±2.33^{a}	120±0.75^{a}	60±6.32^{e}
Aug. 2019	96±0.56^{b}	109±0.91^{b}	122±1.20^{ab}	107±4.30^{b}	83±2.60^{bcd}	73±2.69^{fg}	84±0.95^{abc}	103±0.48^{ab}	110±4.30^{c}	115±0.91^{ab}	71±3.56^{cde}
Sep. 2019	65±2.10^{d}	78±0.82^{d}	115±0.86 ^{b}	106±0.89^{b}	76±0.76^{cde}	61±1.81^{h}	82±3.12^{abcd}	95±2.90^{b}	98±1.10^{d}	115±0.740^{ab}	68±0.92^{cde}
Oct. 2019	70±1.23^{cd}	93±0.73^{c}	86 ± 2.85^{c}	74 ± 0.32^{cd}	68 ± 0.58^{e}	66±1.85^{gh}	73±2.13^{e}	71±0.81^{cd}	72±4.60^{fg}	79±1.90^{cd}	73±0.84^{bcd}

*The lowest values are given in red while the highest values are in green. Significantly different values of a rice accession across 12 planting dates, are indicated by different letters

Table 4. Variation in the average plant height at flowering of accessions across different monthly planting dates throughout the year.

Planting date	Plant height at flowering (cm)										
	Rice accession/ Variety										
	4132	**6412**	**4387**	**4145**	**4772**	**2170**	**5530**	**4237**	**4731**	**4290**	**Bg 300**
Nov. 2018	151.625±1.11^{a}	119.1±0.50^{c}	137.1±0.22^{b}	133.6±0.50^{a}	108.3±1.53^{ab}	138.7±0.55^{a}	149.3±0.34^{bc}	110±0.51^{b}	137.9±0.94^{bc}	136.6±0.95^{bc}	87.12±0.82^{e}
Dec. 2018	85.7±0.36^{e}	104.5±0.67^{cd}	123.2±0.95^{c}	139.4±0.50^{a}	126.7 ± 0.52^{a}	139.7±0.93^{a}	147.5±0.80^{bc}	114.9±1.05^{b}	169.5±0.67^{a}	166.4±0.96^{a}	92.2±0.33^{cde}
Jan. 2019	147.4±0.61^{ab}	89±0.34^{e}	114.7±0.62^{cd}	115.6±1.10^{b}	108.6±0.43^{ab}	141.5±1.21^{ab}	130.1±0.48^{cd}	114.9±1.05^{b}	141.1±1.17^{b}	143.7±1.23^{b}	86±0.74^{de}
Feb. 2019	135±0.47^{bc}	119±0.66^{c}	115±0.43^{cd}	142±2.32^{a}	110±3.32^{ab}	113±1.47^{bcd}	105±1.36^{e}	112 ±1.13^{b}	115±1.66^{d}	138±1.72^{bc}	95±2.07^{cde}
Mar. 2019	115±3.01^{d}	85.8±1.11^{e}	87.6±5.04^{e}	89.8±1.95^{c}	108.7±6.94^{ab}	102.5±2.78^{d}	117.5±4.76^{de}	93.2±2.79^{c}	94.7±3.30^{e}	114±6.97^{c}	87.3±1.07^{e}
Apr. 2019	112.3±2.29^{d}	90.6±0.87^{e}	98.2±0.24^{de}	95.8±0.24^{c}	84±0.60^{c}	78.2±2.72^{e}	80.3±2.7^{f}	83.2±3.02^{c}	91.2±2.01^{e}	99.2±1.00^{e}	68.6±1.91^{f}
May 2019	121±0.75^{cd}	115±0.59^{d}	113±0.48^{cd}	141±2.54^{a}	106±3.32^{b}	108±0.66^{cd}	135±0.76^{cd}	115±3.07^{b}	136±2.81^{bc}	123±0.67^{cd}	113±2.60^{b}
June 2019	161±1.83^{a}	132±0.71^{a}	154±1.58^{a}	146 ±1.72^{a}	110±3.26^{ab}	148±3.02^{a}	169±3.56^{a}	139±4.10^{a}	159±3.83^{a}	162±0.92^{a}	131±3.44^{a}
July 2019	154±1.85^{a}	130±1.77^{a}	138±2.15^{b}	140 ±2.24^{a}	105±3.18^{b}	131±2.38^{abc}	170±3.06^{a}	143±4.14^{a}	161±3.50^{a}	165±1.72^{a}	133±3.14^{a}
Aug. 2019	145±0.57^{ab}	120±0.38^{ab}	120±0.92^{c}	135±1.46^{a}	108±2.54^{ab}	125±2.12^{abcd}	154±2.49^{ab}	114±4.14^{b}	165±4.33^{a}	135±2.26^{bc}	98±4.37^{cd}
Sep. 2019	150 ±0.71^{a}	115±0.54^{d}	138±13.18^{b}	141±1.23^{a}	110±2.84^{ab}	134±2.88^{ab}	140±3.30^{bc}	110±1.95^{b}	135±2.73^{bc}	124±1.59^{cd}	99±3.43^{cd}
Oct. 2019	158 ±0.46^{a}	121±0.91^{ab}	142±0.51^{ab}	135±0.69^{a}	110±1.88^{ab}	140±3.26^{a}	145±3.83^{bc}	115±1.17^{b}	140±3.65^{bc}	141±1.99^{bc}	101±2.99^{c}

*The lowest values are given in red while the highest values are in green. Significantly different values of a rice accession across 12 planting dates, are indicated by different letters

The planting dates from December 2018 to March 2019 produced the lowest DF for *Banawee* 4387. Days to flowering from June to September plantings were the highest for accessions 4387, 4237, and 4290 (Fig. 3C, D and E). For *Mudukirial* accession 4145, plantings in June and July 2019 resulted in the highest DF. Similarly, in *Mudukirial* accession 4772, plantings in March and June 2019 produced the highest DF, while other planting dates led to earlier flowering (Fig. 3F and G). The DF of the *Hondarawala* accession 4731 was significantly influenced by planting dates. Among the 12 planting dates, November 2018 had the lowest DF (64 ± 1.2 days), while July 2019 had the highest DF (134 ± 2.33 days). Early flowering was observed for the plantings in November 2018 (64 ± 1.2 days), December 2018 (76 ± 3.8 days), January 2019 (75 ± 0.36 days), February 2019 (72 ± 0.5 days), April 2019 (84 ± 0.21 days), and October 2019 (72 ± 4.6 days).

Late flowering was reported for plantings in March 2019 (113 ± 2.75 days), May 2019 (119 ± 0.35 days), June 2019 (122 ± 0.79 days), July 2019 (134 ± 2.33 days), and August 2019 (110 ± 4.3 days) (Fig. 3H). The flowering time of accession 6412, from the *Heras* variety, varied from 59 ± 0.92 days in April to 130 ± 0.44 days in June. The analysis of means revealed that the effect of all planting dates on DF was significantly different, except for November 2018 (74 ± 1.32 days) and September 2019 (78 ± 0.82 days). Early flowering occurred in plantings from December 2018 (67 ± 0.35 days), January 2019 (61 ± 0.3 days), February 2019 (62 ± 1.3 days), March 2019 (74 ± 1.8 days), April 2019 (59 ± 0.92 days), and May 2019 (71 ± 0.4 days). Late flowering was observed in June 2019 (133 ± 0.44 days), July 2019 (115 ± 5.23 days), August 2019 (109 ± 0.91 days), and October 2019 (93 ± 0.73 days) (Fig. 3I).

For accession 2170, the lowest DF (61 ± 1.81 days) was recorded at the September 2019 planting, while the highest DF (115 ± 0.43 days) was observed at the May 2019 planting. DF was significantly different across planting dates, except for November 2018 (64 ± 0.91 days), December 2018 (77 ± 0.28 days), January 2019 (78 ± 0.31 days), February 2019 (85 ± 0.39 days), and June 2019 (81 ± 0.3 days), with a significance level of $p<0.05$ and R^2 (adj) = 94.03%. Early flowering occurred with plantings in November 2018 (DF 64 ± 0.9 days), April 2019 (DF 76 ± 0.72 days), August 2019 (73 ± 2.69 days), September 2019 (61 ± 1.81 days), and October 2019 (66 ± 1.85 days). Delayed flowering was recorded for plantings in March 2019, May 2019, and July 2019 (Fig. 3J).

The improved rice variety Bg 300, typically grown in both the *Yala* and *Maha* seasons as a three-month variety, showed extended crop durations when planted in May and June, resulting in a longer DF. The lowest DF (50 ± 0.23) was recorded for the April 2019 planting.

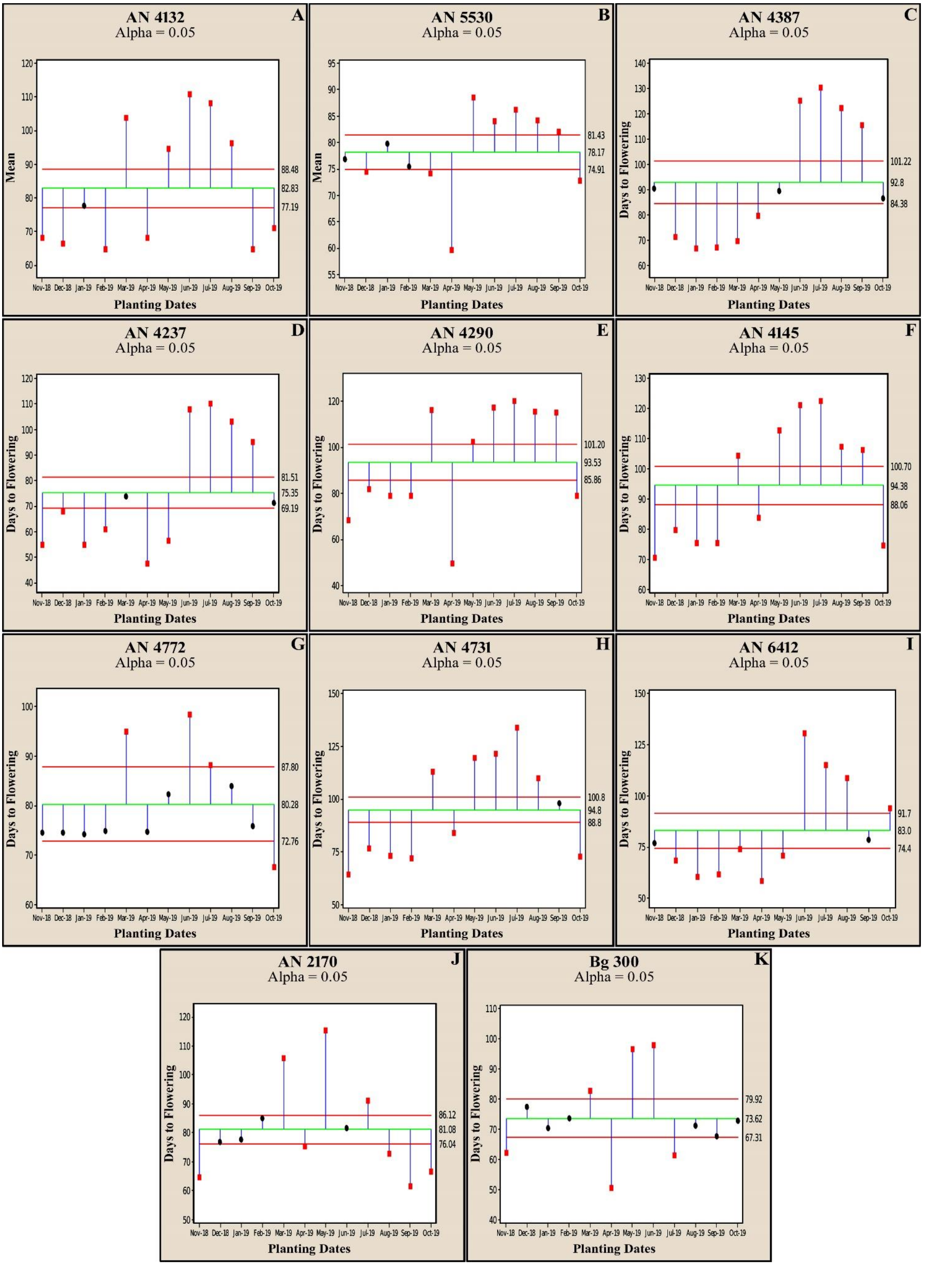

Fig. 3. Effect of planting date on flowering time variation in traditional rice accessions
*A, B, C, D, E, F, G, H, I and J represent traditional rice accessions as (A) 4132 (B) 5530 (C) 4387 (D) 4237 (E) 4290 (F) 4237 (E) 4290 (F) 4145 (G) 4772 (H) 4731 (I) 6412 and (J) 2170 , while K represents Bg 300

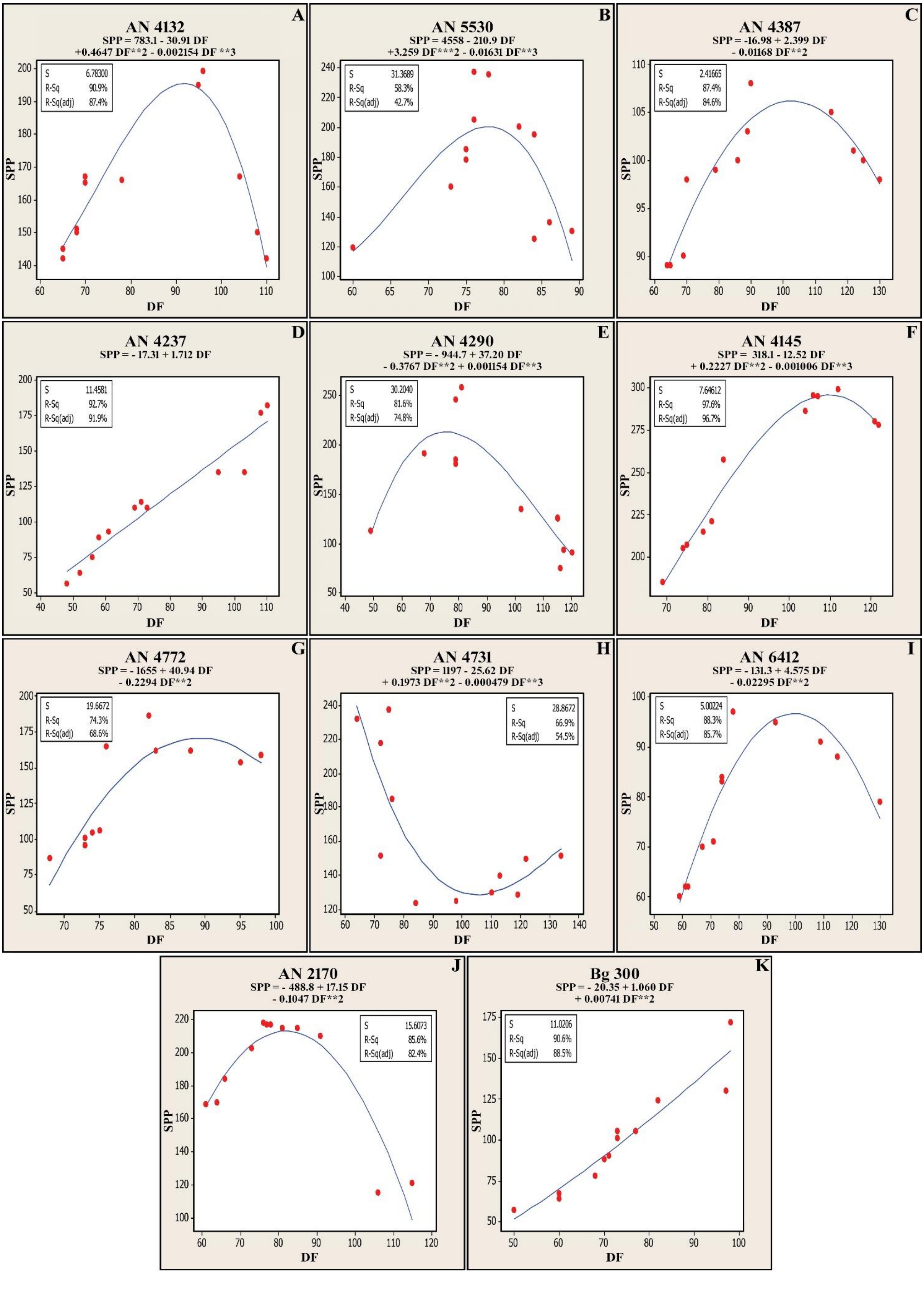

Fig. 4. Diversity in the relationships between number of spikelets per first panicle and days to flowering among selected traditional rice accessions *A, B, C, D, E, F, G, H, I and J represent traditional rice accessions as (A) 4132 (B) 5530 (C) 4387 (D) 4237 (E) 4290 (F) 4237 (E) 4290 (F) 4145 (G) 4772 (H) 4731 (I) 6412 and (J) 2170, while K represents Bg 300.

Table 5. Variation in the number of spikelets per first panicle of accessions across different monthly planting dates throughout the year.

Planting date	Number of spikelets per first panicle*										
	Rice accession/ Variety										
	4132	**6412**	**4387**	**4145**	**4772**	**2170**	**5530**	**4237**	**4731**	**4290**	**Bg 300**
Nov. 2018	151 ± 4.94^{cd}	84 ± 4.78^{bcd}	108 ± 4.92^{a}	185 ± 3.27^{h}	105 ± 7.29^{de}	170 ± 1.36^{d}	205 ± 7.53^{b}	64 ± 20.78^{f}	232 ± 3.17^{a}	112 ± 16.54^{e}	65 ± 9.90^{fg}
Dec. 2018	150 ± 6.00^{cd}	70 ± 10.59^{e}	98 ± 6.83^{bcd}	221 ± 6.39^{e}	96 ± 4.11^{ef}	217 ± 8.57^{a}	237 ± 29.47^{a}	110 ± 8.69^{c}	102 ± 13.22^{f}	191 ± 12.91^{c}	105 ± 8.90^{c}
Jan. 2019	166 ± 7.73^{b}	62 ± 5.80^{f}	89 ± 1.32^{cd}	215 ± 5.83^{ef}	106 ± 1.63^{d}	217 ± 0.25^{a}	235 ± 7.96^{a}	89 ± 21.51^{d}	152 ± 22.25^{d}	245 ± 15.79^{b}	88 ± 4.14^{d}
Feb. 2019	145 ± 1.10^{c}	62 ± 3.47^{f}	89 ± 2.78^{cd}	207 ± 3.93^{fg}	101 ± 7.12^{de}	215 ± 8.72^{a}	178 ± 10.73^{e}	93 ± 1.5^{d}	238 ± 1.29^{a}	180 ± 27.23^{c}	101 ± 3.70^{c}
Mar. 2019	167 ± 7.02^{b}	83 ± 13.15^{cd}	90 ± 4.40^{cd}	286.25 ± 2.56^{bc}	154 ± 2.48^{c}	115 ± 9.25^{e}	185 ± 8.37^{de}	110 ± 249^{c}	185 ± 4.44^{c}	185 ± 1.32^{c}	124 ± 4.93^{b}
Apr. 2019	165 ± 1.55^{b}	60 ± 1.32^{f}	99 ± 5.67^{abc}	257.5 ± 1.70^{d}	105 ± 4.03^{de}	218 ± 2.72^{a}	119 ± 13.10^{i}	56 ± 3.52^{f}	124 ± 4.12^{e}	258 ± 2.86^{a}	57 ± 0.70^{g}
May 2019	195 ± 0.81^{a}	71 ± 2.27^{e}	103 ± 4.87^{ab}	299 ± 2.10^{a}	187 ± 4.40^{a}	121 ± 0.81^{e}	130 ± 0.80^{gh}	75 ± 6.25^{e}	125 ± 5.67^{e}	135 ± 7.76^{d}	130 ± 6.33^{b}
June 2019	142 ± 2.10^{c}	79 ± 3.01^{e}	100 ± 1.37^{ab}	280 ± 2.05^{c}	159 ± 4.76^{bc}	215 ± 6.40^{a}	195 ± 9.67^{cd}	177 ± 6.22^{a}	130 ± 6.46^{e}	125 ± 6.63^{d}	172 ± 2.32^{a}
July 2019	150 ± 1.35^{cd}	88 ± 2.12^{bc}	98 ± 1.32^{bcd}	278 ± 2.12^{c}	162 ± 3.12^{bc}	210 ± 5.12^{ab}	136 ± 7.85^{g}	182 ± 3.52^{a}	201 ± 2.12^{b}	126 ± 3.81^{d}	67 ± 3.51^{f}
Aug. 2019	199 ± 0.98^{a}	91 ± 2.24^{ab}	101 ± 1.36^{ab}	295 ± 3.12^{a}	162 ± 2.27^{bc}	203 ± 2.32^{b}	125 ± 3.89^{hi}	135 ± 3.21^{b}	129 ± 5.23^{e}	74.5 ± 12.12^{g}	90 ± 2.69^{d}
Sep. 2019	142 ± 0.87^{c}	97 ± 3.85^{a}	105 ± 2.12^{ab}	296 ± 2.21^{a}	165 ± 4.85^{b}	169 ± 5.11^{d}	200 ± 2.12^{i}	135 ± 2.22^{b}	150 ± 2.35^{d}	94 ± 11.28^{f}	78 ± 3.24^{e}
Oct. 2019	167 ± 2.12^{b}	95 ± 3.12^{a}	100 ± 2.12^{ab}	205 ± 4.12^{g}	86 ± 2.12^{f}	184 ± 3.48^{c}	160 ± 6.15^{f}	114 ± 4.12^{c}	152 ± 3.62^{d}	90 ± 14.24^{f}	105 ± 2.11^{c}

*The lowest values are given in red while the highest values are in green. Significantly different values of a rice accession across 12 planting dates, are indicated by different letters

Variation in plant height at flowering among rice accessions established at different planting dates: Plant height at flowering (PH) varied across accessions and planting dates (Table 4). Significant differences in PH were observed based on planting date (p<0.01), with the maximum PH of 170 cm ± 1.2 recorded in accession 4731 at the December 2018 planting, and 170 cm ± 0.9 in accession 5530 at the July 2019 planting. The lowest PH (90 cm ± 1.1) was observed in Bg 300 at the April 2019 planting. All accessions reported significantly lower PH during the April 2019 plantings. Both main effects, as well as the interaction between accession and planting dates, significantly affected PH (p<0.05) (R^2 = 0.915; Adjusted R^2 = 0.894).

Variation in the number of spikelets per first panicle of rice accessions at different planting dates: All accessions differed significantly from each other in terms of the number of spikelets per first panicle (SPP) at the p<0.05 level of significance (Table 5). The highest SPP of 299 ± 2.12 was recorded in accession 4145 at the May 2019 planting, while the lowest SPP of 56 ± 3.21 was observed in accession 4237 at the April 2019 planting. Accession 4145 consistently reported the highest SPP across all plantings, except for those in November 2018, December 2018, January 2019, and February 2019. The number of spikelets per first panicle was significantly affected by the interaction between planting date and rice accession (p<0.05, R^2 = 0.997; Adjusted R^2 = 0.996).

Effect of days to flowering variation on the number of spikelets per first panicle: Except for accession 4237 and the Bg 300 variety, which exhibited linear relationships, all other accessions (4132, 5530, 4387, 4290, 4145, 4772, 4731, 6412, and 2170) showed quadratic relationships between days to flowering (DF) and the number of spikelets per first panicle (SPP) at the 0.05 level of significance. For these accessions, the quadratic relationships indicated that the highest SPP was achieved close to the midpoint of the DF range (95, 75, 100, 80, 110, 85, 100, and 80 days), with extended DF reducing the SPP (Fig. 4). For accession 4731, the quadratic relationship revealed that the highest SPP was achieved at a shorter DF close to 60 days. The linear positive relationships observed for accessions 4237 and Bg 300 suggested that increased DF is favorable for achieving the highest SPP.

Discussion

The planting date plays a crucial role in determining exposure to environmental factors such as rainfall and photoperiod, which are vital for rice growth and reproduction. In Sri Lanka, the Department of Agriculture schedules the planting dates based on the age of the rice variety (2.5 to 4.5 months) and considers different agro-ecological regions and irrigation methods. Our results indicate a strong association between planting date, days to flowering (DF), and yield, consistent with the findings of Cerioli *et al*., (2021). Sensitivity to photoperiod is a significant barrier to the cultivation of traditional rice varieties.

The interaction between planting date and variety had a highly significant effect on all agronomic traits, including DF, panicle weight, number of branches, seeds per panicle, and panicle seed weight (Vange & Obi, 2006). Chitnucha *et al*., (2011) similarly reported an interaction between planting date and variety affecting both biomass and yield. Azhar *et al*., (2024) reaffirmed the positive correlation between DF and yield. Additionally, Salihi *et al*., (2023) highlighted that elevated CO_2 levels can enhance photosynthetic efficiency, contributing to increased yields.

Photoperiodic genes have been shown to affect grain yield, with flowering time mutants such as *PRR37*, *ELF3*-1, and *EHd1* exhibiting longer growth periods and more grains per panicle (Qiu *et al*., 2023). Varieties have responded differently to planting dates, impacting yield based on their growing seasons (Satapathy *et al*., 2021). For instance, the *Sudu wee* accession 4193 did not flower during the late short-day (*Maha*) season, indicating an exception to the short-day sensitivity of Sri Lankan traditional rice (Padukkage *et al*., 2017). Pushpakumari & Geekiyanage (2014) confirmed that Sri Lankan traditional rice varieties exhibit higher yields when planted in alignment with the optimal photoperiod season.

Our findings suggest that traditional rice accessions may respond differently to varying photoperiods throughout the year, influencing DF alongside other environmental factors such as temperature. The choice of planting date significantly affects the agronomic performance of traditional Sri Lankan traditional rice varieties in both the *Yala* and *Maha* seasons. Optimizing yield potential and minimizing adverse agronomic traits can be achieved by selecting the appropriate planting date for each season. Among the 10 traditional rice accessions tested, 8 showed that the mid-phase of the DF range was optimal for achieving the highest number of spikelets per first panicle (SPP), while the shortest DF was ideal for accession 4731. Our findings suggest that leveraging genetic factors in traditional rice germplasm for differential responses to mild photoperiod variations can enhance climate-resilient rice breeding, ecological adaptation, and yield optimization.

Conclusion

The results of this experiment demonstrate that the growing period, influenced by planting date, significantly affects the agronomic traits and yield of selected traditional Sri Lankan rice accessions. A notable interaction between rice accession and planting date was observed concerning plant height and the number of spikelets per first panicle (SPP). The relationship between days to flowering (DF) and SPP varied among the accessions: for accessions 4132, 5530, 4387, 4290, 4145, and 4772, the relationship was quadratic, while accession 4237 and the improved variety Bg 300 exhibited a positive linear relationship. Thus, manipulating flowering time in an accession-dependent manner is a viable strategy for optimizing yields.

These findings offer valuable insights for rice breeders seeking to adjust genetic factors for optimal yields and provide farmers with information to optimize yield through strategic planting date adjustments.

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