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Environmental Effect on Variations in Flowering Time and Yield Related Traits in Sri Lankan Traditional Rice Variety '*Masuran*'

W.H.D.U. Pushpakumari [1], L. Jayasekara[2], G. Senanayake[3] and S. Geekiyanage[3]*

ABSTRACT

Growing Sri Lankan traditional rice (*Oryza sativa* L.) in the short day (*Maha*) season is crucial for the flowering initiation of most of the accessions. *Masuran* is a traditional rice variety with a high yielding potential including health-promoting attributes and premium price. This study was conducted to determine the effect of selected environmental factors of the season on the number of days to flowering (DF), plant height at flowering (PH) and selected yield components of two accessions of the '*Masuran'* variety (Acc. No. 4132 and Acc. No. 5530). Planting was carried out on the 05th day of every month for a period of one year. Average daily rainfall (RF), temperature and photoperiod of each month were recorded. The effect of environmental factors on selected agronomic traits was analysed. Days to flowering, PH, Total Effective Tiller Number (TTN) and Number of Spikelets per First Panicle (NSFP) varied from 65 to 110 days, from 85.7 to 158 cm, from 3 to 8 and from 142 to 199 in Acc. No. 4132, respectively while those parameters varied from 60 to 89 days, from 80.3 to 170 cm, from 3 to 16, and from 119 to 283 in Acc. No. 5530, respectively during the experimental period. The analysis of the effect of photoperiod, rainfall and temperature of the first month of each planting revealed that the effect of photoperiod and temperature is significant on DF. The first month of each planting was observed as the photoperiod-sensitive phase of rice accessions. Correlation analysis for DF and NSFP resulted in a strong positive relationship suggesting a multi-factor environmental effect on NSFP of the variety, *Masuran* when it was grown throughout the year. The above results will be important in introducing a novel aspect for optimizing planting schedules and selecting suitable genotypes to enhance rice productivity under different environmental conditions.

Keywords: Days to flowering, Effect of planting-date, Traditional rice '*Masuran*', Yield.

[1]*Faculty of Graduate Studies, University of Ruhuna, Matara, Sri Lanka.*
[2]*Department of Mathematics, Faculty of Science, University of Ruhuna, Matara, Sri Lanka.*
[3]*Department of Agricultural Biology, Faculty of Agriculture, University of Ruhuna, Mapalana, Kamburupitiya, Sri Lanka.*

**sudarshanee@agbio.ruh.ac.lk*
http://orcid.org/0000-0002-3771-2680

INTRODUCTION

Climate change challenges rice production, which is an essential contributor to global food security amid the projected population growth of 9.7 billion by 2050 (FAO, 2023). A 3.2% decline in global rice yields is predicted with each one-degree Celsius increase in average global temperature (Zhou *et al.,* 2021). The traditional rice varieties of Sri Lanka exhibit unique characteristics for environmental resilience, making them essential for future breeding programmes focused on ecological adaptation to climate change. The traditional rice germplasm consists of heat-tolerant varieties such as *Kirimurunga, Suwandel,* and *Suduru* Samba (Munasinghe *et al.,* 2017). Moreover, there are submergence-tolerant varieties like *Godaheenati, Heenkarayal*, *Goda Wee*, and *Dik Wee*. Additionally, the variety *Pachchaperumal* exhibits salt tolerant ability addressing the growing concern of soil salinization in coastal areas while, *Ma Wee* can be grown under water-logging conditions (Pradheeban *et al.,* 2017; Kariyawasam *et al.*, 2023).

Growth of rice plant consists of three stages as vegetative stage, reproductive stage and ripening stage: In the tropics, vegetative stage is the most variable stage among cultivars, which is mainly dependent on the growth duration of a cultivar (Vergara and Chang, 1985). Vegetative stage of Sri Lankan traditional rice varies for a wider range from 2 ½ month to 6 months (Rathnathunga *et al.,* 2014; Padukkage *et al.,* 2015; Pushpakumari *et al.,* 2016). Rice is a facultative short-day plant that the long-days can delay or prevent flowering. The wide variation of rice genotypes in response to environment for flowering had been discussed by Vergara and Chang (1985). Rathnathunga *et al.,* (2016) had confirmed such variations reporting 39 accessions, which did not flower out of 345 accessions when they were grown in the late *Maha* season under Sri Lankan field conditions. As reviewed by Vergara and Chang (1985), the basic vegetative phase of the rice plant is the period for which the photoperiod has no effect, while the sensitivity increases with age during the vegetative stage. The flowering stage is an important agronomic trait in rice breeding because it significantly affects on the architectural characteristics of the plant. Sri Lankan traditional rice varieties exhibit wide variation in flowering time and morphological characters (Rathnathunga *et al.,* 2014; Padukkage *et al.,* 2015; Pushpakumari *et al.,* 2016). This variation is particularly important in Sri Lankan tropical climate, where mild variations in photoperiod ranging from 11 hours and 43 minutes in December to 12 hours and 32 minutes in June, can influence rice plant growth and development. Recent studies reported that the relationship between days to flowering and yield was a positive correlation when several rice accessions were tested (Pushpakumari and Geekiyanage, 2014; Pushpakumari and Geekiyange, 2015; Jayasinghe *et al.*, 2023). Meanwhile, there was a negative correlation between days to flowering and yield for varieties of *Suduru samba, Pachchaperumal* (Rathnathunga *et al.*, 2017), *Sulai* (Rathnathunga and Geekiyanage, 2015) and *Sudu wee* (Rathnathunga and Geekiyanage, 2016). Hence, the relationship between days to flowering, vegetative growth parameters and yield components are of particular interest to rice breeders. The timing of the plant transition from vegetative to the reproductive stage is determined by a complex network between genetic and environmental factors, such as photoperiod, temperature and rainfall (Cho *et al.*, 2017). The traditional rice, *Masuran* is a red pericarp variety. Rathnathunge *et al.* (2014), reported the variation of morphological traits of Acc. No. 4132 and Acc. No. 5530 under field conditions in the Low Country Intermediate Zone of Sri Lanka during *Maha* season. Therefore, this experiment was conducted to determine the effect of environmental conditions resulted due to the different planting dates within the year, on vegetative growth and some yield parameters of the accessions Acc. No. 4132 and Acc. No. 5530 of traditional rice variety, *Masuran*.

MATERIALS AND METHODS

Plant Material

The traditional rice accessions of Acc. No. 4132 and Acc. No. 5530 belonging to *Masuran* rice variety were used in this study. Seeds were obtained from the Plant Genetic Resource Centre, Gannoruwa, Sri Lanka.

Field Establishment

The experiment was conducted from October 2018 to November 2019 at the agro-ecological region IL1b in Sri Lanka.

Seeds were germinated in petri dishes on moist tissue under dark conditions at room temperature. Seedlings were transferred to (15 cm x 10 cm) trays filled with mud. The field experiment followed a randomized complete block design. Two-week old seedlings were used for the field establishment. Ten seedlings from each accession were randomly established in each plot of the field with an inter and intra–row spacing of 25 cm x 45 cm. Twelve monthly plantings were carried out from November 2018 to October 2019 on the 5th day of each month, which were considered as twelve temporal blocks. Weeding and irrigation were practiced regularly.

Data Collection

Meteorological data of the experimental field during the experimental period were recorded. Days to flowering (DF), Plant height at the flowering stage (PH), Total effective tiller number (TTN) and Number of spikelets per first panicle (NSFP) were recorded from the plants of each monthly planting according to the modified descriptors of rice (Rathnathunga *et al.*, 2014; Padukkage *et al.*, 2015; Pushpakumari *et al.*, 2016).

Data Analysis

The average values for monthly rainfall, photoperiod, and temperature were computed using daily records of each month. The experiment was conducted as a two-factor factorial design, with the factors being planting date (12 levels) and accession (2 levels). The interaction effect between planting date and accession types was analysed using a two-way analysis of variance (ANOVA) using IBM SPSS statistical software version 20. The model was

$$Y_{ijk} = \mu + B_i + T_j + (BT)_{ij} + \epsilon_{ijk}$$

where:
Y_{ijk}: Observation for the kth replicate of treatment j in block i
μ: Overall mean
B_i: Effect of the ith block (planting date)
T_j: Effect of the jth treatment (accession)
$(BT)_{ij}$: Interaction effect between planting date and accession
ϵ_{ijk} : Random error term.

Correlation analysis was performed for the correlation between each environmental factor and selected plant parameters. The effect of genotype x selected environmental factors on selected agronomic and yield-related traits was further analyzed using GGE Biplot analysis as described by Yan *et al.* (2000). The analysis was performed using R statistical software (Version 4.4.0).

RESULTS AND DISCUSSION

Variation of Temperature, Rainfall and Photoperiod across the Experimental Period

The average daily environmental temperature increased from November 2018 (29.86 °C) to March 2019 (33.12 °C). Average daily temperature was above 31 ˚C from January 2019 to July 2019 (Figure 1a). The period during October 2018 and November 2019 received average daily rainfall of 10.96 and 11mm, respectively, while January and April 2019 did not receive rain (Figure 1b). The minimum average daily photoperiod of 11 hours and 41 minutes was recorded in December 2018. The average daily photoperiod was above 12 hours in months from March to September 2019 (Figure 1c).

Variations of Agronomic and Yield Traits across 12 Planting Dates of the Experimental Period

The DF of Acc. No. 4132 varied from 110 ±1.25 days (when the planting date was in June) to 65 ± 4.25 days (when the planting date was in February and September 2019). In the Acc. No. 5530, the longest DF period was observed when the planting date was from May to September 2019 (89 ± 0.40, 84 ± 0.23, 86 ± 1.32, 84 ± 2.12 and 82 ± 1.52 days, respectively) while the minimum DF was recorded when the planting date was in April 2019 (60 ± 0.31 days) (Figure 2a).

According to Figure 2 (b), Acc No 4132 recorded higher PHs of 161± 1.84 cm, 154± 1.52 cm, 145± 1.41 cm, 150 ± 0.89 cm, 158 ± 0.59 cm and 151.6 ± 2.12 cm when the planting date was in June, July, August, September and October 2019, and November 2018, respectively while the lowest height of 85.7 ± 0.36 cm was recorded when the planting date was in December 2019. The plants of Acc. No. 5530 recorded the highest PH of 170± 3.07 cm when the planting date was in July 2019 while the lowest PH of 80.3 ± 2.71 cm was obtained when the plants were grown in April 2019.

Total Effective Tiller Number (TTN) varied significantly across different planting dates within the year in both accessions ($P< 0.05$) (Figure 2c). Acc. No. 5530 produced more tillers than Acc. No. 4132, and the highest

TTN was observed in the plants grown in November 2018 (16± 1.66 tillers) while 7± 2.1 tillers were observed in Acc. No. 4132 at the same planting date. The lowest tiller number for both accessions was observed in April 2019, producing 3 ± 1.23 tillers in each. The number of spikelets per first panicle (NSFP) was highest (195±2.12 and 199 ±0.25) in plants grown in May and August 2019 in Acc. No. 4132 while others produced 142 ± 1.32 to 167±3.2 of NSFPs (Figure 2d).

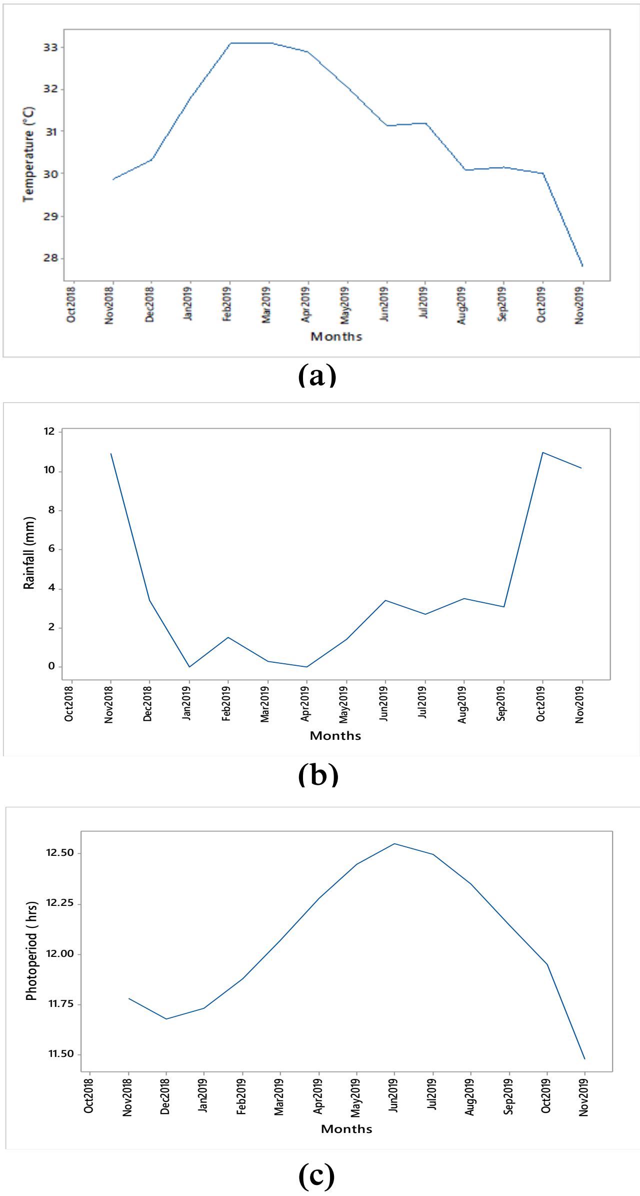


Figure 1. Variation of monthly average daily environmental temperature (a) rainfall (b) and photoperiod (c) during the experimental period.

Moreover, Acc. No. 5530 produced the highest NSFP of 237±1.23 and 235±1.23 in the plants planted in December 2018 and January 2019. The lowest NSFP was observed when the plants were grown in April 2019 (119 ± 0.35) and except the plants grown in May, July and August 2019, other plants produced more than 160 ± 3.25 of NSFP. A panicle with 200 to 250 grains per panicle is considered as a large panicle in rice breeding (Khush, 2005). Although Acc. No. 4132 did not produce large panicles across 12 planting dates, Acc. No. 5530 produced large panicles in 3 out of the 12 planting dates (Figure 2 d).

Effect of Environmental Temperature, Rainfall and Photoperiod on Selected Agronomic and Yield Traits

Each planting date is characterized by average monthly temperature, rainfall and photoperiod. Variations of DF, TTN and NSFP across 12 planting dates in each accession, are explained through the significant effects of planting date and rice accession ($p<0.05$). There are interactions between the planting date and rice accession for DF, TTN and NSFP ($p < 0.05$).

Biplot analysis reveals the effect of environmental variables of photoperiod, rainfall and temperature during the first month of planting on the selected agronomic and yield variables such as DF, PH, TTN and NSFP across twelve planting dates. There are two Principal Components (PC1 and PC 2), explaining the variation of each accession across twelve planting dates (Table 1). Variables are indicated in arrows, while the different months are represented in ellipses along the PC1 and PC2 (Figure 3). In Acc. No. 4132, PC1 and PC2 account for 39.7% and 25.6% of the overall variation in agronomic and yield parameters, respectively.

PC1 elucidates the variation through the contributions of temperature (Eigenvector value of 0.4243), exhibiting a positive correlation, and rainfall (Eigenvector value of 0.4576), demonstrating a negative correlation, indicating that temperature and rainfall substantially influence on the agronomic traits of Acc. No. 4132.

In PC2, the influence of photoperiod on agronomic traits is significant, with an Eigenvector value of 0.48385 for photoperiod. PC1

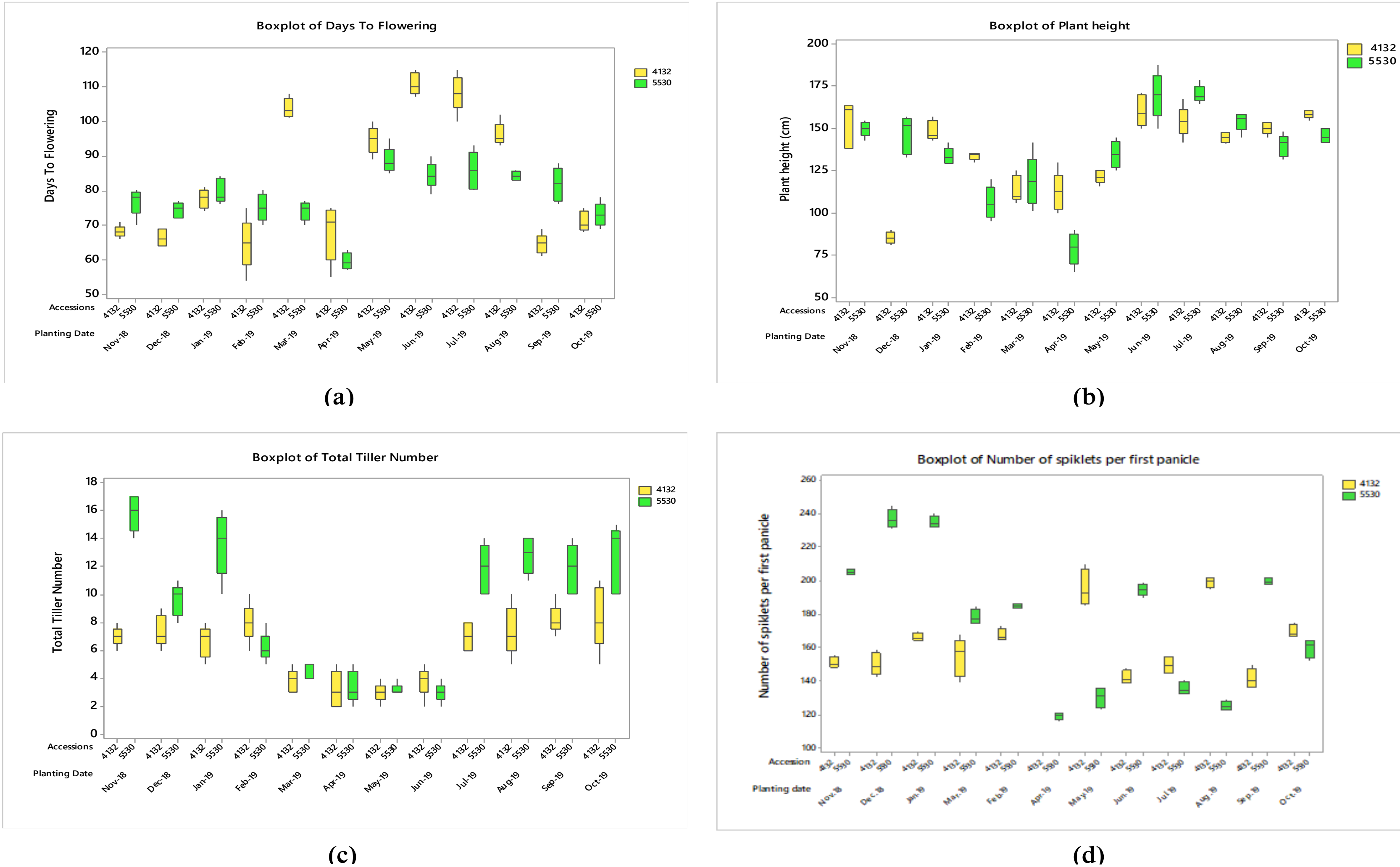
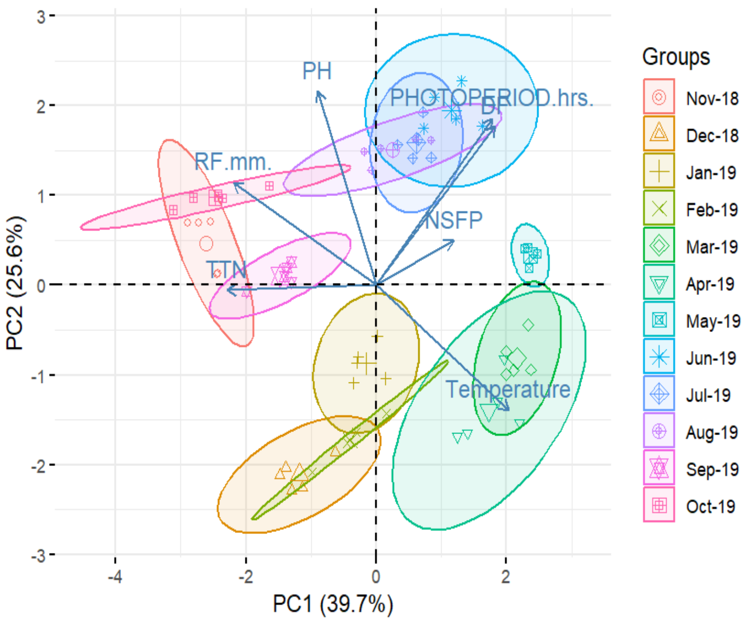


Figure 2: Boxplots for variation of agronomic and yield parameters at different monthly planting dates in Acc No. 4132 and 5530; a. Days to flowering, b. Plant height at flowering, c. Total tiller number at flowering, d. Number of spikelets per first panicle.

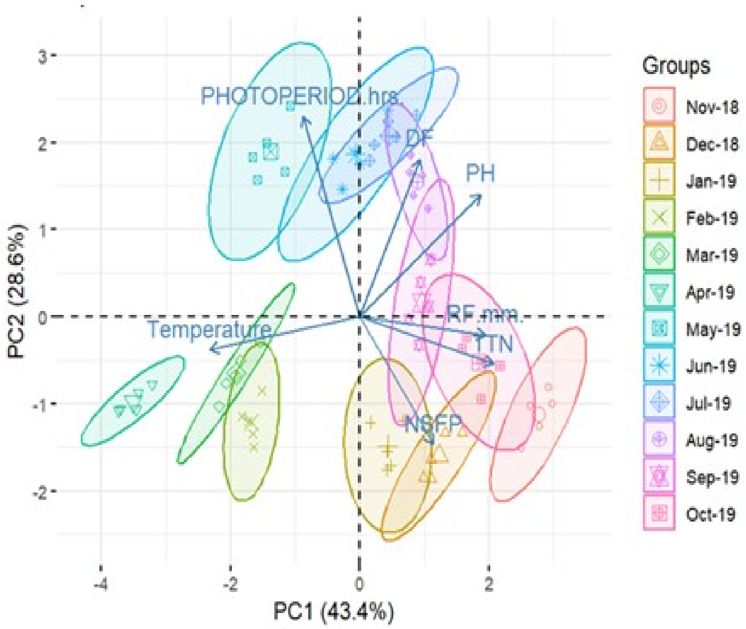
explains the negative effect of temperature (Eigenvector value of 0.4243) on the total tiller number (Eigenvector value of -0.4785) which are in opposite directions, in contrast to the positive effect of rainfall (Eigenvector value of -0.4576) on the total tiller number (Figure 3a), as depicted in Figure 1b and Figure 2c. The strongest correlation between photoperiod (Eigenvector value of 0.48385) and DF (Eigenvector value of 0.46069) is manifested in PC2 with the minimum angle between the two variables in the same direction (Figure 3a). The overlapping of higher photoperiods with increased DF is indicated through the Figure 1c and Figure 2a. Further, the correlation between PH (Eigenvector value of 0.56288) and photoperiod is also explained.

According to Table 1 and Figure 3b, the PC1 and PC2 contribute to 43.4% and 28.6% of total variation of Acc. No. 5530 across the 12 planting dates with a period of one year. PC1 explains the strong negative effect of increasing temperature (Eigenvector value of -0.5210) on TTN (Eigenvector value of -0.4641) and PH (Eigenvector value of -0.4199) in Acc. No. 5530. The adverse effect of long-day photoperiod (Eigenvector value of 0.63259) on yield is explained in PC2, as the variables of NSFP (Eigenvector value of -0.403995) and photoperiod are indicated in opposite directions. The contribution of months of June and July are depicted in ellipses for photoperiod while that of January and December for higher NSFP is indicated in an ellipse for NSFP on the biplot. Correlations between photoperiod and DF (Eigenvector value of 0.49889), and photoperiod and PH (Eigenvector value of 0.38868) are evident on the biplot with smaller angles between the above variable pairs in the same direction. These observations align with Figure 1c and Figure 2.

The seasonal grouping of months into distinct ellipses reveals how environmental variables change throughout the year and affect rice growth (Figure 03). The clustering of months of August and September with high temperatures indicates periods when rice plants may experience heat stress, potentially reducing yields. In contrast, the alignment of months of January and December for NSFP with short day photoperiod suggests the optimal times for higher yields.



(a)



(b)

Figure 3: Biplots showing the effect of environmental factors on agronomic and yield traits; (a) Acc. No. 4132, (b) Acc. No. 5530.

Table1: Eigenvector values of Principal Components in biplot analysis for rice accessions.

Agronomic and Yield Traits	Eigenvector Values			
	Acc. No. 4132		Acc. No. 5530	
	PC.1	PC.2	PC.1	PC.2
Days to flowering	0.3815	0.46069	0.2089	0.49889
Plant height at flowering	-0.1869	0.56288	0.4199	0.38868
Total tiller number	-0.4785	-0.01449	0.4641	-0.15007
Number of spikelets per first panicle	0.2491	0.12853	0.2549	-0.40399
Environmental Factors				
Temperature	0.4243	-0.36300	-0.5210	-0.10383
Rainfall	-0.4576	0.29718	0.4358	-0.05794
Photoperiod	0.3730	0.48385	-0.1955	0.63259

Sowing dates and temperature stresses on morphological traits in rice hybrids were explained through the relationship between environmental conditions and genetic factors on plant development by Bashir *et al.*, (2010). Different environmental settings play a key role for diverse responses among genotypes (Abbas, 2023). Further, Zhang *et al.*, (2023) reported that changing sowing dates had significant effects on the yield components in a hybrid rice, *Oryza sativa* indica. They observed a non-linear relationship between the sowing date and the number of effective panicles which, peaked and reached its lowest point depending on sowing date. As pointed out by Erdemci *et al.* (2018), Naık *et al.* (2022) and Ghazy *et al.* (2024), the significant effect of environmental condition and genotype interaction on grain yield can be utilized in breeding programmes for ecological adaptation. *Masuran* variety Acc. No. 5530 could be nominated as a candidate as it produced a stable higher yield from the plants planted at every planting dates.

Our results support the indigenous knowledge of farmers, who selectively cultivate photoperiod-sensitive varieties of traditional rice during *Maha* season in Sri Lanka. Padukkage *et al.* (2017) studied the effect of photoperiod on flower initiation using photoperiod chambers. They found that most of the tested accessions flowered early under short days, while some accessions flowered early in response to long days. Work done by Pushpakumari *et al.* (2017) has also indicated the significant effects of DF on yield components of *Ma wee* accessions during the inductive season in field conditions which is in agreement with the results of this study.

CONCLUSION

The effect of planting date associated environmental factors for rice Acc. No. 4132 and Acc. No. 5530 are evident. Photoperiod affects days to flowering with a strong positive correlation in Acc. No. 4132, suggesting that it should be grown during *Maha* season for early flowering. High temperature adversely affects plant height. There are correlations between the photoperiod and the plant height, and the photoperiod and total effective tiller number. In Acc. No. 5530, the correlation of photoperiod on days to flowering and plant height are positive, while it negatively affects the number of spikelets per first panicle. This study demonstrated the effectiveness of planting date on achieving higher yield components in a selected variety with two accessions.

REFERENCES

Abbas, S. H. (2023). Effect of planting dates on stability of new rice genotypes traits grown in Iraqi conditions. *Basrah Journal of Agricultural Sciences*, 36: 1–16.

Bashir, M. U., Akbar, N., Iqbal, A. and Zaman, H. (2010). Effect of different sowing dates on yield and yield components of direct seeded coarse rice (*Oryza sativa* L). *Pakistan Journal of Agricultural Research*, 47: 361–365.

Cho, L. H., Yoon, J. and An, G. (2017). The control of flowering time by environmental factors. *The Plant Journal*, 90: 708–719.

Erdemci, I. (2018). Investigation of genotype × environment interaction in chickpea genotypes using AMMI and GGE biplot analysis. *Turkish Journal of Field Crops*, 23: 20–26.

Food and Agriculture Organization of the United Nations (FAO). (2023). The State of Food and Agriculture 2023: Revealing the true cost of food to transform agrifood systems. FAO, Rome: ISBN 978-92-5-138167-0, 1-18 PP

Ghazy, M. I., Abdelrahman, M., El-Agoury, R. Y., El-hefnawy, T. M., EL-Naem, S. A., Daher, E. M. and Rehan, M. (2024). Exploring genetics by environment interactions in some rice genotypes across varied environmental conditions. *Plants*, 13(1): 74

Jayasinghe, H. M. A. S. B., Senanayake, D. M. J. B., Rathnathunga, E. U. U., and Geekiyanage, S. (2023). Correlation of plant height and crop age with yield potential in Sri Lankan traditional rice accessions of *Ma wee*: A comparative study in Kamburupitiya with selected new improved rice varieties. *Tropical Agricultural Research and Extension*, 26(4): 264–272.

Kariyawasam, T., Nanayakkara, D., Sumanarathna, A., Weerasinghe, D., Suriyagoda, L. D. B. and Jayatilake, D. (2023). Germplasm characterization assessment of submergence stress responses and mining allelic variations of submergence tolerance gene Sub1A in Sri Lankan rice germplasm. *Journal of the National Science Foundation of Sri Lanka*, 51(1): 81–91.

Khush, G. S. (2005). What it will take to feed 5.0 billion rice consumers in 2030. *Plant Molecular Biology*, 59(1):1-6.

Munasinghe, S. P., Somaratne, S. and Weerakoon, S. R. (2017). Screening of Sri Lankan rice (*Oryza sativa* L.) landraces for drought tolerance. *Tropical Agriculture Research*, 28(2): 183.

Naik, A., Wani, S. H., Rafiqee, S., Sofi, M., Sofi, N. R., Shikari, A. B., Hussain, A., Mohiddin, F., Jehangir, I. A. and Khan, G. H. (2022). Deciphering genotype × environment interaction by AMMI and GGE biplot analysis among elite wheat (*Triticum aestivum* L.) genotypes of Himalayan region. *Ekin Journal of Crop Breeding and Genetics*, 8(2): 41–52.

Padukkage, D., Rathnathunga, E. U. U., Pushpakumari., W. H. D. U., Geekiyanage, S., Dissanayake, N., Senanayake, S. G. J. N. and Benthota, A. S. S. (2015). Handbook on varietal diversity of Sri Lankan traditional rice (*Oryza sativa*) Volume II. *National Research Council of Sri Lanka*, ISBN: 978-955-0263-04-2.

Padukkage, D., Senanayake, G. and Geekiyanage, S. (2017). Photoperiod sensitivity of very early maturing Sri Lankan rice for flowering time and plant architecture. *Open Agriculture*, 2(1): 580–588. DOI: https://doi.org/10.1515/opag-2017-0061.

Pradheeban, L., Nissanka, S. P. and Suriyagoda, L. D. B. (2017). Influence of whole and sub soil salinity on growth, development, physiology, and yield of selected rice varieties cultivated in Jaffna district, Sri Lanka. *Tropical Agricultural Research*, 28(4): 389.

Pushpakumari, W. H. D. U. and Geekiyanage, S. (2014). Yield potential of medicinally important Sri Lankan traditional rice. *Sri Lanka Journal of Indigenous Medicine*, 4(2): 309–312.

Pushpakumari, W. H. D. U. and

Geekiyanage, S. (2015). Evaluation of yield variation in Sri Lankan traditional rice (*Oryza sativa* L.) *Kalu Heenati*. *Proceedings of KDU International Research Symposium,* 24–26. Available at: http://ir.kdu.ac.lk/handle/345/997.

Pushpakumari, W. H. D. U., Padukkage, D., Rathnathunga, E. U. U., Geekiyanage, S., Dissanayake, N., Senanayake, S. G. J. N. and Benthota, A.S.S. (2016). Handbook on varietal diversity of Sri Lankan traditional rice (*Oryza sativa* L.) Volume III. *National Research Council of Sri Lanka*, ISBN: 978-955-0263-05-9.

Pushpakumari, W. H. D. U., Senanayake, G. and Geekiyanage, S. (2017). Photoperiod driven days to flowering variation affect vegetative growth and yield in Sri Lankan traditional rice (*Oryza sativa* L.) *Ma wee*. *Pakistan Journal of Botany*, 49(3): 945–954.

Rathnathunga, E. U. U., Padukkage, D., Pushpakumari, W. H. D. U., Geekiyanage, S., Dissanayake, N., Senanayake, S. G. J. N. and Benthota, A.S.S. (2014). Handbook on varietal diversity of Sri Lankan traditional rice (*Oryza sativa*) Volume I. *National Research Council of Sri Lanka*, ISBN: 978-955-0263-01-1.

Rathnathunga, E. U. U. and Geekiyanage, S. (2015). Potential flowering time mutants of Sri Lankan traditional rice variety "*Sulai*". *National Symposium on Agriculture, Eastern University, Sri Lanka.*

Rathnathunga E. U. U., Senanayake G., Dissanayake N., Seneweera S. and Geekiyanage, S. (2016). Development of a mini core collection from Sri Lankan traditional rice for flowering time variation. *Australian Journal of Crop Science,* 10: 1357-1367.

Rathnathunga, E. U. U. and Geekiyanage, S. (2016). Within variety flowering time variation leads to yield variation in Sri Lankan traditional rice "*Sudu wee". Ceylon Journal of Science*, 45(2): 25.

Rathnathunga, E. U. U. and Geekiyanage, S. (2017). Morphological diversity of Sri Lankan traditional rice varieties "*Pachchaperumal*" and "*Suduru samba*". *Open Agriculture,* 2(1): 552–560.

Vergara, B. S., and Chang, T. T. (1985). The flowering response of the rice plant to photoperiod - A review of the literature (4th edition*). International Rice Research Institute*, Manila, Philippines.

Yan, W., Hunt, L. A., Sheng, Q. and Szlavnics, Z. (2000). Cultivar evaluation and mega-environment investigation based on the GGE biplot. Crop science, 40(3): 597-605.

Zhang, R. P., Zhou, N. N., Ashen, R. G., Zhou, L., Feng, T. Y., Zhang, K. Y., Liao, X. H., Aer, L. S., Shu, J. C., He, X. W., Gao, F. and Ma, P. (2023).

Effect of sowing date on the growth characteristics and yield of growth-constrained direct-seeding rice. *Plants*, 12: 1–16.

Zhou, Y., Xu, L., Xu, Y., Xi, M., Tu, D., Chen, J. and Wu, W. (2021). A meta-analysis of the effects of global warming on rice and wheat yields in a rice–wheat rotation system. *Food and Energy Security*, 10: 1–12.