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RESEARCH ARTICLE

# Genetic Characterization of Local Adaptable Rice Landraces of Nagaland, India

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Nagaland is one of the parts of the center of origin of rice, and has diversified rice landraces with unique cooking quality, taste, aroma and stress tolerance. In current study, landraces were evaluated for grain quality, yield and stress tolerance. Landraces Aongsho, Semmeki, Goyo Tsük and Moya Tsük showed higher yield as compared to Bhalum-3 check variety in the upland ecosystem. Whereas, Mehourü was the smallest landraces with a height of 65 cm. Among all the landraces under study, Yunghah, Goyo Tsük, Rükhatang and Vepvu Tsük were found strongly aromatic. While, Teke, Aongsho and Semmeki landrace showed moisture stress tolerance. Cluster and principal component analysis grouped the landraces into six distinct clusters. These landraces harbor the genes for various grain quality traits, drought tolerance and brown spot disease (*Cochliobolus miyabeanus*) tolerance. Superior landraces identified for grain quality, drought tolerance and brown spot can be utilized in future breeding programmes. This study may help in pre-breeding activities for development of improved varieties/hybrids for this agro-climatic zone.

**Key Words: Diversity analysis, Genetic variation, Grain quality, Rice landraces, Yield and stress tolerance**

## Introduction

Rice is the major staple food grain crop of the world and its demand is continuously increasing for this staple food crop. Around, 2 billion population (25.9%) of the world population did not have regular access to nutritious and sufficient food in 2019 (FAO, IFAD, UNICEF, WFP and WHO, 2020). Globally, rice productivity has to be increased at the rate of 1.0–1.2% annually beyond 2020 to feed the ever-growing population and keep prices affordable (IRRI, Africa rice and CIAT, 2013). Considering the immediate need for addressing food problem, replacement of poor yielder landraces is required by high yielding improved varieties for greater interest of food security and wellbeing of all nations' peoples. New improved rice varieties have high yield potential and tolerance for biotic and abiotic stresses as compared to landraces. This necessitates development of improved rice varieties by efficient utilization of landraces/germplasm to feed the ever-growing population.

Nagaland lies in the hills and mountains of northeastern part of East Himalayas region of India. This region is deeply dissected by the Doyang and Dikhu in the north, the Barak in the southwest, and the tributaries of the Chindwin River of Myanmar in the southeast. Agro-climatic conditions vary from tropical to sub-temperate. Farmers of Nagaland cultivate rice in diverse ecosystem ranging from upland rice in rainfed *jhum* fields to wetland terrace rice cultivation (WTRC) with varied altitudinal ranges of hills having varied temperature regimes. WTRC is practiced in hilly as well plain areas of Nagaland. About 43 % (91,250 ha) of the total rice cropped area in the state is under rainfed *jhum* cultivation (upland rice) with a production of 1,81,570 tonnes, whereas remaining 57% (1,20,750 ha) is under wetland terrace rice cultivation with a production of 342870 tonnes (Directorate of Economics and Statistics, Nagaland, 2018). In north eastern India, majority of farmers have been cultivating and conserved so many diverse rice landraces since time immemorial. In Nagaland alone, a total of 867 traditional 'landraces' of rice has been identified by the State Agriculture Research Station (SARS), Nagaland (Sharma, 2017). Nagaland is a rich source of rice genetic resources and these landraces were studied by researchers for grain

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quality and yield attributes only (Roy *et al.,* 2014;, Roy *et al.,* 2015; Zeliang *et al.,* 2020). Here, these landraceevolved after long years of acclimatization in local environments. These landracehave unique taste and texture after cooking, early maturity, highly adaptable to local climate and have significant tolerance to biotic and abiotic stress. The traditional landraces can serve as an important gene pool for valuable traits, for example, the upland landraces of rice present in northeast India are drought tolerance, photoperiod insensitivity, disease and insect tolerance, better root system, etc. (Travis *et al.,* 2015; Umakanth *et al.,* 2017; Verma *et al.,* 2019; Verma *et al.,* 2020). So, these landraces have different donor genes which can not only increase genetic diversity and genetic variability in pipelines varieties and hybrids while also lead to food security and sustainability.

Improvement in the grain yield is the prime objective of plant breeders for several decades, however grain and cooking quality attributes preference in a particular region determines the acceptance of a variety at larger scale. Under the regime of climate change climate resilient varieties are preferred by the farming community for cultivation. So, the best strategy is the improvement of limiting traits without compromising the farmers' preferred traits. In this regard, morphological characterization and clustering of traditional landraces on the basis of useful traits can helps in improvement of these local cultivars for limiting traits through different breeding methods (Kapoor *et al.,* 2019). Therefore, considering these points current study evaluated major landrace of Nagaland in local agro-climatic zones to measure the extent of genetic variation and genetic relationships between genotypes for grain quality, yield and stress tolerance for development of improved cultivars. If these are not conserved and characterized, they might be lost in time.

## Material and Methods

### *Experimental Materials*

A total of 38 rice landraces were collected along with passport data containing location, geographic coordinates from Longleng, Kohima, Wokha and Mokokchung districts of Nagaland during 2017-18 (Table 1 and Fig. 1). Seeds of these landraces along with two check varieties were directly sown at a spacing of 30 x 10 cm in Randomized Complete Block Design (RCBD) with three replications during *kharif* season (First fortnight of June to October) of 2018-19 at ICAR Research complex Nagaland Centre, research farm, Medziphema, Nagaland (25$^{o}$45'24"N, longitude of 93$^{o}$50'26"E, and altitude of 295 m above MSL). The soil of experimental field was sandy loam and acidic in reaction (pH 5.6). The landraces were cultivated under recommended agronomic practices including nutrient, pest and disease management practices. Recommended dose of N, P and K @ of 80, 60, 40 was applied. Half dose of N, full dose of P and K were applied basal through urea, Single Super Phosphate and Muriate of potash, respectively. Remaining half dose of nitrogen was applied as top dressing 45 days after sowing (DAS). This region received total rainfall of 1408 mm during 2018 of which maximum rainfall occurs during May to October month and experiences mean annual daily minimum and maximum temperature of 24°C and 36°C, respectively during the rice season.

### *Data Recording*

These 38 landraces along with Bhalum-3 as yield check and Pusa Sughandha-5 as aroma check variety were evaluated for yield traits such as tillers per plant (TP), plant height (cm) (PH), panicle length (cm) (PL), Grains per panicle (GPP), Spikelet Fertility (%) (SF), maturity duration (MD) and yield and grain quality traits such as grain length (mm) (GL), grain width (mm) (GW), grain shape (GS), grain colour, amylose content (AC), gel consistency (GC), gelatinization temperature (GT) and aroma and moisture stress and reaction to brown spot disease (*Cochliobolus miyabeanus*). Ten plants were randomly selected in each plot to record plant height, tillers per plant and grain quality traits. The seed yield (tonnes/ha) and duration were recorded on a plot basis of size 15×6m$^2$.

AC was determined as per Kaur *et al.* (2014) method. GT was assessed indirectly as the alkali spreading value of hulled kernels, as per the procedure of Zhang *et al.* (2020). Similarly, gel consistency was measured by the procedure of Zhang *et al.* (2020). GC was assessed as very hard (< 25 mm), hard (26–40 mm), medium (41–60 mm) or soft (61–100 mm) based on the length of the gel. The aroma of rice was determined as per the method described by Mishra *et al.* (2019) and scored as strongly scented (SS), mild scented (MS) and non-scented. Length and breadth of 10 milled rice kernels were measured using vernier caliper in replication and the average was calculated based on 3 replications. Grain shape was determined following the guidelines of the PPV&FRA (2007) classification.

**Table 1. Passport data with location of rice landraces collected from Nagaland**

| Name of landrace | Date of collection | Place of collection | Location (Geographic coordinate) | Type of seed | Grain Type | Grain color | Awn (Absent/ Present) | Flowering Duration |
|---|---|---|---|---|---|---|---|---|
| Dzükunya | 10/1/2017 | Khonoma Village (Kohima) | 25.650 N 94.033 E | Indica | LB | White | Present | Early |
| Rosholha | 10/1/2017 | Khonoma Village (Kohima) | 25.650 N 94.033 E | Indica | SB | Brown | Absent | Medium |
| Kemenya | 10/1/2017 | Khonoma Village (Kohima) | 25.650 N 94.033 E | Indica | LS | White | Absent | Early |
| Mekrilha kecha | 10/1/2017 | Khonoma Village (Kohima) | 25.650 N 94.033 E | Indica | LB | White | Absent | Early |
| Mekrilha ketei | 10/1/2017 | Khonoma Village (Kohima) | 25.650 N 94.033 E | Indica | LB | White | Absent | Medium |
| Khezharhi | 10/1/2017 | Khonoma Village (Kohima) | 25.650 N 94.033 E | Indica | LB | Brown | Present | Late |
| Nyari | 10/1/2017 | Khonoma Village (Kohima) | 25.650 N 94.033 E | Japonica | LB | White | Absent | Medium |
| Keteiu | 10/1/2017 | Chedema Village (Kohima) | 25.6792 N 94.1424 E | Japonica | SB | White | Absent | Late |
| Tsorenyü | 10/1/2017 | Chedema Village (Kohima) | 25.6792 N 94.1424 E | Indica | MS | Red | Present | Medium |
| Mehourü | 10/1/2017 | Chedema Village (Kohima) | 25.6792 N 94.1424 E | Indica | LB | Brown | Absent | Medium |
| Kemese-u | 10/1/2017 | Chedema Village (Kohima) | 25.6792 N 94.1424 E | Japonica | SB | White | Absent | Late |
| Kemeluo-ü | 10/1/2017 | Chedema Village (Kohima) | 25.6792 N 94.1424 E | Indica | SB | White | Absent | Late |
| Khenulha | 10/1/2017 | Chedema Village (Kohima) | 25.6792 N 94.1424 E | Indica | LB | White | Absent | Early |
| Thevürü | 10/1/2017 | Chedema Village (Kohima) | 25.6792 N 94.1424 E | Indica | SB | Brown | Absent | Medium |
| Boyoh | 10/14/2017 | Dungkhao Village (Longleng) | 26.5145 N 94.8347 E | Indica | SB | White | Absent | Early |
| Doulong | 10/14/2017 | Hukpang Village (Longleng) | 26.4692 N 94.8049 E | Indica | SB | White | Absent | Early |
| Shangha | 10/14/2017 | Hukpang Village (Longleng) | 26.4692 N 94.8049 E | Indica | SB | Brown | Absent | Early |
| Hahhak | 10/13/2017 | Nian Village (Longleng) | 26.5934 N 94.8614 E | Indica | SB | Brown | Absent | Medium |
| Shuphok | 10/13/2017 | Nian Village (Longleng) | 26.5934 N 94.8614 E | Indica | SB | White | Absent | Early |
| Angja | 10/13/2017 | Tangha Village (Longleng) | 26.4902 N 94.8197 E | Indica | SB | Brown | Absent | Early |
| Aongsho | 10/13/2017 | Tangha Village (Longleng) | 26.4902 N 94.8197 E | Indica | SB | White | Absent | Early |
| Maibo | 10/13/2017 | Tangha Village (Longleng) | 26.4902 N 94.8197 E | Indica | SB | Red | Absent | Early |
| Nukjau Nyakla | 10/13/2017 | Tangha Village (Longleng) | 26.4902 N 94.8197 E | Indica | SB | Brown | Absent | Early |
| Nukjau Shola | 10/13/2017 | Tangha Village (Longleng) | 26.4902 N 94.8197 E | Indica | MS | White | Absent | Early |
| Vam | 10/13/2017 | Tangha Village (Longleng) | 26.4902 N 94.8197 E | Japonica | SB | Brown | Absent | Early |
| Yunghah | 10/13/2017 | Tangha Village (Longleng) | 26.4902 N 94.8197 E | Indica | LB | White | Absent | Early |

| Name of landrace | Date of collection | Place of collection | Location (Geographic coordinate) | Type of seed | Grain Type | Grain color | Awn (Absent/ Present) | Flowering Duration |
|---|---|---|---|---|---|---|---|---|
| Mepongchuket Masu | 10/16/2017 | Khensa Village (Mokokchung) | 26.3478 N 94.4889 E | Japonica | SB | Brown | Absent | Medium |
| Semmeki | 10/16/2017 | Khensa Village (Mokokchung) | 26.3478 N 94.4889 E | Indica | LB | White | Absent | Medium |
| Mapok Tanakla | 10/16/2017 | Longjang Village (Mokokchung) | 26.4519 N 94.5483 E | Japonica | LB | Brown | Present | |
| Goyo Tsük | 10/16/2017 | Longkhum Village (Mokokchung) | 26.2611 N 94.4124 E | Indica | LB | White | Absent | Early |
| Moya Maso | 10/16/2017 | Longkhum Village (Mokokchung) | 26.2611 N 94.4124 E | Indica | LB | Red | Present | Early |
| Moya Tsük | 10/16/2017 | Longkhum Village (Mokokchung) | 26.2611 N 94.4124 E | Indica | LB | White | Absent | Medium |
| Teke | 10/16/2017 | Longkhum Village (Mokokchung) | 26.2611 N 94.4124 E | Indica | SB | Brown | Absent | Early |
| Motso Tsuk Wokha | 9/30/2017 | Wokha Town | 26.0915 N 94.2592 E | Indica | LB | White | Absent | Early |
| Rukhatang | 10/30/2017 | Wokha Town | 26.0915N 94.2592E | Indica | SB | White | Absent | Medium |
| Vapvu Tsük | 10/30/2017 | Sanis Village, Wokha | 26.1972N 94.1931E | Indica | SB | White | Absent | Early |
| Tsuktsa | 1/20/2017 | Dibuia Village (Mokokchung) | 26.526 N 94.500 E | Indica | SB | White | Absent | Early |
| Zu Tsük | 10/30/2017 | Wokha Town | 26.091N 94.259E | Indica | LS | White | Present | Medium |

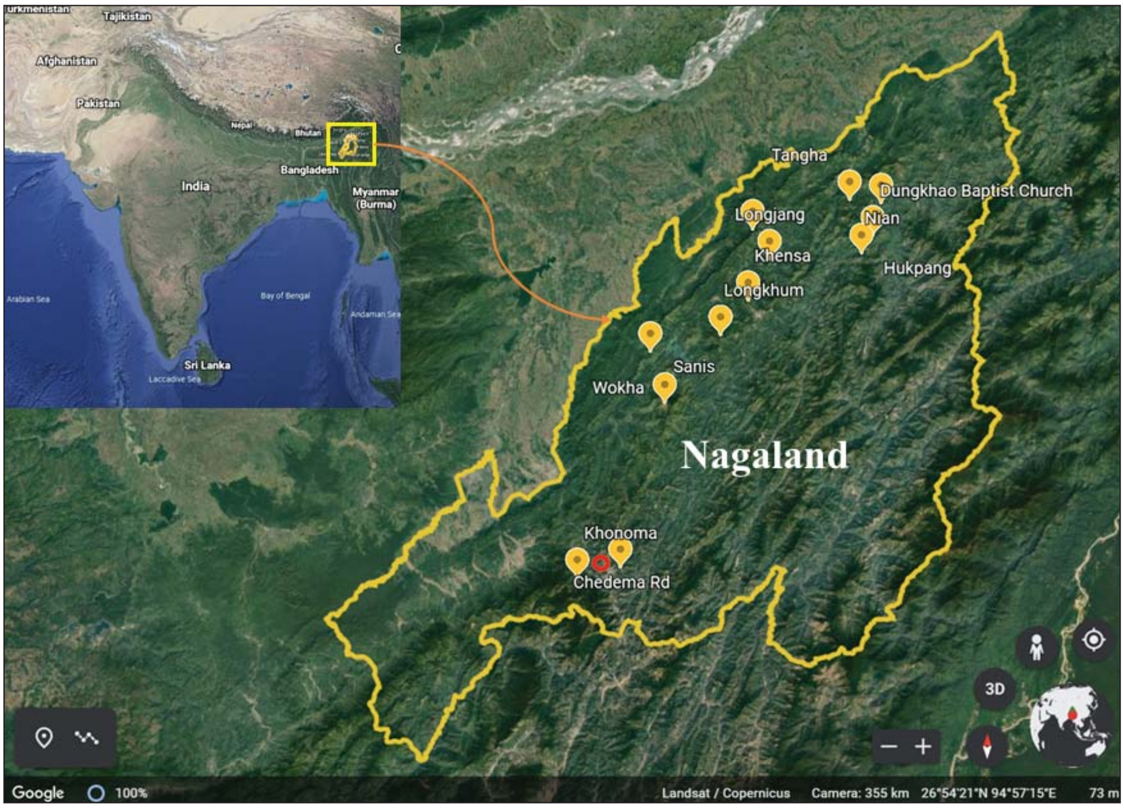


**Fig. 1. Areas surveyed during rice germplasm collection in Nagaland**

Reproductive drought tolerance was recorded based on leaf rolling score and drought recovery rate at 60 days after withdrawal of life-saving irrigation when the soil moisture content was around 6-8% (W/V) using standard evaluation system for rice (Verma *et al.*, 2019). Bhalum-3 was used as an upland check variety. Soil moisture content was determined at three days interval by the gravimetric method (Pask and Reynolds, 2013). The 38 landraces were evaluated for disease reactions against the brown spot of rice using a standard disease rating scale of IRRI (2002). The percentage disease index (PDI) was calculated using the formula given by Khan *et al.* (2014).

### *Statistical Analysis*

The agronomic yield data were subjected to analysis of variance and the genetic parameters such as phenotypic coefficient of variation (PCV) and genotypic coefficient of variation (GCV), heritability in broad-sense (h2), and genetic advance as 5 percent of mean (genetic gain) were worked out as suggested by Falconer (1981). Correlation coefficients were calculated to assess relationship among traits. The mean data were used to determine the phenotypic diversity among the genotypes using principal component analysis by the R package FactoMineR (Le *et al.*, 2008) factoextra (Kassambara and Mundt, 2017) and clustering based on the algorithm of Ward's method (Galili, 2015).

## Results & Discussion

Presently, global focus is to develop climate-resilient improved varieties having high yield potential, good cooking quality. In the present study 40 genotypes were evaluated for grain quality, yield and stress tolerant traits. Analysis of variance revealed significant differences among the genotypes for all traits measured in the study (Table 2). Roy *et al.* (2014) also reported considerable variation in agronomic and grain characteristics of Nagaland rice germplasm.

Descriptive statistics for different agro-morphological, grain quality along with stress tolerance traits are presented in Supplementary Table S1. Results revealed that Mehourü was the shortest landrace (65 cm) and Nukjau Shola was the tallest (180 cm). The negative skewness of plant height indicated that most of the landraces were tall. In the present study majority of landraces were tall, as farmers have selected tall landraces for the upland ecosystem to avoid competition with weeds. The tiller numbers per plant varied from 3 to 8 with a mean value of 4.88. The maximum number of tillers was observed in Mekrilhakecha (8 tillers) followed by Suphok (7). Upland rice usually has low numbers of tillers per plant (IRRI, 1975), in the present study also the majority of landraces have 3-4 numbers of tillers per plant. Landraces Aongsho (4.5 t/ha), Semmeki (4.2 t/ha), Goyo Tsük (4.3 t/ha) Moya Tsük (4.2 t/ha) and Moya Maso (3.9 t/ha) also showed significantly high yield compared to check variety Bhalum-3 (3.8 t/ha). Yield per plant was higher as compared to other studies (Rao *et al.*, 2018) this might be attributed to genotypic, cultivation management practices and adaptability (Mellidou *et al.*, 2020).

Grain quality in rice is determined by physical appearance, cooking and eating quality and nutritional quality (Fitzerald *et al.*, 2009; Verma *et al.*, 2015a; Sharma & Khanna 2019). In the present study, four distinct types of grain shape were observed. The maximum number of genotypes were short bold followed by long bold. It indicates that for daily consumptions Nagas prefer to eat bold rice grains and occasionally they use long slender and medium slender. Roy *et al*. (2015) also reported short and long bold grain shapes in the landraces of Nagaland. Pathak *et al*. (2016) reported the

**Table 2. Analysis of variance for yield and yield attributes**

| Source of Variation | df | Mean square | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Tiller/plant | Plant Height | Panicle length | Grains/panicle | Spikelet fertility | Duration | Yield |
| Genotypes | 39 | 5.17* | 2977.60* | 25.61* | 13842.14* | 309.93* | 451.46* | 231.34* |
| Replication | 2 | 0.13 | 11.80 | 1.38 | 63.60 | 10.67 | 4.18 | 5.63 |
| Error | 78 | 0.77 | 10.82 | 2.67 | 17.02 | 5.67 | 8.16 | 3.75 |
| CV | | 18.02 | 2.47 | 6.72 | 3.09 | 2.79 | 2.37 | 6.32 |

*Significant at 1%

**Supplementary Information: Supplementary table or figure mentioned in the article are available in the online version.*

majority of *sali* rice of Assam has long bold grain shape. Among the landraces, 11 brown and 4 red rice kernels were observed. Brown rice is consumed as piping hot and served during special festivals. Red rice is a good source of iron (Fe) and magnesium (Mg), therefore it is good food for pregnant women and the populace suffering from iron deficiency and heart patients (Raghuvanshi *et al.,* 2017; Priya *et al.,* 2019).

The cooking and organoleptic properties of rice grain are determined by AC, GC and GT (Rani *et al.,* 2011; Sharma and Khanna, 2019). AC is the major determinant of rice eating and cooking quality (Juliano, 1993). AC determines the hardiness, cohesiveness, tenderness and texture of cooked rice (Kumar & Kush, 1986; Sabouri, 2009; Verma *et al.,* 2015b). Rice varieties with very low AC (3-9%) become very sticky, moist and tender on cooking, whereas varieties with intermediate AC (20-25%) become fluffy, soft, moist and tender and those with high AC (>25%) becomes fluffy, dry and harden on cooling (Kumar & Kush, 1986). The AC varied from 0.64% in 'MepongchuketMasu' to 16% in Shuphok and Zu Tsuk. Among the 38 landraces, majority of the landraces (23) were in low amylose class (10-19%) followed by 13 landraces with very low amylose class (3-9%), whereas, Mepongchuket Masu and Vam genotypes have very low AC (< 3%). Thongbam *et al.* (2012) evaluated 18 traditional landraces of Tripura and revealed that the majority of them have low amylose content (<20%) and few of them have intermediate amylose content (20-25%). In the *Sali* rice of Assam, AC varied from very low to very high and the majority of them have low amylose content (Verma *et al.,* 2015b; Pathak *et al.,* 2016). The famous 'Chakhao' aromatic rice of Manipur has low amylose content (2-8%) (Shijagurumayum *et al.,* 2018). Amylose content of Sikkim rice landraces varied from 15 to 26%, and the majority of them have intermediate amylose content (Kapoor *et al.,* 2019).

Gel consistency of rice varied from-soft to hard (Tang *et al.,* 1991). Cooked rice with soft gel consistency cooks tender and remain soft upon cooling for long hours as compared to rice with hard gel consistency (Tang *et al.,* 1991). Gel consistency varied from 23.0 mm (hard) in Shuphok to 110 mm (soft) in 'Mekrilhakecha'. Kapoor *et al.* (2020) reported the presence of soft to hard GC in Sikkim rice and the majority of Sikkim rice has medium-soft GC, whereas the majority of Assam rice has soft GC (Verma *et al.,* 2015b; Pathak *et al.,* 2016). Based on alkaline spreading value, six distinct classes of GT were recorded among the landraces. Intermediate GT (69-74$^{o}$C) was present in 10 landraces. Rice with soft to medium gel consistency (GC), intermediate amylose content (AC) and intermediate gelatinization temperature (GT) are preferred by most consumers (Rohilla *et al.,* 2000; Pang *et al.,* 2016).

Among all the landraces, Yunghah, Goyo Tsük, Rükhatang and Vepvu Tsük have strong aroma and 9 of them have mild aroma. Genotypes Goyo Tsük, Yunghah, Kemenya, Zu Tsuk, Rukhatang and Vapvu Tsuk are popular aromatic rice of Nagaland.These aromatic rices are used staple food and served as special rice items such as deserts, during the festive occasion and religious and marriage ceremonies. Aromatic landraces of Nagaland have short bold, long bold and the long slender grain shape. Whereas the aromatic rice of Bangladesh generally has short bold and medium bold grain shape (Islam *et al.,* 2016). The basmati rice of north-western Indo-Gangetic region of India has extra-long slender grains, pleasant aroma, highlinear grain elongation on cooking (Kaur *et al.,* 2011; Singh *et al.,* 2018).

Based on leaf rolling and drought score Teke, Aongsho and Semmeki genotypes were reproductive moisture stress-tolerant. The *Ahu* rice of Assam, north-eastern India cultivated from March to June are also drought tolerant. Most of the moisture stress-tolerant genotypes were identified from the north-eastern rice germplasm (Torres *et al.,* 2013; Rahman *et al.,* 2016; Verma *et al.,* 2019).

Brown spot is the major disease of upland rice and severely reduces productivity. The result of screened genotypes against brown spot disease is presented in supplementary Table S1. The occurrence of brown spot severity among the genotypes ranged from 5.50 to 76.10%. The maximum brown spot disease index of 63.5% was observed in 'Maibo', whereas the least disease index was observed in Nyari (4.5%). Based on the disease reaction, again evaluated genotypes were categorized into different classes (online supplementary Table S2). Out of 40 genotypes, none of the genotypes were immune, whereas only one genotype Nyari showed resistance against the brown spot. It was observed that under field conditions, the severity of brown spot disease was fairly significant. Similarly, the 15 genotypes showed moderate resistance, whereas 8 genotypes showed high susceptibility to brown spot disease. In other studies, also variation for the brown spot was reported and resistant

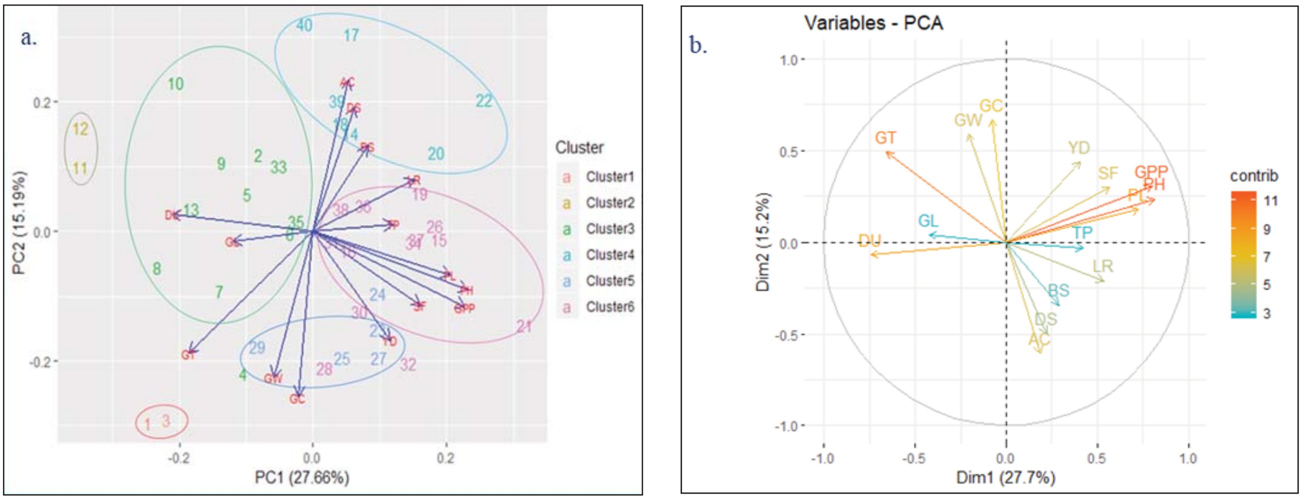


**Fig. 2 a. Grouping of landraces based on first two principal components. b. Biplot of 40 rice landraces for PC1 and PC2, arrows show the magnitude and direction of the trait in PC1and PC2**

genotypes have been identified (Chauhan *et al.*, 2000; Alam *et al.*, 2016). In the present study, brown spot disease severity ranged from 6 to 76%. Whereas, Liu *et al.* (2007) reported 0-80 % of the brown spot severity in rice. These differences in disease severity might be attributed to differences in genotypes' capacity to resist and weather conditions. The level of disease severity in the host plant mainly depends on the interaction between the R genes in the host and pathogenicity factors of a pathogen.

Various variability parameters studied are presented in the Table 3. The maximum variation among all the traits was observed in grains per panicle, ranging from 34 in Nyari to 293 in Mepongchuket Masu. Whereas The low degree of variation among the landraces was observed for maturity duration ranging from 95 days in Maibo to 150 days in Kemeluo-u with a mean of 121 days. The difference between GCV and PCV was less which indicate the high correspondence between phenotype and genotype. Large variation, high heritability coupled with high genetic advance as per cent of mean was recorded for grains per panicle which indicates preponderance of additive gene action and can be improved through simple selection. Heritability in combination with genetic advance would give a more reliable index of selection value (Pathak *et al.*, 2016). The high heritability estimates along with low genetic advance indicates that non-additive type of gene action and genotype-environment interaction plays a significant role in the expression of the traits. Thus, the characters showing high heritability along with moderate or low genetic advance could be improved by intermating the superior genotypes of segregating population developed from combination breeding (Samadia, 2005; Pathak *et al.*, 2016).

In the present study, genotypic correlation coefficients between all pairs of combinations for grain quality, yield attributes and stress-tolerant parameters are presented in Table 4. A positive correlation between plant height and panicle length suggests that the selection of tall landraces might result in increased panicle length and a high number of grains per panicle. Similar associations were reported by Sohrabi *et al.* (2012). A negative correlation between maturity duration and spikelet fertility indicates that a long duration of maturity in upland landraces results in poor yields. Over a period of time, it has been observed that monsoon withdraws by the end of September or first fortnight of October, therefore late-maturing landraces faces moisture stress problem and results in chaffy grains and poor yields.

### *PCA Analysis*

The PCA biplot diagram (Fig. 2a) between PC 1 and PC2 explained the distribution and the nature of diversity for both variables and the genotypes. The loadings depicts that almost all the genotypes and variables have high degree of variation. PCA analysis revealed that the first principle component contributed to 27.66% of variation to the total variation in the present germplasm set with an eigenvalue of 4.2 and the second principal component accounted for additional 15.19% of contribution to total variation with an eigenvalue of 2.3 (Fig. 2b). These two principle components indicated that grain number per

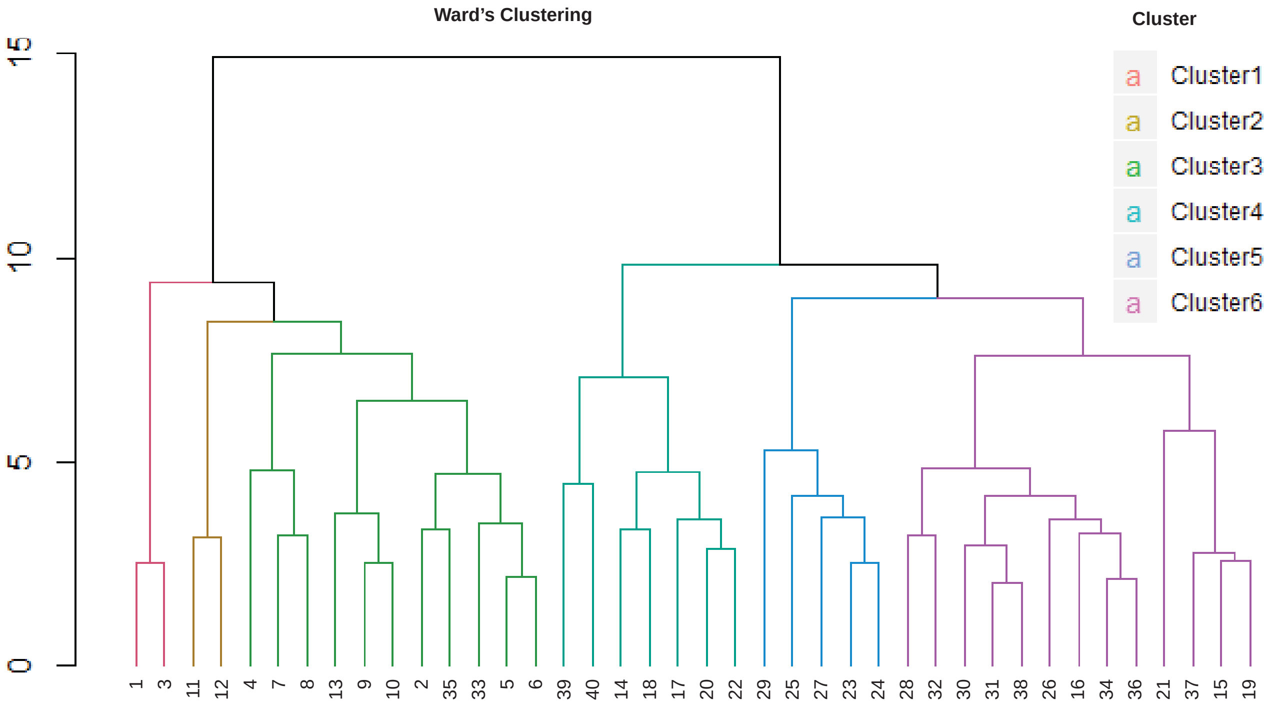


**Fig. 3. Grouping of landraces for yield attributes, grain quality and stress tolerance characteristics using Ward's clustering method**

**Table 3. Genetic variability of grain quality, yield attributes and stress tolerance in rice**

| Trait | Range | | Mean±SEm | GCV | PCV | Heritability in broad sense | GA as 5 % of mean |
|---|---|---|---|---|---|---|---|
| | Min. | Max. | | | | | |
| TP | 3.0 | 8.0 | 4.9±0.50 | 24.8 | 30.6 | 0.65 | 41.3 |
| PH | 65.2 | 179.6 | 133.1±1.89 | 23.6 | 23.7 | 0.98 | 48.4 |
| PL | 19.2 | 29.4 | 24.3±0.94 | 11.4 | 11.4 | 0.74 | 20.2 |
| GPP | 34.3 | 293.5 | 133.1±2.38 | 51.0 | 51.1 | 0.98 | 104.9 |
| SF | 55.2 | 98.6 | 85.1±1.37 | 11.8 | 12.2 | 0.94 | 23.7 |
| MD | 94.6 | 149.7 | 120.5±1.65 | 10.1 | 10.4 | 0.94 | 20.2 |
| Yield | 1.5 | 4.5 | 3.07±0.11 | 28.4 | 29.1 | 0.95 | 57.1 |
| GL | 4.1 | 9.0 | 5.92±0.11 | 16.7 | 17.0 | 0.96 | 33.8 |
| GW | 2.0 | 3.5 | 2.7±0.13 | 13.5 | 16.0 | 0.71 | 23.5 |
| AC | 0.6 | 22.0 | 10.9±0.89 | 40.8 | 43.1 | 0.89 | 79.5 |
| GC | 24.6 | 107.0 | 46.3±2.05 | 43.7 | 44.4 | 0.96 | 88.6 |
| GT | 1.0 | 6.0 | 2.7±0.15 | 54.0 | 54.8 | 0.97 | 109.6 |
| DS | 1.2 | 5.6 | 4.9±0.10 | 21.0 | 21.2 | 0.98 | 42.8 |
| LR | 1.3 | 11.0 | 6.9±0.03 | 29.3 | 30.2 | 0.94 | 58.6 |
| BS (PDI) | 5.5 | 76.1 | 33.2±1.54 | 51.6 | 52.2 | 0.97 | 104.9 |

TP: Tillers per plant, PH: Plant height (cm), PL: Panicle length (cm), GPP: Grains per panicle, SF: Spikelet fertility, MD: Maturity duration, GL: Grain length (mm), GW: Grain width (mm), AC: Amylose content (%), GC: Gel consistency (mm), GT: Gelatinization temperature, DS: Drought score, LR: leaf rolling score, BS (PDI): Brown spot (percent disease index)

**Table 4. Correlation coefficient at genotypic (above diagonal) and phenotypic level (below diagonal) among various yield and grain quality traits**

| Traits | TP | PH | PL | GPP | SF | MD | Yield | GL | GW | AC | GC | GT |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TP | 1 | 0.374 | 0.214 | 0.167 | 0.257 | -0.052 | 0.259 | -0.255 | -0.382 | 0.073 | 0.128 | -0.224 |
| PH | 0.308 | 1 | 0.679** | 0.626** | 0.460 | -0.568 | 0.338 | -0.311 | -0.194 | -0.055 | 0.211 | -0.340 |
| PL | 0.143 | 0.584** | 1 | 0.566 | 0.393 | -0.531 | 0.360 | -0.294 | -0.135 | -0.065 | 0.107 | -0.479 |
| GPP | 0.128 | 0.621** | 0.484 | 1 | 0.674** | -0.564 | 0.438 | -0.125 | 0.196 | 0.048 | -0.044 | -0.265 |
| SF | 0.214 | 0.444 | 0.323 | 0.656** | 1 | -0.605** | 0.467 | -0.098 | 0.214 | 0.054 | -0.051 | -0.286 |
| MD | -0.052 | -0.551 | -0.429 | -0.548 | -0.578** | 1 | -0.144 | 0.234 | -0.098 | -0.174 | 0.133 | 0.465 |
| Yield | 0.211 | 0.330 | 0.298 | 0.427 | 0.441 | -0.144 | 1 | 0.049 | 0.040 | -0.094 | 0.149 | -0.114 |
| GL | -0.199 | -0.303 | -0.247 | -0.123 | -0.090 | 0.228 | 0.052 | 1 | 0.179 | 0.206 | 0.111 | 0.201 |
| GW | -0.327 | -0.160 | -0.080 | 0.164 | 0.171 | -0.064 | 0.047 | 0.1381 | 1 | -0.172 | 0.202 | 0.318 |
| AC | 0.081 | -0.050 | -0.015 | 0.047 | 0.044 | -0.152 | -0.084 | 0.1980 | -0.118 | 1 | -0.540 | -0.423 |
| GC | 0.101 | 0.204 | 0.081 | -0.041 | -0.044 | 0.131 | 0.141 | 0.1052 | 0.160 | -0.506 | 1 | 0.384 |
| GT | -0.166 | -0.331 | -0.417 | -0.261 | -0.272 | 0.445 | -0.105 | 0.1986 | 0.251 | -0.394 | 0.374 | 1 |

**Significant at 5%

TP: Tillers per plant, PH: Plant height (cm), PL: Panicle length (cm), GPP: Grains per panicle, SF: Spikelet fertility, MD: Maturity duration, GL: Grain length (mm), GW: Grain width (mm), AC: Amylose content (%), GC: Gel consistency (mm), GT: Gelatinization temperature

plant, plant height, maturity duration, panicle length, GT, GC, AC, spikelet fertility and yield traits were the main discriminatory traits (Fig 1).

In the present study, the first two PC contributed to 43% to the total variation whereas in other studies the first two PC contributed below 34% to the total variation (Gour *et al.*, 2017; Roy *et al.*, 2014). While Asante *et al.*, (2019) reported that the first two principal components explained 57 % of the total variation. In the present study, genetic variation and PCA analysis revealed that grain number per plant, plant height, maturity duration, panicle length, GT, GC, AC, spikelet fertility and yield govern the main diversity. Asante *et al*. (2019) reported Kernel length-to-width ratio, kernel length, days to flowering, and yield were the main principle discriminatory characteristics.

### *Cluster Analysis*

The set of 40 rice landraces was grouped into six different clusters based on Ward's clustering and showed similar results as of PCA. Clusters I and II each comprised of two genotypes. Cluster III, IV, V and VI comprised 11, 7, 5 and 13 genotypes respectively (Fig. 3). Cluster I consist of Dzukunya and Kemenya which showed moisture stress-tolerance. Cluster II consists of Kemese-u and Kemeluo, these two genotypes are famous as Nagaland special rice among 'Angami' community because of their good taste and cooking qualities. Genotypes of cluster III were moderate to highly tolerant for the brown spot disease. Among cluster III landraces, the Nyari genotype showed a resistant reaction against brown spot pathogen. The cluster IV genotypes were poor yielder. Genotypes of cluster V were tall and also have low AC and soft GC. Genotypes of cluster VI showed a high number of grains per panicle, spikelet fertility, high tillering ability and high yield potential. The five genotypes of cluster VI Aongsho, Semmeki, Moya Tsük, Goyo Tsük and Yunghah were the best genotypes for yield and yield attributes. These genotypes were the best genotypes of *Phom*, *Ao* and *Lotha* tribes for yield. Cluster analysis revealed that traditional landraces of *Angami* tribe were distinct from *Ao*, *Phom* and *Lotha* tribes. Grouping patterns in cluster analysis was not according to their geographical origin. A similar trend was also reported in other studies (Roy *et al.*, 2014; Mbanjo *et al.*, 2019).

These multivariate analyses revealed that traditional landraces have wide genetic variation for grain quality, yield, yield attributes, drought tolerance and brown spot resistance traits. PCA as well Ward's cluster analysis were equally effective in revealing the relationship among the rice germplasm (Roy *et al.*, 2016; Mbanjo *et al.*, 2019).

All this analysis suggests that hybridization between Aongsho and Kemese-u would be effective for development of short duration high yielding and moderately drought tolerant cultivar with acceptable grain and cooking quality. Hybridization between Aongsho and Teke would results in trailing of early maturing, drought tolerant genotype with high yield. Crossing of Nyari with Aonsho may help in development of brown spot tolerant improved variety.

## Conclusion

These diversified landraces are a reservoir of important genes/alleles for yield, quality traits such as taste, glutinous trait, aroma and grains shape; and abiotic and biotic stresses. These landraces can be used as principal foundation material in breeding programmes for the development of new improved varieties. These landraces must be collected and conserved using *in-situ* as well as *ex-situ* conservation methods for their effective use in future crop improvement programmes. Considering the uniqueness of such landraces, it is of paramount importance to conserve such resources wither in-situ or ex-situ. The utilization of such a rich gene pool in the breeding programmes will help in the development of suitable rice varieties.

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*Supplementary Table or Figure mentioned in the article are available in the online version.

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