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DEVELOPING RICE VARIETIES WITH ENHANCED ADAPTATION TO COLD PRONE RICE GROWING AREAS UNDER LOWLAND RAIN FED CONDITIONS OF ETHIOPIA

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AUTHORS' CONTRIBUTIONS

This work was carried out in collaboration among all authors. Author TL deigned the sudy, wrote the protocol, excuted the experiment, collected data, performed the statistical analysis, wrote the first and final draft of the manuscript, and Authors AD, AB, BA, DK and HS managed the experiment and collected data. All authors read and approved the final manuscript.

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ABSTRACT

Sixteen lowland rice genotypes were arranged in a randomized complete block design of four replications and assessed for cold tolerance, performance and yield stability. Analysis of variance revealed highly significant effects of genotype and environment for all traits studied while the interaction effect was significant for six of eleven traits. The AMMI analysis in grain yield showed that genotype, environment and their interaction were highly significant and the environment explained the highest variation, followed by the interaction. The first two multiplicative interaction principal component axes were highly significant and explained 83.8% of the interaction sum of squares. Spikelete fertility ranged from 89.9% (G1) to 97.8% (G9 and G11). Genotypes G4, G9, G11, G10, G12, G13 and G14 exhibited nearly complete panicle exesertion and high spikelet fertility indicating their tolerance to cold stress. AMMI 1 and GGE ranking biplots identified G4, G9, G11 and G12 as high yielding genotypes. While G9 was the best genotype in terms of mean yield, G4 was both high yielding and most stable genotype. Thus, genotypes that combine cold tolerance, high yield, and farmers' preference (G4, G9 and G11) were verified and consequently, G9 and G11 were recommended for release in Fogera and similar areas.

Keywords: Rice genotype; cold tolerance; AMMI biplots; GGE biplots; grain yield.

1. INTRODUCTION

Rice (*Oryza sativa* L.) is a tropical and subtropical, diploid (2n=24) and self-pollinating crop that belongs to the Gramineae family [1,2,3]. The crop is the most important cereal in the world and one of the main staple foods for millions of people in developing counties including Sub-Saharan Africa. It is the principal source of energy, protein, iron, calcium, thiamine, riboflavin and niacin in many developing countries where rice is the major food source. Rice being a tropical and sub-tropical plant requires a fairly high temperature, ranging from 25° to 35°C. The optimum temperature of 30°C during day time and

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20°C during night time is considered favorable for its growth and development [4]. Temperatures below 25^o C can cause growth abnormalities in temperate and high-elevated tropical areas [5]. Cold stress shows different effects on germination, seedling, vegetative, reproductive and grain maturity and weakens photosynthetic ability by inducing leaf discoloration, reduces plant height, produces degenerated spikes, delays days to heading, reduces spikelet fertility and can cause yield losses of 26% to 80% [6,7,8]. Although the main symptom of damage from cold is the high spikelet sterility [9], incomplete panicle exsertion has also been cited as a symptom of cold injury in many rice growing countries [10] and this trait has been suggested as an indicator of genotype adaptability to cold affected areas [11].

In Ethiopia, rain fed rice is predominantly cultivated in altitudes above 1000 m.a.s.l. [12,13] such as Fogera, Dera, Libokemkem, Dembia, North Achefer, Tis-Abay, Pawe, Jimma, Bako-Chewaka, Guraferda, Assosa-Kamashi, and Tepi for both home consumption and local market. Districts such as Fogera, Dera, Libokemkem, Dembia, and Jimma, with minimum daily temperature of always $\leq$ 15^{o}C, most often experience damage to rice crop due to low temperature effect. Ethiopia is also reported to have several water lodged areas where other crop plants do not grow well and are assumed to be potential for rice cultivation. Expanding rice cultivation to such localities in the country could contribute towards meeting the food demand of the rapidly growing human population and help curb the huge annual rice import. However, such areas often experiences low temperature effect. Except few, most improved rice varieties in Ethiopia are sensitive to cold stress and hence cannot be grown in such cold prone areas which implicate the critical demand for cold tolerant, high yielding and stable rice varieties. It is therefore important to assess the performance of rice genotypes in areas that are most often cold affected with a view of growing the genotypes in the high elevation areas of Ethiopia.

However, multi-location evaluation of rice genotypes for identifying high yielding, stable and cold tolerant rice varieties is not a straight forward. Plant breeders most frequently encounter Genotype by Environment Interaction (GEI) when testing genotypes across a number of environments influencing the selection process [14]. Several methods are employed to estimate stability and adaptability performance in genotypes tested across environments by determining GEI effects. The two frequently used analysis methods are the Additive Main effects and Multiplicative Interaction (AMMI) model and the genotype main effects and GEI effects (GGE) model [15]. AMMI is preferred when both main effects and interaction effects are important and it integrates analysis of variance and principal component analysis [16]. The GGE provides visual evaluation of the data by creating a biplot that simultaneously represents mean performance and stability as well as identifying winner genotypes with respective mega-environments and relationships among testing environments [17,18]. Therefore, the objectives of this investigation were (1) to evaluate introduced lowland rice genotypes for cold tolerance under field conditions and (2) to assess adaptability and stability performance of rice genotypes for grain yield and related traits and identify genotypes that showed higher grain yield performance with wider or specific adaptation.

2. MATERIALS AND METHODS

2.1 Plant Materials and Testing Locations

Through AfricaRice breeding task force network and in connection with STRASA (Stress-Tolerant rice for Africa and South Asia) project, a total of 99 lowland rice genotypes were obtained for cold tolerance evaluation and for overall adaptation in Ethiopia. Of these, thirty three rice genotypes which showed better performance and cold tolerance were selected for preliminary variety trial in 2013 main cropping season, out of which only 14 genotypes were selected and promoted to multi-location variety trial in 2014 and 2015. Including two control varieties (one improved and cold tolerant i.e *Ediget* and another cold tolerant local variety i.e *X-Jigna*), a total of 16 rice genotypes were evaluated as national variety trial for their adaptability, stability and performance in grain yield and related traits in addition to their tolerance to cold stress under field conditions (Table 1).

The experiment was conducted under rain fed lowland conditions at research fields of Fogera (Woreta and Kokit), Jimma (Jemma and Gojeb) and Assosa (Assosa) research centers during the main cropping seasons (May to November) of 2014 and 2015 at five locations (Table 2). At these locations, the rice crop often experiences low temperature effect at least once during the growing periods. The locations varied in rainfall amount and distribution, elevation, temperature (Table 2) and soil types (data not shown). The location-year combination indicated seven environments such as E1 (Woreta2014), E2 (Jimma2014), E3 (Assosa2014), E4 (Woreta2015), E5 (Kokit2015), E6 (Jimma2015), and E7 (Gojeb2015) in this study.

Table 1. Description of 16 rice genotypes used in this study

No.	Genotypes	Code	Source
1	scrid079-1-5-4-2	G1	AfricaRice
2	exp304	G2	AfricaRice
3	FOFIFA 161	G3	AfricaRice
4	FOFIFA 171	G4	AfricaRice
5	FOFIFA 172	G5	AfricaRice
6	FOFIFA 167	G6	AfricaRice
7	HR 17512-11-2-3-1-4-2-3	G7	AfricaRice
8	scrid006-2-4-3-4-5	G8	AfricaRice
9	scrid006-3-2-3-2	G9	AfricaRice
10	scrid14-1-1-1-1	G10	AfricaRice
11	scrid017-1-4-4-4-1	G11	AfricaRice
12	scrid019-1-1-1-1-2	G12	AfricaRice
13	scrid037-4-2-2-5-2	G13	AfricaRice
14	scrid113-3-5-3-5-4	G14	AfricaRice
15	Edget(standard check)	G15	Fogera NRTC, Ethiopia
16	X-JIGNA(local check)	G16	Fogera NRRTC, Ethiopia

Table 2. Description of testing locations used for the evaluation of 16 rice genotypes

Location	Geographic coordinates		Elevation (m a.s.l)	Rain fall (mm)	Temperature (^{O}C)		Soil Type
	Latitude	Longitude			Tmax	Tmin	
Woreta	11° 58' N	37° 41' E	1810	1292.6	26.7	13.0	Vertisol
Jimma	7° 46' N	36° 00' E	1753	1091.0	26.9	11.1	Nitosol
Kokit	11^{o} 92’N	37^{o} 7’E	1780	1292.6	26.7	13.0	Vertisol
Assosa	10^{o} 03’N	34^{o} 59’E	1590	1020.0	26.7	15.2	Nitosol
Gojeb	7^{o} 15’N	36^{o} 0’E	1235	1710.0	24.0	16.7	NA

m.a.s.l: meter above sea level, mm: millimeter, Min: minimum, Max: maximum. Note: Rainfall amount and temperature conditions refers to the average values during rice growing periods at each location, NA: not available

2.2 Experimental Design and Trial Management

At each location, the experiment was laid out using a randomized complete block design of four replications. Seeds of each genotype were planted at the rate of 60 kg/ha by hand drilling in a plot size of 7.5m^2 and with a spacing of 25cm between rows. Each experimental plot was with six rows of 5m long each. Fertilizers (UREA and DAP) were applied as per to local recommendations. All DAP was applied at planting while UREA was used in split. Other crop management and protection practices were applied to the entire experimental area uniformly when necessary.

2.3 Data Collection

Data on yield, yield related and other morphological traits were collected both on plot and individual plant bases. Five randomly selected plants from the middle four rows of each experimental plot were used in plant base data collection for panicle length (PL, cm), plant height (PH, cm), number of filled grains per panicle (FGP), number of fertile tillers per plant(FTP). Fertility rate (FR, %) was calculated from the ratio of filled grains per panicle to total grains per panicle. Data for days to 50% heading (DH, days), days to 85% maturity (DM, days), panicle exertion (Panex-scale: 1-5; 1 completely exerted, 5 remain closed), phenotypic acceptability (Phac-scale: 1-9; 1 fully accepted, 9 completely poor and not accepted) were collected on plot basis following standard evaluation system of IRRI [19]. Grain yield (Gy) and thousand seed weight (TSW) were also taken on plot basis from the four harvestable rows in gram. Grain yield harvested from each plot was converted into kg/ha at 14% standard grain moisture content.

2.4 Data Analysis

Data collected on grain yield, agronomic and morphological traits were subjected to analysis of variance using the General Linear Model (PROC GLM) of the SAS Procedure version 9.0 of the SAS software [20] to determine significant variation among genotypes and environments and their interaction. Mean performance of different traits were separated using Least Significant Difference (LSD) method at 0.05 level of probability. Additive main effects and multiplicative interaction (AMMI) model was applied to assess the effect of genotype by environment interaction, adaptability and stability of rice genotypes [16] using GenStat 16th edition statistical package. Moreover, GGE analysis, according to [21], was employed to visualize grain yield stability and performance of 16 rice genotypes at seven environments.

3. RESULTS AND DISCUSSION

3.1 Environmental Conditions of Test Locations

Rain fall amount and distribution, and temperature are critical in rice cultivation. Test locations varied in elevation and all the test locations received different rainfall amount, obviously with varied distribution during the growing season (Table 2, Fig. 1). The highest rainfall was recorded at Gojeb, followed by Jimma, while the lowest rainfall was recorded at Assosa. The highest mean maximum temperature was recorded at Assosa, Woreta and Kokit whereas Gojeb recorded the lowest mean maximum temperatures. The most important was the minimum mean temperatures which usually affected panicle exertion and spiklete fertility in rice and the lowest minimum temperature was recorded at Jimma, Woreta, and Kokit (Table 2, Fig. 1). Unlike the other locations, Woreta and Kokit usually experienced terminal moisture stress in addition to low temperature effect. Fig. 1 also confirmed this as September, most important month for rice, received lower amount of rain fall in Fogera (Woreta).

3.2 Genotype Performance for Cold Tolerance, Grain Yield and Related Traits

Combined analysis of variance and overall mean performance of 16 rice genotypes at seven environments for cold tolerance indicator traits (spikelet fertility and panicle exesertion) and all other traits are presented in Table 3. Highly significant genotype and environment effects were observed for spikelet fertility and panicle exesertion and for all other traits. The genotype by environment interaction (GEI) was highly significant for spikelet fertility but not for panicle exesertion. Similarly, GEI was also highly significant for five traits including grain yield but not for days to heading, panicle length, fertile tillers/ plant, and thousand seed weight (Table 3). The presence of highly significant G x E interactions for grain yield indicates that genotypes tended to rank differently in grain yield at different locations and over years.

Cold tolerance indicator traits, spikelet fertility and panicle exsertion, exhibited linear relationship with grain yield indicating higher yielding genotypes showed strong tolerance to cold stress under field condition across locations (Fig. 2). Genotypes G9, G10, G11, and G12 were with the best panicle exertion, high spikelet fertility and best phenotypic acceptability (Table 3). The overall mean grain yield of 16 rice genotypes ranged from 3196.7 kg ha^{-1} to 5166.4 kg ha^{-1} with a grand mean yield of 4254.0 kg ha^{-1} and the highest grain yields were obtained from Genotypes G9, G12, G4, and G11 (Table 3).

As indicated in Table 3, seven genotypes scored highest grain yield over grand mean (4254.0 kg ha^{-1}) and thirteen genotypes scored highest grain yield over standard (*Ediget*) and local checks *(X-Jigna*). The wide variation in grain yield explained by the environments revealed the presence of different mega-environments where specific genotypes performed best within each mega-environment. The average environmental grain yield across genotypes ranged from 238.9 kg ha^{-1} at Assosa2014 to 5361.1 kg ha^{-1} at Jimma2015, with a grand mean yield of 4254.0 kg ha^{-1} (Table 4).

Environments E4 (4667.5 ka ha^{-1}) and E6 (5361.1 kg ha^{-1}) were the highest yielding environments while E1 and E3 were the lowest whereas E2, E5, and E7 scored intermediate mean grain yield (Table 4). Average grain yield of genotypes across environments ranged from the lowest of 3196.7 kg ha^{-1} for G5 to the highest of 5166.4 kg ha^{-1} for G9. The genotypes G4, G9, G11 and G12 had higher average grain yield across environments with average yield of 4826.3, 5166.4, 4841.2, and 4903.9 kg ha^{-1}, respectively (Table 4). Genotype G4 ranked first at four environments (E1, E2, E3, and E5). The other better performing genotypes at different environments include G1 (E4, E5, E6, and E7), G2 (E1, E2, and E6), G3 (E3 and E4), G5 (E4), G7 (E7), G9 (E5, E6, and E7), G10 (E7), G11 (E1, E2, E3), G12 (E1, E3, and E6) and G13 (E5) (Table 4). The local check (G16 i.*e X-Ji*gna) showed better performance for average grain yield at two environments (E2 and E4). Genotypes G3 and G9 recorded the best yield of 5998 kg ha^{-1} and 9580 kg ha^{-1}at the highest yielding environments (E4 and E6), respectively, while G4 had the best yield of 4327 kg ha^{-1} and 4796 kg ha^{-1} at the lowest yielding environments, E1 and E3 (Table 4).

3.3 AMMI Analysis

Significant analysis of variance for the main effects and their interaction in grain yield indicated the importance of the additive main effects and multiplicative interaction (AMMI) model for further interpreting the grain yield data to identify stable genotypes. AMMI model calculates genotypes and environment additive (main) effects using analysis of variance and then analyze the residual from this model using principal component analysis (PCA) [16]. AMMI analysis of variance for grain yield revealed highly significant effect for genotypes, environments, and genotype by environment interaction (Table 5). The effect of the environment was higher than the genotype but lower than the interaction effect (data not shown) indicating wider variation among environments and differential response of genotypes across environments. The AMMI analysis also showed that the first interaction principal component axis (IPCA1) and second interaction principal component axis (IPCA2) explained 70.57% and 13.26% of the interaction sum squares, respectively (Table 5). Significant interaction indicated that the genotypes respond differently across the environments. The report in the present study are in line with the previous findings [22] and AMMI procedure has been widely applied by various authors in selection of stable rice genotypes [23,24].

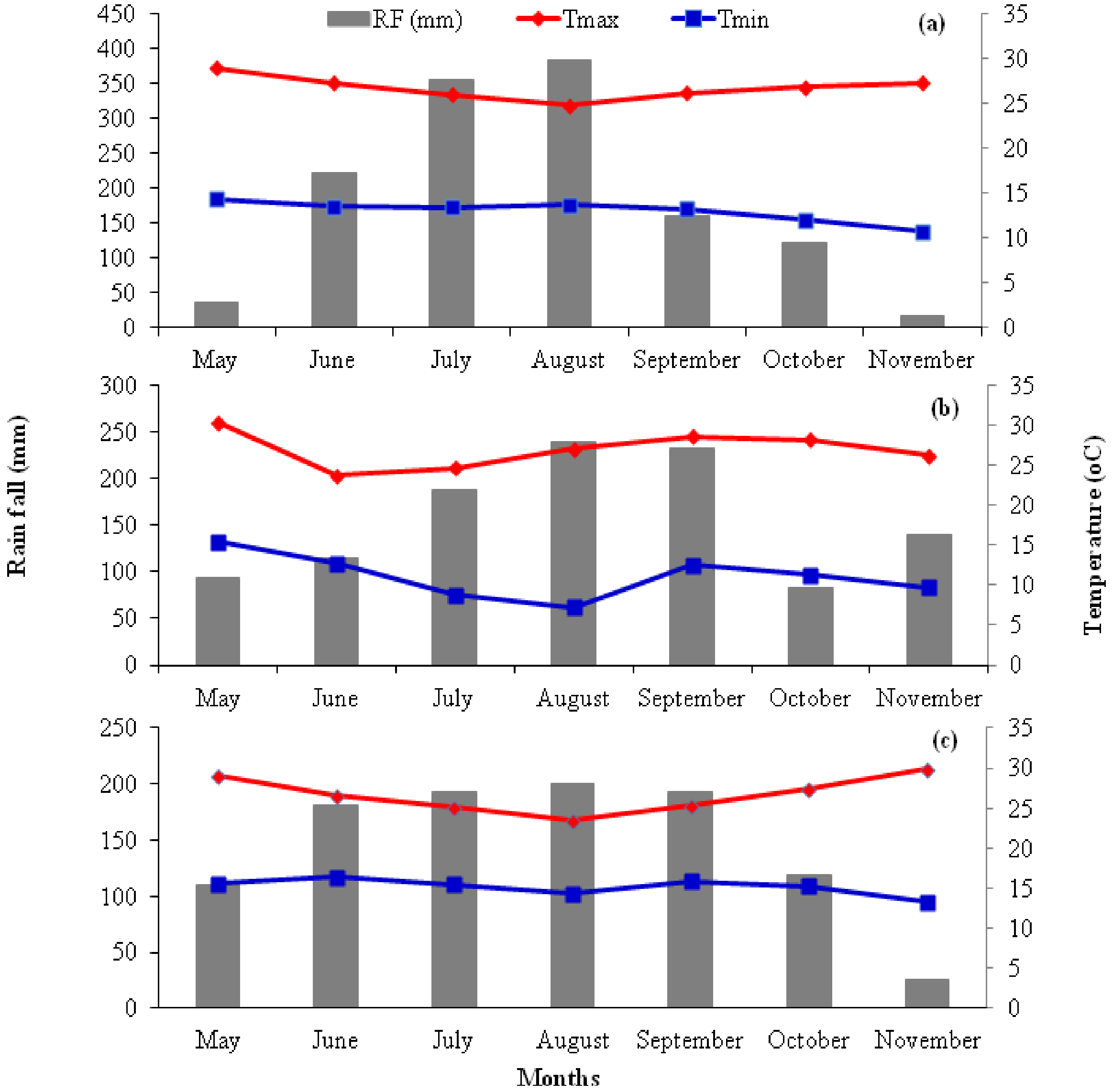

Fig. 1. Monthly rainfall distribution (bars), maximum daily average temperature (Tmax), and minimum daily average temperature (Tmin) at Woreta (a), Jimma (b) and Assosa (c) experimental stations during rainfed rice growing months. These data were provided by the Ethiopian Meteorology Agency

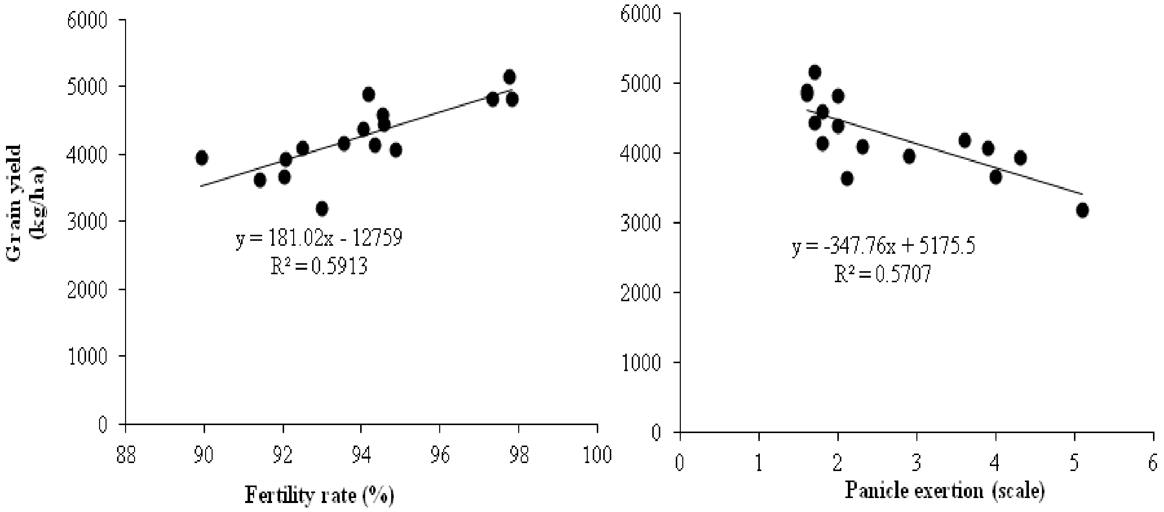

Fig. 2. Relationship of grain yield with panicle exertion and fertility rate in 16 rice genotypes evaluated at seven environments

Table 3. Mean performances of lowland rice genotypes for grain yield (kg/ha) and yield related traits across seven environments during 2014 and 2015 main cropping season

Genotype	DH	DM	PL	PH	FTP	FGP	FR	TSW	Gy	Panex	Phac
G1	93.6	132.1	19.8	103.1	7.5	90.5	89.9	27.4	3952.2	2.9	4.9
G2	86.7	130.1	18.7	100.2	8.0	91.5	93.6	28.1	4184.0	3.6	4.5
G3	89.8	128.8	16.6	83.8	6.3	86.4	94.8	28.1	4070.8	3.9	4.5
G4	89.9	130.0	19.2	97.7	7.1	84.6	97.3	29.8	4826.3	2.0	3.4
G5	78.0	126.0	15.2	80.4	8.3	55.8	93.0	28.9	3196.7	5.1	7.2
G6	91.4	127.0	17.7	105.2	7.8	85.2	92.5	24.1	4108.5	2.3	3.9
G7	95.7	134.4	16.2	72.0	8.2	89.7	92.1	20.1	3934.8	4.3	5.6
G8	86.4	126.1	19.0	102.8	7.8	76.2	94.0	34.6	4385.7	2.0	3.4
G9	98.4	125.8	19.0	97.6	8.2	79.4	97.8	34.7	5166.4	1.7	2.8
G10	89.0	129.2	19.5	106.6	7.1	108.4	94.6	21.8	4449.0	1.7	2.6
G11	90.1	129.0	18.4	105.3	7.2	106.1	97.8	24.3	4841.2	1.6	1.7
G12	92.4	130.5	18.5	101.1	6.8	103.0	94.2	25.4	4903.9	1.6	2.4
G13	93.0	128.8	18.5	102.5	7.1	104.0	94.5	25.1	4588.0	1.8	2.7
G14	90.1	127.8	17.3	100.4	7.1	87.7	94.3	24.4	4146.6	1.8	2.8
G15	87.4	130.8	17.4	88.1	6.1	80.2	92.0	29.7	3671.4	4.0	4.5
G16	95.4	132.3	19.1	97.6	6.9	94.0	91.4	25.5	3637.3	2.1	4.0
Mean	89.8	96.5	18.1	96.5	7.34	88.9	94.0	27	4254.0	2.67	3.8
CV (%)	10.23	6.11	8.1	6.1	23.8	16.65	3.73	10.51	23.1	32.8	31.34
LSD (0.05)	4.84	2.08	0.77	3.1	0.92	7.78	1.84	1.49	516.62	0.46	0.63
Genotype (G)	***	***	***	***	***	***	***	***	***	***	***
Environment (E)	***	***	***	***	***	***	***	***	***	***	***
G x E	NS	**	NS	**	NS	***	***	NS	***	NS	***

, **, and *, significant at 0.05, 0.01 and 0.001 levels, NS: not significant at 0.05 level, DH: days to heading, DM: days to maturity, PL: panicle length (cm), PH: plant height (cm), FTP: fertile tillers per panicle, FGP: filled grains per panicle, FR(%): fertility rate of spikelets per panicle, TSW: 1000 seed weight (g), Gy: grain yield (kg ha^{-1}), Panex: panicle exertion (scale; 1-5, 1-fully exeserted, 5-remain closed), Phac: phenotypic acceptability (scale; 1-9, 1-fully accepted and 9-not accepted at all)*

Table 4. Mean grain yield (kg ha^{-1}) performance of 16 rice genotype at seven environments

Genotype	E1	E2	E3	E4	E5	E6	E7	Mean
G1	2734	4216	3235	5867	4949	1855	4807	3952.2
G2	4254	5002	2404	4922	4938	6321	3466	4184.0
G3	3145	4811	3833	5998	3939	5575	3701	4070.8
G4	4327	5068	4796	4945	5102	5780	3807	4826.3
G5	2520	4568	2823	5354	3534	4670	3024	3196.7
G6	3583	4744	2966	4056	3895	5750	4118	4108.5
G7	3977	3731	2405	4750	4415	4156	4939	3934.8
G8	3387	3587	2785	4288	4607	7251	4553	4385.7
G9	3969	3797	2881	4108	5033	9580	4733	5166.4
G10	4083	3790	2719	4512	4342	5343	4580	4449.0
G11	4309	5044	4322	4928	4656	5212	4479	4841.2
G12	4183	2821	4699	2985	4910	6044	4547	4903.9
G13	3739	4556	3762	4043	4979	5167	3801	4588.0
G14	3810	3877	3135	4595	4077	5404	3652	4146.6
G15	3031	3654	2433	4076	3777	4325	4378	3671.4
G16	3225	4895	2624	5253	4016	3344	3966	3637.3
Mean	3642.3	4260.1	3238.9	4667.5	4448.1	5361.1	4159.4	4254.0
CV (%)	9.5	15.6	33.7	19.1	17.1	26.3	21.2	23.1
LSD (0.05)	491.2	946.6	1553.4	1268.1	1080.5	2005.3	1253.8	516.6

E1: Woreta 2014, E2: Jimma 2014, E3: Assosa 2014, E4: Woreta 2015, E5: Kokit 2015, E6: Jimma 2015, E7: Gojeb 2015

Table 5. AMMI analysis of variance for grain yield (kgha^{-1}) of 16 lowland rice genotypes grown at seven environments

Source	d.f.	s.s.	m.s.	v.r.	F pr
Total	447	828169840	1852729		
Genotypes	15	117483339	7832223	9.33	<0.001
Environments	6	182255791	30375965	11.15	<0.001
Interactions	90	206788573	2297651	2.74	<0.001
IPCA 1	20	145929536	7296477	8.69	<0.001
IPCA 2	18	27420057	1523336	1.81	0.0229
IPCA3	16	13356291	834768ns	0.99	0.4625
Error	315	264430076	839461		

d.f: degree of freedom, s.s: Sum square, m.s: mean square, v.r: variance ratio, Fpr: probability level.

AMMI recommendation of genotypes for environments is shown in Table 6. AMMI selection identified first four high yielding genotypes per environment. The result indicated that some high yielding genotypes are suitable for specific environment (G10, G3) and some other genotypes (G4, G11, G2, G12, G8, G9, G13, G1) can be recommended for two or more environments. The illustration in Table 6 suggested that we can advise the right genotype for all environments or specific genotype for specific environments through AMMI evaluation. As reported by [22] and [25] the AMMI analysis indicates recommendations of correct genotype for one or more environments. In our report, therefore, the selection of best candidates based on overall performance above coincides with that of AMMI recommendation as G4, G9 and G11 work for more than one environment. Table 7 also showed mean grain yield performance and stability coefficient of 16 lowland rice genotypes across seven environments through AMMI analysis. The mean grain yield value of genotypes averaged over environments indicated that genotype G9 had the highest (5166 kgha^{-1}), and genotype G5 (3197 kgha^{-1}) the lowest grain yield, respectively. Genotype superiority with the smallest and the highest measured values indicate the more stable and less stable genotypes, respectively. Therefore, from the present study, genotype G9 was the most stable, followed by genotypes G12, G8, G4 and G11 while genotype G1 was the least stable genotype, followed by genotypes G5, G16, G15, G7 and G14 (Table 7).

Table 6. AMMI selections of genotypes per environment

Environment	IPCAe[1]	IPCAe[2]	Mean ($kgha^{-1}$)	Score	First four AMMI selections 1	2	3	4
E1	0.9587	-0.8826	3642	0.96	G4	G11	G2	G12
E2	7.5632	-4.2214	4260	7.56	G12	G4	G10	G9
E3	15.2395	-41.7081	3239	15.24	G4	G12	G11	G3
E4	24.0049	13.2793	4668	24.00	G11	G1	G13	G9
E5	8.3692	7.6541	4448	8.37	G4	G9	G13	G1
E6	-70.0667	0.8925	5361	-70.07	G9	G8	G2	G12
E7	13.9313	24.9864	4160	13.93	G8	G1	G10	G11

IPCAe1 and IPCAe2: the first and second interaction principal component axis for the environments.

Table 7. Mean grain yield ($kgha^{-1}$) and stability coefficient 16 lowland rice genotypes

Genotypes	Grain yield ($kgha^{-1}$)	Standard deviation	Genotype superiority
G1	3952	1406	4672945 (16)
G2	4184	1255	1695345 (7)
G3	4071	1056	1792192 (10)
G4	4826	625	1204886 (4)
G5	3197	1082	3679873 (15)
G6	4109	886	1789834 (9)
G7	3935	840	2841980 (12)
G8	4386	1443	1163475 (3)
G9	5166	2188	323865 (1)
G10	4449	811	1722031 (8)
G11	4841	360	1406870 (5)
G12	4904	1123	992304 (2)
G13	4588	605	1551579 (6)
G14	4147	731	1906506 (11)
G15	3671	712	2973606 (13)
G16	3637	934	3673647 (14)

Numbers in brackets give the position of each genotype, ranked according to the stability coefficient (running downwards from 1 = best).

3.4 AMMI Biplots

In the AMMI biplot analysis, the IPCA scores of environments and genotypes are plotted against main effect means and the plot helps to visualize the average productivity of the genotypes, environments and their interaction. Nature and magnitude of interaction can be visualized for each genotype and each environment using IPCA1 vs. IPCA2 biplot of AMMMI 2 [22,23]. In AMMI1 biplot (Fig. 3), genotype and environment main effects are drawn against their corresponding IPCA1 score. In this biplot, the genotypes with IPCA1 scores close to zero tend to express general adaptation and the larger scores showed more specific adaptation to one or more environments. Rice genotypes plotted on the right-hand side of the vertical midline have higher grain yield compared to those on the left-hand side (Fig. 3). Genotypes G9, G12, G4, G11, G13, G10 and G8 had high average yield with G9, G12, G11 and G4 being the highest yielding genotypes. Genotypes G11 and G13 adapted to E4, E5, and E2 while genotypes G8 and G9 adapted to the most favorable environment (E9). On the other hand, genotypes G4, G12, G10, G14, and G3 had small IPCA1 scores, suggesting their general adaptation. Genotypes G1, G16, G15, G7 and G5 had low average yield and G1 had the largest positive IPCA1 score making it the most unstable genotype. Of the environments, E1, E2, and E5 exhibited relatively small IPCA1 scores, suggesting that they had little interaction with genotypes indicating stable environments, of which E1 being the most stable environment. On the other hand, two favorable environments (E4 and E6), one intermediate environment (E7), and the poorest environment (E3) had relatively high IPCA1 scores producing large interactions with genotypes, making them unstable (Fig. 3). As demonstrated by AMMI 2 biplot in Fig. 4, environments with short vectors exert weak interaction and those with long vectors exert strong interaction [26]. Environments E3, E4, E6, and E7 with long vectors were very interactive and discriminated differences among genotypes more than environments with short vectors (E1, E2 and E5) which were less interactive and provide little information about differences among genotypes for grain yield performance [23].

The genotypes near the origin are not sensitive to environmental interaction and those away from the origins are sensitive and have large interaction [17]. As a result, G1, G8, G9 and G16 are sensitive to the environments since they were away from the origin whereas most other genotypes were relatively close to the origin and hence they were less sensitive to the environments.

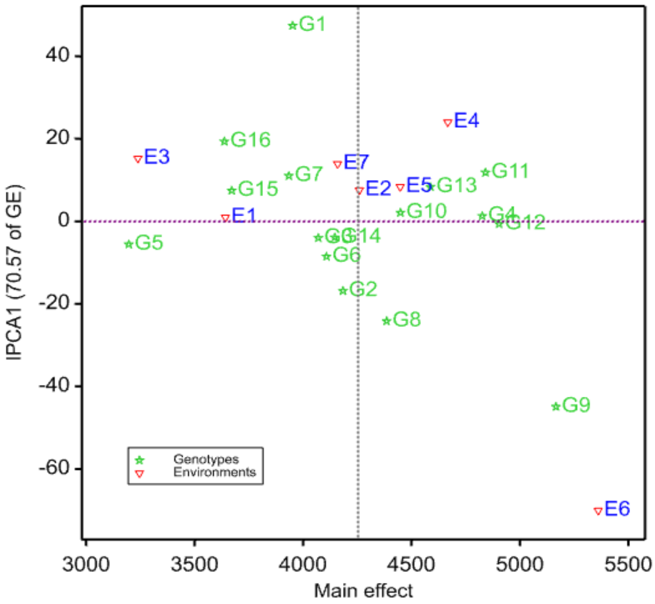

Fig. 3. AMMI1 biplot showing the main effect vs. stability (IPCA1) of both genotypes and environments on grain yield (kgha^{-1}). E1: Woreta2014, E2: Jimma 2014, E3: Assosa2014, E4: Woreta2015, E5: Kokit2015, E6: Jimma2015, E7: Gojeb2015

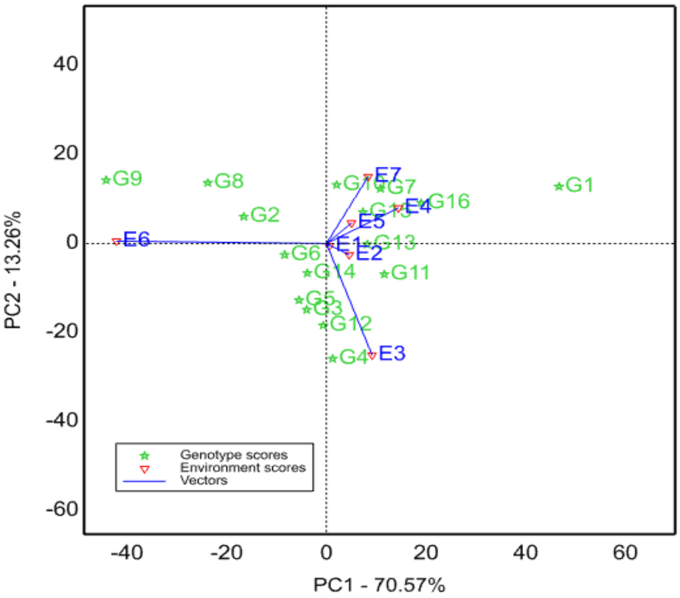

Fig. 4. AMMI 2 biplot graph showing interaction of PC1 and PC2 scores of 16 rice genotypes at seven environments. E1: Woreta2014, E2: Jimma 2014, E3: Assosa2014, E4: Woreta2015, E5: Kokit2015, E6: Jimma2015, E7: Gojeb2015

3.5 GGE Biplots

Fig. 5 shows the polygon view of which-won-where pattern in GGE biplot analysis of mean grain yield in 16 lowland rice genotypes evaluated at seven environments. The GGE biplot accounted for 70.02% of the total variation consisting of 51.19% and 19.01% of the variation attributed to the first and second principal components (PC1 and PC2), respectively. The polygon in the biplot was divided in to six sectors in which environments are grouped to different sectors. The genotype at the vertexes of each sector is the best genotype to the environment(s) contained in the particular sector and all other genotypes within the sector are recommended for all environments contained in that sector [26]. In this study, GGE biplot analysis recommended G1 as the best genotype at two environments (E4 and E7), which represented one mega-environment while the winner genotypes at environments (E3 and E5) were G10, G11 and G13; with G11 being the best fit genotype. Similarly, genotypes G4 and G9 performed best at environments E1 and E6. On the other hand, the remaining two sectors with G2 and G5 as vertex genotypes contained no environment within them suggesting that grain yield performance of all genotypes, including checks (G15 and G16), in the two sectors was low in any of the environments.

Fig. 6 shows ranking of 16 lowland rice genotypes based on their mean grain yield performance and stability using genotype focused scaling of GGE analysis. The average-environment coordination (AEC) line (abscissa) which passes through the biplot origin points towards the direction of high mean yield across environments and vector line of each genotype which is perpendicular to the AEC indicates the stability of the varieties. Regardless of the direction of vectors, varieties with longer vector are less stable compared to varieties with shorter vectors [27]. Genotypes placed bellow the AEC ordinate line (red line in this case) performed bellow the average and those placed above ordinate line performed above average [17,27]. Thus, genotypes G12, G4, G9, and G11 were the best performing genotypes for mean grain yield, followed by G13 and G10 while G1, G2, G3, G6, G7, G8, G14, G16 and G15 were low yielding genotypes, with G5 being the least in grain yield performance (Fig. 6). Genotypes G3, G7, G10, and G15 were relatively stable genotypes while genotypes G1, G2, G5, and G16 were less stable, with G1 being the most unstable genotype. Of the top four high yielding genotypes (G4, G9, G11 and G12), G12 was the most stable genotype, followed by G4, while G9 and G11 were less stable. The latter two high yielding genotypes could be recommended to specific environments. With regard to environments, four environments (E1, E4, E6 and E7) were relatively unstable while the remaining three (E2, E3 and E5) were stable environments (Fig. 6) though E3 was illustrated contrary to this in AMMI 2 biplot.

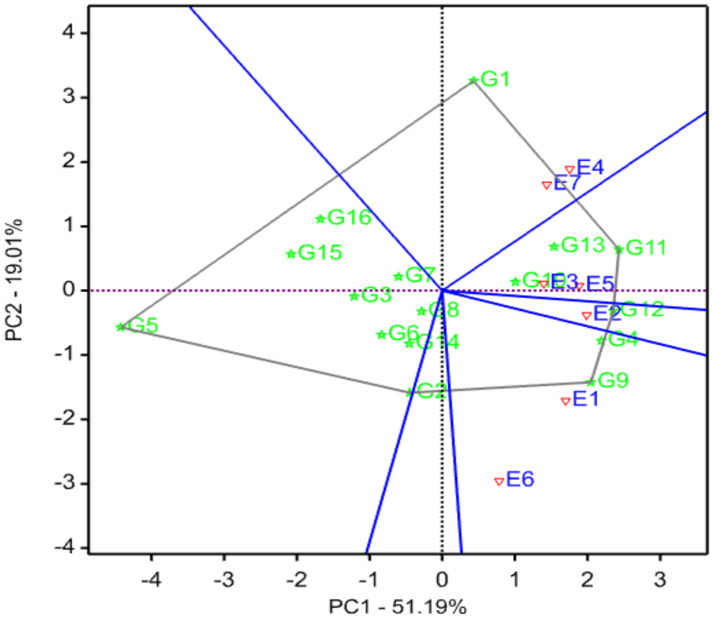

Fig. 5. GGE biplot showing winner genotypes at specific environments. E1: Woreta2014, E2: Jimma 2014, E3: Assosa2014, E4: Woreta2015, E5: Kokit2015, E6: Jimma2015, E7: Gojeb2015

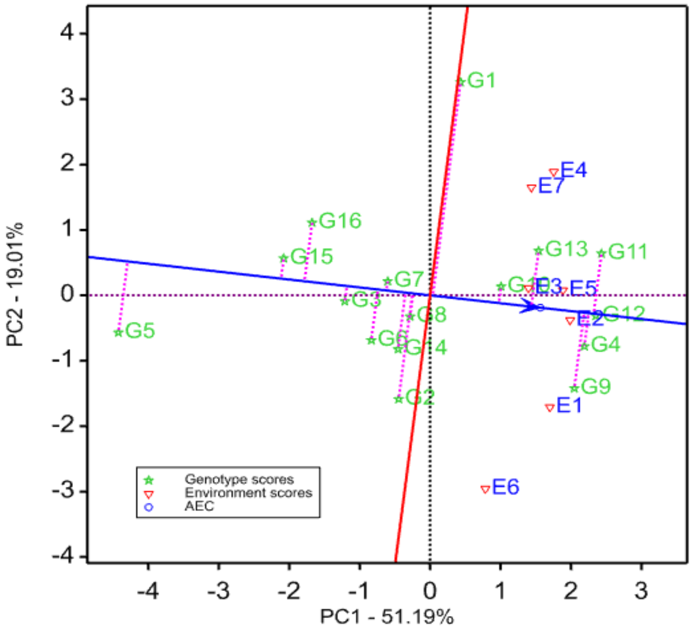

Fig. 6. GGE biplot showing grain yield rank and stability of 16 lowland rice genotypes across seven environments. E1: Woreta2014, E2: Jimma 2014, E3: Assosa2014, E4: Woreta2015, E5: Kokit2015, E6: Jimma2015, E7: Gojeb2015

4. CONCLUSION AND RECOMMENDATION

The current study assessed the cold tolerance, performance and stability of 16 lowland rice genotypes under rain fed field condition. All the traits considered were significantly affected by genotype, environment, and partly with genotype by environment interaction. The significant interaction effect for grain yield indicated the inconsistent performance of genotypes across test locations and over seasons. Application of different statistical techniques including ANOVA, AMMI and GGE biplots enabled us to detect variation and identify broadly and/or specifically adapted and high yielding rice genotypes. As result, desirable lowland rice genotypes in terms of cold tolerance, yield performance and stability had been identified that can be recommended to farmers for cultivation. Although no genotype showed superior performance uniformly across all the test environments, some genotypes were identified with better mean grain yield performance. Among the tested genotypes, genotype G4 ranked the first at three of the seven environments, followed by G8, G9, G11, and G12 which ranked first at least in one of the environments as recommended by AMMI selection. Vertex genotypes including G1, G9, G11 and G12 in GGE polygon biplot were identified as winner genotypes for different sectors. Similarly, GGE ranking biplot identified four genotypes (G9, G4, G12 and G11) as high yielding, out of which G4 was the most stable, followed by G9 and G12 while G11was less stable. Considering wider and /or specific adaptation, farmers' positive feedback, and response to cold stress, three genotypes (G4, G9 and G11) were identified as candidate varieties and verified for final evaluation by variety releasing committee. Consequently, genotypes G9 and G11 were officially approved for release by the national variety releasing committee for cultivation in cold prone potential rice growing agro ecologies of Ethiopia, predominantly in Fogera and similar areas. Genotypes G4 and G12 can be used as potential parental lines in the national rice crossbreeding program.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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