Yield Stability and Genotype x Environment Interactions of Upland Rice in Altitudinal Gradient in Madagascar

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Suchit Prasad Shrestha[a], Folkard Asch[a], Holger Brueck[a], Julie Dusserre[b] and Alain Ramanantsoanirina[c]

[a] University of Hohenheim, Dept. of Plant Production and Agroecology in the Tropics and Subtropics, Germany
[b] CIRAD / URP SCRID, Madagascar
[c] National Centre for Applied Research and Rural Development (FOFIFA), Madagascar

Introduction

The growing demand for rice and the increasing pressure on irrigated land in Madagascar is strengthening efforts to developing upland rice systems. Actual yield is below its potential yield in farmers' field due to biotic and abiotic stresses. In higher altitude, specific cold tolerant upland rice genotypes are planted due to temperature constraints. According to climate change prediction, it is easy to expect positive effects on upland rice production systems in high altitude. The rise in temperature will increase productivity mainly via reduced spikelet sterility, considering that other climatic parameters such as rainfall patterns will not have adverse effects. Climate change will increase the number of genotypes which can be cultivated in upland areas; however genotypes still will be sensitive to weather experienced during sensitive physiological and phenological periods. To avoid negative impacts, crop adaptation strategies are needed in terms of varietal development and crop management. Grain yield depends on genotype, environment and management practices and their interaction with each other (Messina et al., 2009). Under the same management conditions, variation in grain yield is principally explained by the effects of genotype and environment (Dingkuhn et al., 2006). Interaction between these two explanatory variables gives insight for identifying genotype suitable for specific environments. The objective of this study was to compare contrasting genotypes which cover a broad range of phenological and physiological traits across a temperature gradient in Madagascar in order to quantify the extent of genotype by environment interaction and to characterize yield stability and adaptability across different environments.

Material and Methods

The experiment was designed in split plot with sowing dates as main plots and ten upland rice genotypes (G1 to G10 as shown in Table 1) as sub-plots arranged in a randomized complete block design. Three locations differing in altitude along temperature gradient in Madagascar (Andranomanelatra, 1625 m asl; Ivory, 965 m asl and Ankepaka, 25 m asl) were selected for field trials with two sowing dates (early and late season sowing, one month apart) in two consecutive years (2008/09 and 2009/10), thus creating twelve different rice growing environments (E1 to E12). Experimental fields were located in high altitude (HA) at 19°46'45.3" S and 47°06'24.5"

E, mid altitude (MA) at 19°33'16.8" S and 46°25'29.1" E and low altitude (LA) at 22°11'31.6" S and 47°52'32.7" E. During cropping season, average minimum air temperature (T_{min}) and maximum air temperature (T_{max}) were 13°C and 19°C respectively with 1300 mm of total rainfall in HA location (Fig. 1). In MA location, average T_{min} was 19°C and average T_{max} was 24°C with 1200 mm of total rainfall. LA location had the highest total rainfall (2100 mm) with average T_{min} 19°C and T_{max} 27°C. HA location had clay soil of pH 4.5, MA location had clay loam soil of pH 4.5 and LA location had silt loam soil of pH 4.0 which were dominant in upland rice ecosystem in Madagascar. Five plants per hill were maintained at tillering stage due to high mortality. Hill to hill spacing was 20 cm x 20 cm in all locations. Complex fertilizer (11:22:16 N-P-K) at the rate of 300 kg ha^{-1}, dolomite 500 kg ha^{-1} and FYM 5 t ha^{-1} was applied as basal dose at the time of sowing. Top dressing was done with urea (46 % N) at the rate of 35 kg ha^{-1} at first weeding and 30 kg ha^{-1} at second weeding. Grain yield was obtained from the central hills excluding 2 border lines. Yield stability analysis was done according to Finlay and Wilkinson, 1963. The result of AMMI model analysis (Yan et al., 2007; Gauch Jr et al., 2008) was shown in the biplot.

Table 1. Characteristics of genotypes used in the study. Abbreviations: sat, *Oryza sativa*; trop, tropical; temp, temperate; isc, interspecific crosses; imp, improved; trad, traditional.

Code	Genotypes	Sub-species	Specific traits	Growing altitude
G1	B 22	*O. Sativa* (tropical japonica)	Plasticity (aspect)	Mid-Low
G2	Botramaintso	*O. Sativa* (tropical japonica)	Vigor growth	Mid
G3	Chomrong	*O. Sativa* (temperate japonica)	Cold tolerant	High
G4	FOFIFA 161	*O. Sativa* (tropical japonica)	Cold tolerant	High
G5	FOFIFA 167	*O. Sativa* (tropical japonica)	Cold tolerant	High
G6	FOFIFA 172	*O. Sativa* (tropical japonica)	Cold tolerant	High
G7	IRAT 112	*O. Sativa* (tropical japonica)	Plasticity (aspect)	Mid
G8	Nerica 4	*O. Glaberrima* x *O. Sativa* (interspecific crosses)	Stay green	Mid
G9	Primavera	*O. Sativa* (tropical japonica)	Grain quality	Mid-Low
G10	WAB 878	*O. Glaberrima* x *O. Sativa japonica* (interspecific crosses)	Vigor growth	Mid

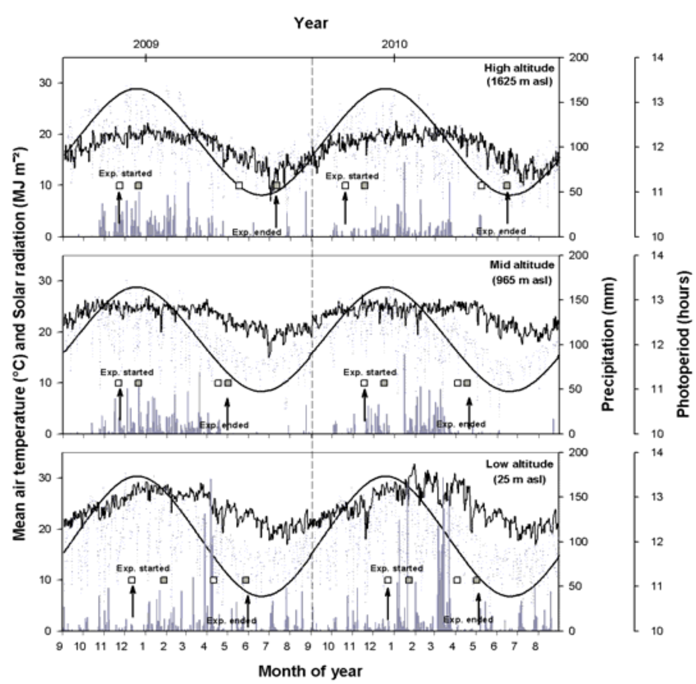

Figure 1. Daily weather patterns of two experimented years (from Sept 2008 to Aug 2010) of three altitudinal gradient locations in Madagascar. Solid zigzag lines are 24 hours mean air temperature (°C), smooth solid lines are photoperiod (h), dotted gray zigzag lines are solar radiation (MJ m^{-2} d^{-1}) and vertical gray bars depicts total daily precipitation (mm). White square boxes indicate start and end of the early sowing date and the gray square boxes indicate start and end of the late sowing date.

Results and Discussion

Based on the linear regression between genotypic and environmental mean yields (Fig. 2a), regression coefficients of each genotype were plotted against genotypic mean grain yield to categorise yield stability (Fig. 2b). B22 and IRAT 112 had the highest regression coefficients with the highest yields (more than 6 t ha^{-1}) in high yielding environments (more than 5 t ha^{-1}) but comparably low yields (less than 1 t ha^{-1}) in low yielding environments (less than 1 t ha^{-1}) as shown in Fig. 2a. Chhomrong and FOFIFA 172 were the highest yielding (between 2 and 3 t ha^{-1}) genotypes in low yielding environments (the HA location) and had low to medium grain yields in the most productive environment resulting in the lowest regression coefficients. Local landrace Botramaintso had low yields across all environments. Taking the yields in the HA location as an indicator of cold tolerance, genotypes Chhomrong, FOFIFA 161, FOFIFA 167 and FOFIFA 172 can be considered as cold-tolerant. These varieties are clustered in the high yielding group (Fig 2b) with low regression coefficients. These genotypes had above average yield stability and were well adapted to all environments without significant yield penalty. The grouping of varieties B22 and IRAT 112 indicates that these varieties were responders with average yield stability. Similarly, WAB 878 and Primavera had average yield stability but were less responsive to more productive environments. Botramaintso had the lowest yield with a regression coefficient close to one and below average yield stability.

AMMI-1 biplot (Fig. 3a) of main effects (genotype and environment) and IPCA1 supports the genotypic and environmental characterization given above. Genotypic grouping was very similar to that already presented in Fig. 2b based on the simple yield stability approach of Finlay and Wilkinson. Environments E7 and E3 were the highest and the lowest yielding environments, respectively. Environmental means of the high altitude (E1 to E4) varied greatly indicating that sowing dates and years had pronounced effects on the environmental yield potential (Fig. 3a). Contrary, environments of the MA location (E5 to E8) were clustered very close to each other, indicating that sowing dates and climatic variation between the two years had only small effects on the environmental mean. Genotypes G9 and G3 had greatest interaction with environments. Similarly, environment E2 indicated greater interaction with genotypes. AMMI-2 biplot (Fig. 3b) illustrates the relative magnitude of the GEI for specific genotypes and environments. Genotypes closest to zero IPCA scores are more stable and adapted across all twelve environments considered in this study. G3 was well adapted to early sowing in HA location (E1 and E2). G5 and G6 were well adapted in HA location late sowing in the first year (lowest yielding environment, E3). G2 was specifically adapted to early sowing in MA location (E5 and E6). Genotypes G3 to G6 were adapted to HA location (E1 to E4). Within twelve environments, environment E10 had less GEI whereas all other eleven environments had potential for large GEI.

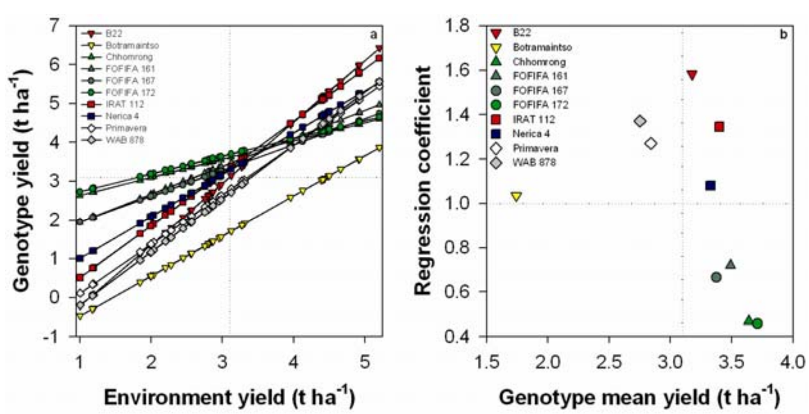

Figure 2. Mean grain yield (t ha^{-1}) of ten upland rice genotypes across twelve environments. (a) Relation between genotype mean yield (t ha^{-1}) and environment mean yield (t ha^{-1}) showing G x E interaction. Symbols used are the fitted values for each genotype. Horizontal and vertical dotted lines shows population mean yield (3.1 t ha^{-1}). (b) Scattered plot between regression coefficients versus genotype mean yield (t ha^{-1}) showing yield stability. Vertical dotted line shows population mean yield (3.1 t ha^{-1}) and the horizontal dotted line indicates regression coefficient equals to 1.

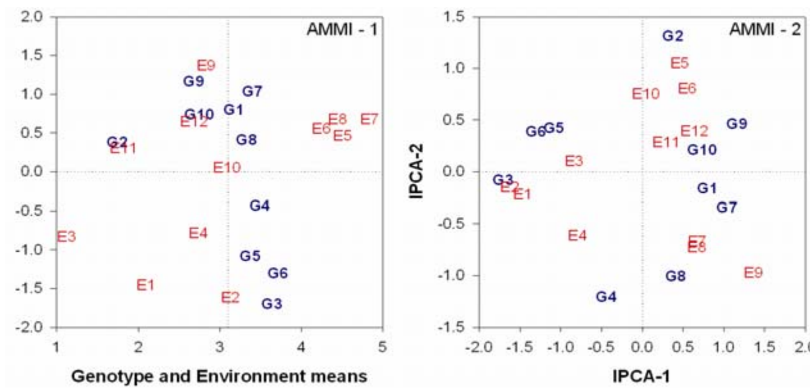

Figure 3. AMMI biplots for grain yield of ten genotypes across twelve environments. (a) AMMI-1 biplot where ordinate is Interaction Principal Component Axes 1 (IPCA-1) scores and abscissa is Genotype and Environment mean grain yield (t ha^{-1}) explaining genotype and environment characteristics. (b) AMMI-2 biplot where ordinate is IPCA-2 and abscissa is IPCA-1 showing interaction between specific genotype and environment.

Conclusions and Outlook

Chhomrong, FOFIFA 161, FOFIFA 167 and FOFIFA 172 are tolerant to cold environments. These cultivars can adapt to all environments without significant yield penalty. B22 and IRAT 112 are high yielding cultivars under favourable environmental condition. Environmental yield potential is affected by climatic variation between sowing dates, and years in high altitude. Contrary, it is less influenced in mid altitude. Cold tolerant cultivar Chhomrong adapts well when early sown in high altitude. Local landrace cultivar Botramaintso is specifically adapted to early sowing in mid altitude. Cold sensitive cultivar B22 yield better when lately sown in mid altitude. Low altitude rice production system is vulnerable. Morpho-physiological traits contributing to cold tolerance need to be identified for further breeding.

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