Screening of rice landraces for potential drought tolerance through comparative studies of genetic variability and principal component analysis

Sujan Acharjee¹, Nihar Ranjan Chakraborty¹ and Sankar Prashad Das²

¹ Department of Genetics and Plant Breeding, Institute of Agriculture, Palli Sikhsha Bhavan, Visva Bharati, Sriniketan, West Bengal-731236, India.
² Indian Council of Agricultural Research-Complex for North Eastern Hilly region, Tripura Centre, Lembucherra, Tripura-799210, India
E-Mail : acharyasujan.agt@gmail.com

Abstract
To identify stable yielding rice landraces with optimum drought tolerance ability, the present comparative study of genetic variability and principal component analysis was carried out based on different morphological traits of 60 landraces of northeast India belonging to upland rice. The sensitivity of the landraces under drought stress conditions was confirmed by the first-order statistics of genetic variation as well as Principal component analysis (PCA) since comparatively more numbers (6) of principal components were found under drought stress over the irrigated conditions with 74.12 per cent of cumulative variability. Characters viz., leaf rolling index, root: culm ratio, the number of spikelets per panicle, the number of filled grains per panicle, 100 seed weight and grain yield per plant were identified as suitable selection indexes for landraces under drought stress conditions. Based upon the eigenvalue and scattered diagram analysis under PCA, the landraces viz., Garomalati, Chikanswari Kabar, Turkey, Tarkol, Maimi Taukha and Madoop were found to be diverse and promising genotypes under drought stress. Hence, these landraces may be utilised as potential parents in the future breeding programme.

Key words: Rice, landraces, drought stress, genetic variability, principal component analysis.

INTRODUCTION
Rice (Oryza sativa L.) is the major staple food for one-third of the world’s population providing around 80 % of individuals’ daily calories (Ashkani et al., 2015). But being a semi-aquatic cereal crop, it requires a relatively higher amount of water for its normal growth in comparison to other crops (Pandey and Shukla, 2015). Rice plant suffers at different stages of their life cycle due to water scarcity under rain-fed conditions. To be more specific, it suffers most during the booting or reproductive stage (Agarwal et al., 2016). The effect of drought on rice is more severe when compared to other food crops in the present scenario of severe climate change. Worldwide, approximately 27 million hectares of rice grown area is subjected to drought stress (Zu et al., 2017). On the other hand, as per World Bank Population projections (2020), the population growth trend in the major rice-growing countries of Asia, as well as, in the world can be expected to increase at an annual average growth rate of 0.9%. Thus, to meet the rising demand of the continuously increasing population with depleting water supply, rice varieties that are highly adapted or tolerant to dry environments are required to be traced out with due gravity (Foley et al., 2011). Despite many studies on drought tolerance of crops, the improvement of drought-tolerant crops is delayed greatly.
due to largely unknown mechanisms of different crop’s responses to drought stress. However, genetic variations in the rice genotypes for drought tolerance were observed by many researchers in their screening and characterization studies on rice germplasm under drought stress (Zu et al., 2017). Thus, to neutralize the adverse effect of drought stress in rice by developing drought-tolerant varieties, a genetic variability study seems to be a useful approach. Genetic variability is the basis for any plant improvement programme towards tracing out new genotypes for a particular purpose. Hence, to plan an efficient breeding programme, reliable estimates of genetic variation through studies of coefficient of variation, heritability and genetic advance are found to be the key components. Variability studies help plant breeders to make a suitable selection of genotypes by assessing the magnitude of genetic improvement (Tuhina-Khatun et al., 2015). Apart from this, knowledge of multivariate analysis like principal component analysis (PCA) is also identified as an essential tool in the identification of promising germplasm by analyzing its greater performance in a given condition. In view of the above, the research hypothesis was fixed for the identification of important yield contributing and drought-tolerant traits as well as to trace out potential drought tolerance landraces.

**MATERIALS AND METHODS**

The experiment was carried out on the farm of the Indian Council of Agricultural Research (ICAR) Complex for the North Eastern Hilly Region, Tripura Centre, Lembucherra, Tripura, (23°90' E, 92°29’ N), India. Sixty local rice landraces (Table 1) were collected from the different hill ranges of Tripura, a north-eastern state of India and evaluated through Randomised Complete Block Design with three replications. The experiment was conducted under both irrigated (in ‘Kharif’ seasons) and artificial drought stress conditions (in ‘boro’ seasons) for two consecutive years of 2015-16 and 2016-17. Artificial drought stress conditions were imposed in the trial field during the ‘Boro’ seasons of those years. For drought stress evaluation of the landraces, an un-bunded, well-drained field was chosen under the local upland ecosystem of the farm complex. The collected seeds were directly sown in dry soil maintaining a spacing of 25 cm x 25 cm. Subsequently, furrow type of irrigation was provided up to 30 days after sowing (DAS). Proper inter culture techniques were carried out at regular intervals to ensure the maintenance of row-row and plant-plant distance and eradication of off-type plants. After 30 DAS, the field was kept unirrigated until the soil surface is completely dried out or the experimental plants showed severe wilting symptoms. When the required levels of soil dryness, as well as plant stress, were observed, the experimental field was abundantly irrigated to saturate the root zone. This irrigation pattern was repeated until harvesting the crop. However, for irrigated trials, no such specifications were followed during field selection as well maintenance of irrigation schedule. Seedlings were transplanted in the puddled field maintaining the same

| S.No. | Name of the land races | S.No. | Name of the land races | S.No. | Name of the land races |
|-------|------------------------|-------|------------------------|-------|------------------------|
| 1     | Kaporok                | 21    | Saanki ka Phool        | 41    | Bongbu                 |
| 2     | Releng                 | 22    | Bihar                  | 42    | Sadok                  |
| 3     | Beti                   | 23    | Chikanswari Kabar      | 43    | Kali Jira              |
| 4     | MaimiUzrao             | 24    | Bangbu Jhum            | 44    | Gaigash                |
| 5     | Kalikhasa              | 25    | Lal Biroin             | 45    | Vanbang                |
| 6     | Chinal                 | 26    | DhalaBalam             | 46    | Makajaria              |
| 7     | American               | 27    | Goria                  | 47    | Jilong                 |
| 8     | Khasa Kasam            | 28    | Bahadur                | 48    | American Ration        |
| 9     | Biroin                 | 29    | Maimiwatlok Mandoori   | 49    | Kala Dhan              |
| 10    | Galong                 | 30    | Maimi Hungar           | 50    | Turkey                 |
| 11    | FazuVom                | 31    | Darka Sona             | 51    | Saanki Kachak          |
| 12    | Garo Malati            | 32    | Tankol Kolte           | 52    | Maimi Ukhlao           |
| 13    | Maimi Usha             | 33    | SadaBiroin             | 53    | Mawaisha               |
| 14    | Maimi Red              | 34    | Maimi Taukha           | 54    | Maimi Watoklok         |
| 15    | Suri                   | 35    | Saluma                 | 55    | Santim Wakhum          |
| 16    | Lebuka                 | 36    | Tarkol                 | 56    | Yang Dhan              |
| 17    | Aaduma                 | 37    | Madoop                 | 57    | Badaya                 |
| 18    | Fazu Sen               | 38    | Waibang                | 58    | Kanchali               |
| 19    | Fazu Ngoi              | 39    | Jhum Bini              | 59    | Australian Biroin      |
| 20    | Beti Kalai             | 40    | Fazu Sen (White)       | 60    | Assam Paisom           |

Source: Acharjee et al.(2019)
plant to plant and row to row distance like drought stress. The precaution was taken to maintain one seedling per hill to keep parity with the stress condition evaluation. Fertilizers were applied @ 100:40:40 N: P: K kg/ha under both conditions.

Twelve morphological traits viz., plant height (cm), the number of productive tiller per plant, panicle length (cm), the number of primary branches per panicle, root length (cm), root: culm ratio, the number of spikelets per panicle, the number of filled grains per panicle, spikelet fertility (%), 100 seed weight (g.), harvest index (%) and grain yield per plant (g) were taken into consideration for statistical analysis under irrigated and drought stress conditions. Apart from these, four drought tolerant traits viz., seedling vegetative vigour, leaf rolling index, leaf drying index and drought recovery index were also evaluated under drought stress conditions. Five numbers of competitive plants, preferably from the middle rows over the replications, were considered for recording the morphological observation as per the Standard Evaluation System of Rice, IRRI (2002).

In this study, the genetic parameters viz., genotypic and phenotypic coefficient of variation (GCV and PCV), heritability (H²), and the genetic advance (GA), were calculated using the formula given by Johnson et al. (1955). The whole statistical analysis of genetic parameters including the multivariate analysis of the Principal component was done by using Windostat Version 9.2 from the Indostat service.

RESULTS AND DISCUSSION

The development of rice cultivars with high yield potential under stress can be obtained by screening breeding lines under both favourable and stress conditions (Serraj and Atlin, 2008). Hence, in the present study, the stable yield performance of the landraces under both irrigated and drought stress conditions along with good drought tolerance ability were considered as reliable parameters for screening of the landraces.

Under mean value analysis, most of the yield contributing characters showed lower mean performance in stress condition in comparison to the irrigated condition and the finding is in agreement with the comparative variability study of Singh et al. (2018) and Muthuramu and Ragavan (2020) except root length and root: culm ratio. In this regard, Haider et al. (2013), opined that plants tolerate drought by lowering their shoot length and developing a large root system for extracting more water from the soil. However, the percentile mean difference between drought stress and irrigated condition were found to be minimal against the traits viz., 100 seed weight and spikelet fertility, whereas, high percentile differences were observed against the traits viz., grain yield per plant and root: culm ratio. The estimates of mean values, GCV, PCV, heritability and genetic advance are presented in Table 2. The magnitude of phenotypic and genotypic coefficient of variations (PCV and GCV) were found to be highest in the case of leaf rolling index followed by leaf drying index and grain yield per plant, which is in confirmatory with the findings of Chuchert et al. (2018) and Nithya et al. (2020) under drought stress. Whereas, under irrigated conditions, the high magnitude of PCV and GCV values are in agreement with the studies of Mauyra et al. (2018), Meena et al (2019) for grain yield per plant as well as the number of filled grains per panicle and Hossain et al (2015) for root: culm ratio and root length. Under drought stress, the high magnitude of genetic variation values of leaf rolling index and leaf drying index are in agreement with the studies of Haider et al. (2012) and Kumar et al. (2015). The wide difference in GCV and PCV for leaf drying index under drought stress environment certainly justified the high environmental effect or more specifically the stress effect on the said traits. Although high heritability estimates are effective in the selection of landraces based on the phenotypic expression, heritability estimates along with genetic advances are more useful in predicting the effects for selection of the desired type of landraces (Acharjee et al., 2019). Improvement of the genotypic value of a particular character of a new population in comparison to the base population under selection refers to Genetic advance (GA) (Wolie et al., 2013). Heritability and genetic advance are found to be very effective selection parameters when considered jointly. Under the irrigated condition, high estimates of heritability (H²) coupled with moderate to high genetic advance were observed in various traits and the results are in accordance with the findings of Khan et al. (2019), Meena et al. (2019) and Perween et al. (2020) for grain yield per plant and the number of filled grains per panicle, Perween et al. (2020) for the number of spikelets per panicle and Panja et al. (2017) for root: culm ratio and root length of rice. Whereas, under drought stress conditions, high magnitudes of heritability with moderate to the high genetic advance of traits are in agreement with Haider et al. (2012) for leaf rolling index, Panja et al.(2017) for root: culm ratio, Perween et al.(2020) and Nithya et al.(2020) for the number of filled grains per panicle, the number of spikelets per panicle, grain yield per plant and 100 seed weight of rice. The result implies the predominance of additive gene action for these characters. Thus, based on the findings, it can be concluded that the selection of rice landraces based on these characters would be effective.

Principal Component Analysis is a multivariate analysis to measure the importance and contribution of each component to the total variance. It also can be used for the measurement of the independent impact of a particular trait on the total variance whereas, each coefficient of proper vectors indicates the degree of contribution of all original variables with which each principal component is related (Nachimuthu et al., 2014). Eigenvalue, the contribution of
Table 2. Estimates of Genetic parameters for different Morpho-Physiological characters of 60 rice land races under irrigated and drought stress condition

| Character   | Range     | Condition | Min. | Max. | Mean   | GCV (%) | PCV (%) | \( \text{H}^2 \) (%) | GA as % of mean |
|------------|-----------|-----------|------|------|--------|---------|---------|------------------|-----------------|
| VGR        |           | D         | 5.0  | 9.0  | 7.17   | 14.15   | 18.60   | 0.57            | 22.19           |
| LRI        |           | D         | 0.00 | 5.00 | 0.89   | 137.95  | 147.01  | 0.88            | 266.66          |
| LDI        |           | D         | 0.00 | 4.50 | 1.11   | 86.06   | 112.20  | 0.58            | 135.99          |
| PL         |           | D         | 61.24| 125.41| 86.17  | 15.14   | 18.31   | 0.68            | 25.79           |
| PRI BR     |           | I         | 86.66| 148.58| 113.55 | 9.77    | 12.68   | 0.59            | 15.52           |
| PT         |           | D         | 2.74 | 4.5  | 3.47   | 10.51   | 16.29   | 0.41            | 13.98           |
| PL         |           | I         | 3.16 | 6.08 | 4.3943 | 14.24   | 20.27   | 0.49            | 20.62           |
| PH         |           | D         | 16.83| 29.49| 22.87  | 12.40   | 15.59   | 0.63            | 20.31           |
| LRI        |           | I         | 17.66| 31.99| 24.49  | 12.11   | 16.09   | 0.56            | 18.77           |
| LDI        |           | D         | 5.25 | 10.24| 7.11   | 14.95   | 18.87   | 0.62            | 24.41           |
| PH         |           | I         | 5.16 | 11.99| 7.91   | 19.51   | 23.61   | 0.68            | 33.20           |
| PT         |           | I         | 7.11 | 26.52| 14.28  | 34.44   | 37.64   | 0.83            | 64.94           |
| PL         |           | D         | 8.23 | 21.30| 13.55  | 24.49   | 27.27   | 0.80            | 45.32           |
| PRI BR     |           | D         | 0.13 | 0.35 | 0.22   | 26.76   | 27.99   | 0.91            | 52.69           |
| RL         |           | I         | 0.07 | 0.26 | 0.15   | 28.13   | 31.74   | 0.78            | 51.35           |
| R:C        |           | D         | 57.49| 195.33| 88.51  | 30.68   | 33.42   | 0.84            | 58.03           |
| NSP        |           | I         | 59.41| 221.49| 110.34 | 32.40   | 34.61   | 0.87            | 62.49           |
| NFG        |           | D         | 45.41| 178.58| 74.08  | 34.45   | 37.30   | 0.85            | 65.55           |
| SF         |           | I         | 53.08| 209.58| 97.73  | 25.39   | 37.70   | 0.88            | 68.42           |
| HI         |           | D         | 78.29| 94.65| 88.04  | 4.23    | 5.26    | 0.64            | 7.02            |
| HSW        |           | I         | 1.10 | 2.99 | 2.29   | 18.60   | 19.65   | 0.89            | 36.25           |
| NSP        |           | D         | 1.15 | 3.11 | 2.48   | 18.58   | 19.11   | 0.94            | 37.23           |
| NFG        |           | I         | 12.8 | 40.86| 23.81  | 25.61   | 29.43   | 0.75            | 45.90           |
| SF         |           | D         | 15.76| 44.42| 30.47  | 20.53   | 24.75   | 0.68            | 35.07           |
| GYP        |           | D         | 0.39 | 0.82 | 0.58   | 14.68   | 25.68   | 0.32            | 17.30           |
| GYP        |           | I         | 5.20 | 30.35| 11.34  | 46.26   | 50.42   | 0.84            | 87.44           |

Data for irrigated condition: Source - Acharjee et al. (2019)

Min-Minimum, Max- Maximum, GCV - genotypic coefficient of variation PCV- phenotypic coefficient of variation, \( \text{H}^2 \) – Broad sense heritability, GA – Genetic advance, D- Drought stress conditions, I- Irrigated conditions.

VGR- Seedling vegetative vigour, LRI- Leaf rolling index, LDI-Leaf drying index, PH - Plant height (cm), PT – Numbers of productive tillers per plant, PL- Panicle length (cm), PRI BR- Numbers of primary branch per panicle, RL-Root length (cm), R: C – Root: Culm ratio, NSP- Number of spikelets per panicle, NFG - Number of filled grains per panicle, SPK-Spikelet fertility (%), HSW-100 Seed weight (g), GYP-Grain yield per plant (g)

variability and Eigenvectors for the principal component axes and component loading of different traits of rice landraces under irrigated and drought stress conditions are presented in Table 3.

In the present study, an effort was made to identify the important traits that play prominent roles in classifying the variation existing in the rice landraces as well as to enhance the potential of drought tolerance. As per the
Table 3. Eigen value, contribution of variability and Eigen vectors for the Principal component axes and component loading of different traits of rice landraces under irrigated and drought stress conditions.

| Parameters          | Irrigated condition Principal Components (PCs) | Drought stress condition Principal Components (PCs) |
|---------------------|-----------------------------------------------|---------------------------------------------------|
|                     | PC 1   | PC 2   | PC 3   | PC 4   | PC 5   | Eigen Value Root | % Var. Exp. | Cum. Var.Exp. | Factor loadings after Varimax rotation | PC 1   | PC 2   | PC 3   | PC 4   | PC 5   | PC 6     | PC 7 |
| Eigen Value Root    | 2.76   | 2.34   | 1.35   | 1.30   | 0.96   | 4.49     | 2.41         | 1.53         | 1.31         | 1.11     | 1.02     | 0.15 |
| % Var. Exp.         | 23.02  | 19.46  | 11.21  | 10.84  | 8.02   | 28.05    | 15.09        | 9.56         | 8.16         | 6.92     | 6.34     | 0.09 |
| Cum. Var.Exp.       | 23.02  | 42.47  | 53.68  | 64.52  | 72.53  | 28.05    | 43.14        | 52.70        | 60.85        | 67.78    | 74.12    | 74.20 |
| Traits              |        |        |        |        |        |          |              |              |              |          |          |      |
| VGR*                | -      | -      | -      | -      | -      | 0.33     | 0.20         | 0.05         | 0.01         | 0.09     | 0.42     | 0.15 |
| LRI*                | -      | -      | -      | -      | -      | -0.20    | 0.46         | 0.15         | -0.17        | 0.01     | 0.21     | 0.09 |
| LDI*                | -      | -      | -      | -      | -      | 0.33     | -0.06        | 0.21         | -0.08        | -0.34    | 0.19     | 0.25 |
| PH                  | 0.31   | 0.36   | 0.20   | 0.04   | 0.21   | -0.18    | -0.45        | -0.12        | 0.18         | 0.06     | 0.15     | 0.15 |
| PT                  | 0.47   | -0.01  | -0.23  | -0.20  | 0.08   | -0.20    | -0.16        | 0.38         | -0.03        | 0.12     | -0.60    | 0.13 |
| PL                  | -0.19  | 0.30   | -0.02  | -0.37  | 0.18   | -0.31    | 0.11         | -0.28        | 0.01         | 0.11     | 0.24     | 0.38 |
| PRI BR              | 0.06   | 0.46   | -0.02  | -0.26  | -0.29  | -0.05    | -0.35        | 0.10         | -0.07        | -0.69    | 0.10     | 0.12 |
| RL                  | -0.20  | -0.19  | -0.39  | -0.03  | -0.44  | -0.36    | 0.23         | 0.12         | 0.09         | -0.27    | 0.01     | -0.07 |
| R:C                 | 0.20   | 0.34   | 0.45   | 0.15   | -0.25  | -0.28    | 0.34         | -0.05        | 0.17         | 0.00     | -0.07    | -0.01 |
| NSP                 | 0.14   | 0.41   | -0.35  | -0.26  | 0.00   | -0.23    | -0.29        | 0.18         | 0.12         | 0.30     | 0.26     | 0.06 |
| NFG                 | 0.32   | 0.10   | -0.54  | 0.22   | -0.21  | -0.14    | 0.10         | 0.19         | -0.65        | 0.01     | -0.12    | 0.43 |
| SPK                 | 0.05   | -0.26  | -0.05  | -0.65  | 0.33   | 0.11     | 0.28         | 0.17         | 0.44         | -0.26    | 0.03     | 0.00 |
| HSW                 | -0.41  | 0.28   | -0.27  | 0.17   | 0.16   | -0.22    | 0.05         | -0.35        | -0.36        | -0.29    | 0.04     | -0.48 |
| HI                  | -0.35  | 0.08   | 0.19   | -0.37  | -0.51  | -0.09    | 0.04         | -0.54        | 0.23         | -0.18    | -0.23    | 0.49 |
| DRI*                | -      | -      | -      | -      | -      | 0.38     | 0.20         | -0.05        | 0.02         | 0.01     | -0.15    | 0.15 |
| GYP                 | -0.39  | 0.30   | -0.13  | 0.18   | 0.37   | -0.29    | 0.08         | 0.39         | 0.29         | -0.14    | 0.27     | 0.02 |

VGR- Seedling vegetative vigour, LRI- Leaf rolling index, LDI-Leaf drying index, PH - Plant height, PT – Numbers of productive tillers per plant, PL -Panicle length, PRI BR- Numbers of primary branch per panicle, RL-Root length, R: C –Root: Culm ratio, NSP- Number of spikelets per panicle, NFG - Number of filled grains per panicle, SPK-Spikelet fertility, HSW-100 Seed weight, DRI – Drought recovery Index, HI-Harvest index, GYP-Grain yield per plant.

* Traits for which analysis was not carried out in the irrigated condition.

criteria set by Brejda et al. (2000), the PC with Eigenvalue > 1 and which explained at least 5% of the total variations in the data were considered in the present study for analysis. Accordingly, in our study, the first four Principal components (PC) showed more than ‘1’ eigenvalue and exhibited 64.52 per cent cumulative variability under irrigated conditions. Further, the PC with higher eigenvalues and variables with high factor loading was considered as the best representative of system attributes. As per Raji (2002), to determine the critical limit for the coefficients of the proper vectors, coefficients greater than 0.3 (regardless of the direction, positive or negative) are considered to have a large effect on the overall variation present in the landraces. The PC1 showed 23.02 per cent of total variability comprised of significant loading values (coefficients values greater than 0.3) of most of the important yield contributing traits viz., the number of productive tillers per plant, 100 seed weight, grain yield per plant, harvest index and plant height. PC 2 with 19.46 per cent of the total variability is also loaded with high factor values of yield contributing traits of a number of primary branches per panicle, the number of spikelets per panicle. PC 3 and PC 4 were found to be enriched with the high loading values of root: culm ratio, the number of filled grains per panicle and spikelet fertility.

Principal component analysis, however, results in more divergence assessment under drought stress conditions with six numbers of principal components with eigenvalue ≥ 1 and total cumulative variability of 74.12 per cent. Cumulative count of 43.14 per cent of total variability by PC1 and PC2, justify the major contribution of the first two principal components towards tracing out the important traits for enhancing the potential of the rice landraces under drought stress. A major contribution of the first two principal components towards the total variability of
rice genotypes under drought stress conditions was also found by Maji et al. (2012) and Nachimuthu et al. (2014). PC 3, PC 4, PC 5 and PC 6 also contributed significantly with PC wise variability count of less than 10 per cent.

Under drought stress conditions, significant contributions of most of the drought stress indicative traits viz., drought recovery index, root length, leaf drying index and vegetative vigour are found in PC 1. In addition, PC 2 is also found to be enriched with high loading values of drought stress indicative traits like leaf rolling index, root: culm ratio along plant height. PC 3 settled itself as a yield contributory principal component with significant contribution of harvest index, grain yield per plant, the number of productive tillers per plant and 100 seed's weight, while the number of filled grains per panicle render remarkable contribution in PC 4. The result is confirmatory with the findings of Ojha et al. (2017) and Pavithra and Vengadessan (2020). Hence, in comparison to the irrigated situation, more specific PC wise categorization of discriminating traits was found under drought stress, wherein, PC 1 and PC 2 were found to be attributed with most of the drought-tolerant traits and PC 3 along with PC 4 categorized as grain yield contributing components. Overall, the traits viz., 100 seed weight, harvest index, grain yield per plant and number of filled grains per panicle are found to be worthy for stable performance of the landraces under both irrigated and drought stress conditions. As far as the drought tolerance ability of rice landraces is concerned, factors like drought recovery index, root length, leaf rolling index, leaf drying index and root: culm ratio should be considered with due gravity. The importance of comparative principal component analysis (PCA) towards the quantification of genetic divergence and selection of superior plant type under drought stress were also accessed in the studies of Ojha et al. (2017) and Turin et al. (2021).

Scree plot explained the percentage of variation associated with each principal component obtained by drawing a graph between eigenvalues and principal component numbers. It displays the eigenvalue associated with a component or factor in descending order versus the number of components or factors. Scree plot depicting eigenvalue variation of Principal components under irrigated and drought stress conditions is elucidated in Fig. 1. The ideal pattern in a scree plot is a steep curve, followed by a bend and then a flat or horizontal line (Chandra et al., 2017) which is more or less similar to an elbow bend. In this study, it was clear from the depiction of the scree plot that the first three principal components showed the maximum variability under both irrigated and stress conditions. Further, elbow pattern lines are also found after PC3. The PCA scores of 60 rice landraces under irrigated and drought stress condition is presented in Table 4.

Based on the trend of scree plot curve, the PCA scores of 60 landraces in the first three principal components were computed and considered as three axes as X, Y and Z. The PCA scores of 60 landraces were plotted in graph to get three-dimensional scatter diagrams (Fig. 2 and Fig. 3) Evaluation of rice genotypes through PCA 3D scatter diagram was also carried out by Tejaswini et al. (2018) and Ibrahim et al. (2021). According to Tejaswini et al. (2018), the genotypes identified on the extremely positive side of both the X and Y axis were considered to be better genotypes against the contributing traits of PC 1 and PC 2, respectively, however, in the 3D (three dimensional) scattered diagram, it was considered an additional vertical Z-axis and in that case, the genotypes plotted higher along the Z-axis will also be considered as better performers against the contributing traits of PC 3.

![Fig. 1. Scree plot showing eigenvalue variation of Principal components under irrigated and drought stress condition.](https://doi.org/10.37992/2021.1204.151)
Table 4. PCA scores of 60 rice landraces under irrigated and drought stress condition

| Landraces  | Irrigated Condition |  |  | Drought Stress Condition |  |  |
|------------|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|
|            | PCA X axis | PCA Y axis | PCA Z axis | PCA X axis | PCA Y axis | PCA Z axis |
| Kaporok    | 7.60       | -4.78      | 0.25      | Darka Sona | 7.05       | -6.28      | 0.39      |
| Releng     | 6.53       | -5.12      | 1.63      | Tarikol Kolte | 7.38       | -4.96      | 0.91      |
| Beti       | 7.63       | -5.69      | 0.02      | SadaBiroin | 6.63       | -5.94      | 2.00      |
| Maimi Uzrao | 7.36    | -5.53      | 1.91      | Maimi Taukha | 7.04       | -5.30      | 0.69      |
| Kalikhasa  | 12.68      | -7.51      | 4.09      | Saluma    | 7.52       | -6.50      | 1.16      |
| Chinal     | 9.11       | -5.93      | 0.94      | Tarkol    | 6.53       | -4.36      | -1.14     |
| American   | 7.30       | -5.17      | 1.23      | Madoop    | 9.81       | -5.04      | 1.00      |
| Khasa Kasam | 10.85   | -7.12      | 4.66      | Waibang   | 6.92       | -5.84      | -0.37     |
| Biroin     | 7.20       | -5.80      | 0.46      | Jhum Bini | 6.33       | -4.80      | 0.71      |
| Galong     | 8.47       | -2.31      | -0.89     | Fazu Sen (White) | 7.89       | -7.49      | 0.41      |
| FazuVom    | 6.35       | -5.00      | 1.90      | Bongbu    | 6.38       | -4.91      | 1.93      |
| Garo Malati | 8.70    | -0.41      | -0.66     | SadoK     | 6.21       | -5.98      | 1.62      |
| Maimi Usha | 7.34       | -6.10      | 1.51      | Kali Jira | 11.36      | -8.49      | 1.38      |
| Maimi Red  | 6.04       | -5.21      | 0.86      | Gaigash   | 7.01       | -4.75      | 0.56      |
| Suri       | 7.85       | -6.85      | 1.59      | Vanbang   | 7.89       | -6.60      | 1.21      |
| Lebuka     | 7.76       | -5.35      | 2.31      | Makajaria | 9.84       | -5.25      | 3.00      |
| Aaduma     | 10.80      | -7.02      | 0.96      | Jiling    | 8.08       | -6.58      | 1.78      |
| Fazu Sen   | 6.71       | -5.02      | 1.81      | American Ration | 8.69       | -6.43      | 1.32      |
| Fazu Ngoi  | 7.13       | -6.89      | 0.91      | Kala Dhan | 7.16       | -5.67      | 0.62      |
| Beti Kalai | 7.09       | -5.44      | 0.44      | Turkey    | 9.23       | -2.20      | 0.21      |
| Saanki ka Phool | 9.67  | -6.78      | 1.88      | Saanki ka Phool | 8.84       | -4.54      | 1.29      |
| Bihar      | 10.36      | -7.46      | 1.54      | Maimi Ukhlao | 8.21       | -5.14      | 2.57      |
| Chikanswari Kabar | 8.72 | -0.93      | -0.80     | Mawiasha | 5.50       | -5.76      | 0.96      |
| Bangbu Jhum | 5.59     | -5.91      | 1.35      | Maimi Watoklok | 6.69       | -3.27      | -0.14     |
| Lal Biroin | 6.20       | -5.63      | 0.74      | Santimn Wakhum | 7.33       | -4.89      | 2.01      |
| DhalaBalam | 8.03       | -4.35      | -0.21     | Yang Dhan | 8.51       | -6.11      | 2.44      |
| Goria      | 7.77       | -5.69      | 1.91      | Badaya    | 6.95       | -5.67      | 0.62      |
| Bahadur    | 9.66       | -6.56      | 1.99      | Kanchali  | 9.36       | -5.46      | 3.25      |
| Maimiwatoklok Mandoori | 8.30 | -4.67      | 1.60      | Australian Biroin | 7.45       | -4.41      | 3.74      |
| Maimi Hungar | 5.88    | -4.59      | -0.51     | Assam Paisom | 11.59      | -6.51      | 1.21      |

https://doi.org/10.37992/2021.1204.151
Under, irrigated condition, PC1 was loaded with high coefficient values (irrespective of direction) of most of the grain yield-related traits, thus the genotypes reside towards the higher value or right side along with the PCA score I axis (X-axis) of the 3D scattered diagram (Fig 2) may be considered as promising landraces as far as grain yield is concerned. The finding is in confirmatory with Gour et al. (2017). Similarly, landraces settled towards the comparatively right side of the Y-axis may also be selected, as PC 2 was enriched with the high coefficient values of grain yield-related traits and grain yield itself. PC 3 was loaded with high factors of root and grain-related traits, thus the landraces, which plotted themselves, higher along the Z-axis also to be considered with due gravity. For convenience in the identification of landraces in the 3D scatter plot, we have cited the serial numbers of the landraces within the parenthesis behind the name of the landraces. Landraces viz., Galong, Garomalati, Chikanswarikabar, Turkey were plotted along the middle to the right of the X-axis and extreme right side of the Y-axis. Hence, these landraces may be selected as better yielders. Interestingly, the same genotypes were also found to be outliers, away from the centre cluster, which revealed the variability of the genotypes from the rest of the set. On the other side, landraces viz., Kalikhasa, Khasakasam and Kalijira plotted themselves high along the Z-axis and extreme right of the Y-axis away from the cluster, justifiably, they seem to be desirable landraces with significant values of yield and root related traits. Accordingly, these outlier landraces with significant values along the X, Y and Z-axis may be referred to as potential parents in further breeding programmes.

Under drought stress conditions, PC1 was contributed with high coefficient positive values of drought recovery index, vigour and root length, which are in agreement with the studies of Baghyalakshmi et al. (2016), Mishra et al. (2019) and Verma et al. (2019). Justifiably, the landraces plotted on the right side along the X-axis may be identified as a stable grain yielder with developed root morphology. Similar to the finding of Siahsar et al. (2010), positive values for traits like leaf rolling index and root: culm ratio were found to be dominant in PC 2, hence the landraces plotted on the right side of the Y-axis may have better drought escaping capacity. While the landraces plotted high along the Z-axis may be identified as high yield contributors under drought stress conditions as the PC 3 component was enriched with significant-high loading values of grain yield and other grain yield contributing characters. The 3D scattered diagram for drought stress depicts that landraces viz., Garomalati and Chikanswari Kabar, which were grouped under irrigated conditions, positioned themselves in the extreme left side of both X and Y axis but high along the Z-axis, away from the centroid. This position of the landraces for the Y and Z axis proved those as stable yielders with less expression of drought escaping traits under stress. Another two landraces viz., Tarkol and Maimi Taukha settled themselves in the extreme right or high-value side along the Y-axis and high along the Z-axis. They were also been found to be outliers from the central cluster of most of the landraces. Hence, they were identified as diverse but most promising landraces attributed with stable yielding and drought escaping quality under stress.

The 3D scatter plot position of the landraces Madoop and Turkey were also found to be significant as those landraces plotted high along the Z-axis and middle way along the X-axis, which justify the adaptability of those landraces under drought stress.
The sensitivity of the landraces under drought stress conditions was confirmed by both the first-order statistics of genetic variation and multivariate analysis of principal components under the study. Therefore, a greater possibility of improvement in the overall performance of the rice landraces through the selection of appropriate traits appears to be existed in drought stress conditions. Based on the genetic variation and principal component analysis, certain yield contributing and drought stress indicative traits viz., 100 seed weight, harvest index, grain yield per plant, the number of filled grains per plant, leaf rolling index, leaf drying index and root length found to be suitable discriminating factors towards screening of rice landraces for potential drought tolerance and yield stability under drought stress conditions. Further, the outlier promising landraces of the 3D scatter plot of PCA viz., Garomalati, Chikanswari Kabar, Turkey, Tarkol, Maimi Taukha and Madoop, could be taken into consideration while selecting suitable parents in future drought stress rice breeding programmes.

ACKNOWLEDGEMENT
Authors articulate honest gratitude to the Indian Council of Agricultural Research (ICAR) Complex for North Eastern Hilly Region, Tripura Centre for extending necessary support for the conduction of the study.

REFERENCES
Acharjee, S., Chakraborty, N.R. and Das, S.P. 2019. Exploration and agro-morphological evaluation of rice (Oryza sativa L.) land races grown under the upland ecosystem of Tripura. Journal of Pharmacognosy and Phytochemistry, 8: 2316-2323.

Agarwal, P., Parida, S.K., Raghuvanshi, S., Kapoor, S. P., Khurana, J.P. and Tyagi, A.K. 2016. Rice Improvement through genome-based functional analysis and molecular breeding in India. Rice, 9:1. [Cross Ref]

Ashkani, S., Rafii, M.Y. and Shabanimofrad, M. et al. 2015. Molecular breeding strategy and challenges towards improvement of blast disease resistance in rice crop. Frontiers in Plant Science, 6: 886. [Cross Ref]

Baghyalakshmi, K., Jeyaprakash, P., Ramchander, S., Raveendran, M. and Robin, S. 2016. Determination of stress indices for selection of superior genotypes under drought situation in rice (Oryza sativa L.). International Journal of Agricultural Science, 8(38):1791-1795. [Cross Ref]

Brejda, J.J., Moorman, T.B., Karlen, D.L. and Dao, T.H. 2000. Identification of regional soil quality factors and indicators I. central and southern high plains. Soil Science Society of America Journal, 64: 2115-2124. [Cross Ref]

Chandra, K., Gobu, R. and Sharma, R. 2017. Switch from climate prone to climate resilient agriculture: A Need in Current Scenario. Trends in Biosciences, 10(2):519-522.

Chuchert, S., Nualsri, C., Junsawang, N. and Soonsuwon, W. 2018. Genetic diversity, genetic variability, and path analysis for yield and its components in indigenous upland rice (Oryza sativa L. var. glutinosa). Songklanakarin Journal of Science and Technology, 40 (3): 609-616.
Foley, J.A., Ramankutty, N., Brauman, K.A., Cassidy, E.S., Gerber, J.S. et al. 2011. Solutions for a cultivated planet. *Nature*, **478** (7369):337–342. [Cross Ref]

Gour, L., Maurya, S.B., Koutu, G.K., Singh, S.K., Shukla, S.S. and Mishra, D.K. 2017. Characterization of rice (*Oryza sativa* L.) genotypes using principal component analysis including scree plot & rotated component matrix. *International Journal of Chemical Studies*, **5**(4):975-983.

Haider, Z., Khan, A.S. and Zia, S. 2012. Correlation and path coefficient analysis of yield components in rice (*Oryza sativa* L.) under simulated drought stress condition. *American-Eurasian Journal of Agricultural & Environmental Sciences*, **12**:100–104.

Haider, Z., Razaq, A., Mehboob, A., Rehman, S., Iqbal, A., Hussain, A., *et al.* 2013. Comparison of associations among yield and yield components in rice (*Oryzae sativa L.*) under simulated drought stress condition using multivariate statistics. *International Journal of Scientific and Engineering Research*, **4**(8): 329-340.

Hossain, S., Maksudul Haque, M.D. and Rahman, J. 2015. Genetic variability, correlation and path coefficient analysis of morphological traits in some extinct local aman rice (*Oryza sativa L.*). *Journal of Rice Research*, **3**:158. [Cross Ref]

Ibrahim, S.A., Rafii, M.Y., Ismail, M.R., Ramlee, S.I., Shamsudin, N.A.A., Ramli, A. *et al.* 2021. Evaluation of inherited resistance genes of bacterial leaf blight, blast and drought tolerance in improved rice lines. *Rice Science*, **28**(3): 1672-6308. [Cross Ref]

Johnson, H.W., Robinson, H.F. and Comstock R.E. 1955. Estimates of genetic and environmental variability in soybeans. *Agronomy Journal*, **47**(7):314–318. [Cross Ref]

Khan, A., Shah, S., Schail, A., Haleem, A., Maryam, M., Bumi, T. and Asad, M. 2019. Genetic variability, heritability and selection response for yield attributes in nine rice (*Oryza sativa L.*) genotypes. *Journal of Biodiversity Conservation and Bioresource Management*, **5**(1):55-60. [Cross Ref]

Kumar, S., Singh, N. K, Kumar, R. and Kumar, C. 2015. Genetic divergence analysis for morphophysiological traits of rice (*Oryza sativa L.*) under drought condition. *The Ecoscan*, **9**(1&2):653-658.

Maji, A.T. and Shaibu, A.A. 2012. Application of principal component analysis for rice germplasm characterization and evaluation. *Journal of Plant Breeding and Crop Science*, **4**:87–93. [Cross Ref]

Maurya, V., Prasad, R., Meen, S., Bisen, P., Loitongbam, B. and Rathi, S.R. 2018. Assessment of genetic variability, correlation and path analysis for yield and yield related traits in rice (*Oryza sativa L*). *International Journal of Agriculture, Environment and Biotechnology*, Special Issue: 935-940.

Meena, S., Kumar, R., Maurya, V., Bisen, P., Loitongbam, B., Rathi, S., Upadhyay, S., Singh, P.K. 2019. Estimation of variability parameters, correlation and path coefficient for yield and yield associated traits in rice (*Oryza sativa L*).. *International Journal of Agriculture, Environment and Biotechnology*, Special Issue : 867-873.

Mishra, S. S., Behera, P K, and Panda, D. 2019. Genotypic variability for drought tolerance-related morphophysiological traits among indigenous rice landraces of Jeypore tract of Odisha, India. *Journal of Crop Improvement*, **3**(2): 254-278. [Cross Ref]

Muthuramu, S. and Ragavan, T. 2020. Studies on indices and morphological traits for drought tolerance in rainfed rice (*Oryza sativa L*). *Electronic Journal of Plant Breeding*, **11**(01):1-5.

Nachimuthu, V.V., Robin, S., Sudhakar, D., Raveendran, M., Rajeswari, S. and Manonman S. 2014. Evaluation of rice genetic diversity and variability in a population panel by principal component analysis. *Indian Journal of Science and Technology*, **7**(10):1555-1562. [Cross Ref]

Nithya, N., Beena, R., Roy, S., Abida, P.S., Jayalekshmi, V.G., Viji, M.M. and Manju, R. V. 2020. Genetic variability, heritability, correlation coefficient and path analysis of morphophysiological and yield related traits of rice under drought stress. *Chemical Science Review and Letters*, **9** (33), 48-54. [Cross Ref]

Ojha, G.C., Sarawgi, A.K., Sharma, B. and Parikh, M. 2017. Principal component analysis of morphophysiological traits in rice germplasm accessions (*Oryza sativa L.*) under rainfed condition. *International Journal of Chemical Studies*, **5**(5):1875-1878.

Pandey, V. and Shukla, A. 2015. Acclimation and tolerance strategies of rice under drought stress. *Rice science*, **22**(4):147-161. [Cross Ref]

Panja, S., Garg, H., Mandi, V., Sarkar, K. and Bhattacharya, C. 2017. Effect of water stress at tillering stage on different morphological traits of rice (*Oryza sativa L.*) genotypes. *International Journal of Agricultural Science and Research*, **7**(3): 471-480. [Cross Ref]

Pavithra, S. and Vengadessan, V. 2020. Selection for drought tolerance in rice genotypes based on principal components and selection indices. *Electronic Journal of Plant Breeding*, **11**(04):1032-1036. [Cross Ref]
Perween, S., Kumar, A., Singh, S., Satyendra, Kumar, M. and Ranjan, R. 2020. Genetic variability parameters for yield and yield related traits in rice (Oryza sativa L.) under irrigated and drought stress condition. *International Journal of Current Microbiology and Applied Sciences*, 9:1137-1143. [Cross Ref]

Raji, A. A. 2002. Assessment of genetic diversity and heterotic relationships in African improved and local cassava (Manihot esculenta Crantz) germplasm. PhD thesis, University of Ibadan, Ibadan, Nigeria.

Serraj, R. and Atlin, G. 2008. Drought-Resistant Rice for Increased Rainfed Production and Poverty Alleviation: A Concept Note In: Serraj, R., Bennett, J. and Hardy, B., Eds. Drought Frontiers in Rice: Crop Improvement for Increased Rainfed Production, International Rice Research Institute, Los Baños, Philippines. p. 385-400. [Cross Ref]

Siahsar, B.A., Ganjali, S. and Allahdoo, M. 2010. Evaluation of drought tolerance indices and their relationship with grain yield of lentil lines in drought-stressed and irrigated environments. *Australian Journal of Basic and Applied Sciences*, 4:4336–4346.

Singh, S., Kumar, A.S., Kumar, M., Nahakpam, S., Sinha, S. et. al. 2018. Identification of drought tolerant rice (Oryza sativa L.) Genotypes using drought tolerance indices under normal and water stress condition. *International Journal of Current Microbiology and Applied Sciences*, 7: 4757-4766.

Standard Evaluation System (SES) for Rice .2002. International Rice Research Institute, Manila. IRRI http://www.knowledgebank.irri.org/images/docs/rice-standard-evaluation-system.pdf accessed on February, 22, 2015.

Tejaswini, K., Manukonda, S., Kumar, B., Puram, V., Mohammad, L.A. and Raju, S. 2018. Application of principal component analysis for rice F1 families characterization and evaluation. *Emergent Life Sciences Research*, 4: 72-84. [Cross Ref]

Tuhina-Khatun, M., Hanafi, M. M., Rafii, Y., Wong, M., Salleh, M. Y. et. al. 2015. Genetic variation, heritability, and diversity analysis of upland rice (Oryza sativa L.) genotypes based on quantitative traits. *BioMed Research International*, 2015.1–7. [Cross Ref]

Turin,M.T.S., Arifuzzaman,M. and Azad M.A.K. 2021. Screening of rice germplasm for drought stress tolerance using multivariate analysis. *Pakistan Journal of Botany*, 53(2): 393-400. [Cross Ref]

Verma, H., Borah, J.L. and Sarma, R.N. 2019. Variability assessment for root and drought tolerance traits and genetic diversity analysis of rice germplasm using SSR Markers. *Scientific Reports*, 9:16513. [Cross Ref]