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Performance evaluation of upland Rice (*Oryza sativa* L.) varieties for grain yield in Buno Bedele, South West Oromia, Ethiopia

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ABSTRACT

Rice has become a commodity of strategic significance across many African countries. It is also the most rapidly growing food source across the continent due to the great urbanization in Africa than any other region in the world. Eleven Upland rice varieties were evaluated in a randomized complete block design with three replications in Gechi, Bedele, and Dabo Hana during the 2023 and 2024 main cropping seasons to evaluate, select, and recommend high-yielding and stable upland rice varieties for the study areas and other similar agro-ecologies. The mean squares due to varieties, locations, year, and their interaction effects were highly significant (P<0.01) for most traits studied. The highest yields were recorded from Chewaka and Adet (6612 and 5525 kg ha^{-1} respectively), while the lowest yield (3229 kg ha^{-1}) was recorded from Kokit. AMMI analysis revealed a highly significant difference (P<0.001) for varieties, locations, years and their interactions. The magnitude of environmental variation was higher than the varieties and their interaction, which indicates the testing locations were diversified in discriminating the varieties. The AMMI model clearly demonstrates the variety-by-location interaction by partitioning it into two significant principal components that capture 92.52% of the variation. According to the GGE Biplot stability analysis, the two varieties Chewaka and Adet were the most stable, coupled higher grain yield greater than the grand mean from the overall locations. Other stability models like AMMI Stability Value and Yield Stability Index also confirm the same result with AMMI and GGE. Therefore, Chewaka and Adet were recommended to be demonstrated on a farmer's field for further scaling up.

KEY WORDS: *AMMI*; *GGE bi-plot*; *GEI*; *Upland rice*; *Stability*; *Varieties*

1. Introduction

Rice belongs to the genus *Oryza* with two cultivated, *viz*. the Asian rice, *Oryza sativa* L. and the African rice, *Oryza glaberrima* Steud, and 22 wild species (Martin *et al*., 2006). Rice is a diploid species (2n=24), and a self-pollinated crop with up to 3% natural out-crossing that may occur depending on the cultivar and the environment (Poehlman and Sleper, 1995). It is the second most important cereal crop next to wheat worldwide. It is by far the most economically important food crop in many developing countries. It provides two-thirds of the calories intake for more than three billion people in Asia and one-third of calories for 1.5 billion people in Africa and Latin America. In Africa, the economic importance of rice has steadily increased over the past two decades (FAOSTAT, 2017).

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In recognition of its importance, the Government of Ethiopia (GoE) has developed a national strategy for rice research to promote the rice sector to ensure food security (MoARD, 2010). Rice was introduced and tested initially at different areas of Ethiopia, such as Gambella, Pawe, and Woreta, in the beginning of the 1970s. However, due attention was given in the mid-1990s (Meron, 2016). Since the mid-1990s, about 22 upland rice varieties have been released in regions where rain-fed rice is cultivated (Amhara, Tigray, Oromia, South NNPR, Gambella, and Benshangul Gumuze Regions) (MoARD, 2010). The national average yield of rice in Ethiopia is 3.15 ton ha^{-1} (CSA, 2021), which is much lower than the world‘s average rice yield of 5.1 ton ha^{-1} (FAOSTAT, 2017). The regional and Zonal (Buno Bedele) average yield of rice is 2.84 and 2.98 tones ha^{-1} respectively.

Regarding the ecological zones important for growing rice, the rain-fed upland rice can be grown in the altitudinal range of 1000 to 2000 meters above sea level (Shahi, 1994). Ethiopia has a huge potential for rice production, which is estimated to be about 30 million hectares (MoARD, 2010). Upland rice is cultivated in tropical and sub-tropical rain-fed environments in aerobic soils without impounding water. However, production in high altitudes is limited due to an extended vegetation period that may not be supported by the extended rainfall. The cold weather can be stressful because it induces pollen or spikelet sterility. Therefore, it is important to identify cold-tolerant genotypes capable of coping with the environmental stresses and produce stable grain yield in the potential areas (Shrestha, 2012). Ethiopia is vulnerable to climate change, experiencing the variation of weather conditions both from season to season and from place to place in the same season over relatively small areas (Girma *et al.*, 2018). The country is known to have great environmental variations (EMA, 1988).

Amongst the target commodities that have received due emphasis in the promotion of agricultural production, rice is considered the “Millennium crop” expected to contribute to ensuring food security in the country. Even though it is a recent introduction to the country, rice has shown promise as to be among the major crops that can immensely contribute towards ensuring food security in Ethiopia. The country has vast suitable ecologies for rice production, along with the possibility of growing it where other food crops do not do well (Teshome and Alemu, 2011).

Rice production and productivity are mainly affected by both biotic and abiotic factors. Among the biotic factors, economically important endemic diseases (leaf and panicle blast, brown spot) and insect pests (stalk eye fly, termite), which result in huge losses of yield, are common problems in rice. The effects of climatic variability, which has currently threatened global environmental condition also favor the evolution of unknown deadly diseases, insects, and result in frequent outbreaks of disease-causing microorganisms (Meron, 2016). The main focus of rice research is thus to identify and isolate genotypes with a good level of resistance to the economically important diseases and pests on a regular and proactive basis. Continuous surveillance of newly emerging diseases and insect pests should be undertaken in order to design and generate integrated control mechanisms. In addition to these shortages of varieties with specific traits and adaptability, threshing facilities, drought stress, and field management aspects of rice crop are also challenges (Abebaw, 2018). The rice research and development is still constrained, among other things, by a shortage of farmer-preferred varieties, lack of improved agronomic packages, low input utilization, terminal drought, low temperature effect, biotic stresses, soil fertility decline, lack of irrigation facilities, erratic rainfall pattern, and pre and post-harvest management problems (MoARD, 2010). Therefore, the objective of this study was to evaluate, select, and recommend better adapted upland rice varieties that are high yielder, diseases tolerant and stable for the study area and other similar agro-ecologies.

2. Material and Methods

2.1 Description of the study area

The experiment was conducted at Gechi, Bedele and Dabo Hana districts (**Fig. 1**) on different farmers' fields during the 2023-2024 main cropping seasons.

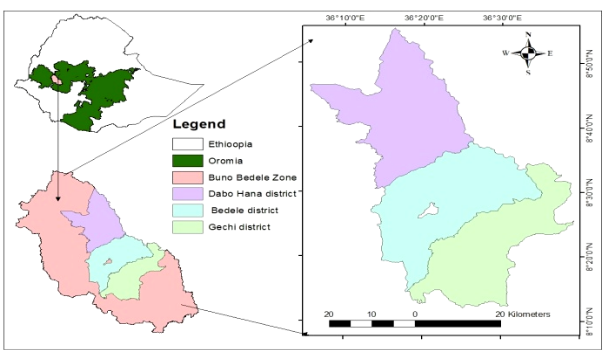

Fig. 1: Map of the study areas

2.2 Gechi district

Gechi is one of the districts in Buno Bedele Zone, Oromia Regional State, and the southwest part of Ethiopia. The district is bordered on the south by Didessa, on the west by Didessa River, on the north by Bedele, and on the east by the Jima Zone. The administrative center of this district is Gechi. The district is located 465 km away from the capital city of the country and 18 km away from Bedele Town. The district is located at an average elevation 1277-2467 m.a.s.l and is located at 8°16'60"N latitude and 36°34'00"E longitude. The annual rainfall ranges from 1500 to 2100mm. The economy of the area is based on a coffee production system in which the dominant crops are maize, tef, sorghum, and wheat, and also horticultural crops.

2.3 Dabo Hana district

Dabo Hana is one of the districts in Buno Bedele Zone, Oromia Regional State Southwest part of Ethiopia. The district is bordered on the south by Bedele, on the west by Dega and Mako, on the north by Chewaka and Leka Dulecha, on south west by Chora, and on the east and northeast by Jima Arjo. The administrative center of this district is Dabo Hana. The district is located 521 km away from the capital city of the country and 38 km away from Bedele Town. The district is located at an average elevation of 1190-2323 masl and is located at 8°30' 21" to 8°43' 29" N latitude and 36°5'27" to 36°26' 19" E longitude. It is generally characterized by a warm climate with a mean annual maximum temperature of 28°C and a minimum temperature of 11°C. The annual rainfall ranges from 900 to 2200 mm. The soil of the area is characterized as Nitisol, Acrisol, Lithosol, Cambisol and Vertisols.

2.4 Bedele district

Bedele district, which is located in BunoBedele zone of Oromia Regional National State, Southwestern Ethiopia. The district is located between 8°14'30"N to 8°37'53"N and 36°13'17"E to 36°35'05"E is about 483km road distance south-west of Finfine. It covers 74497.425 hectares of which 47,986, 9477, and 10,120 hectares are cultivated, forest, and grazing land, respectively. The area is covered with a variety of crops and species of natural vegetation. The dominant crops in the area are maize, tef, sorghum, finger millet, and haricot bean. The major land use types are cultivated land/crop land, forest land, and grazing land (Bedele development agricultural office, 2019).

2.5 Experimental materials and design

Eleven (11) upland rice varieties (**Table 1**) brought from Bako ARC, Adet, Pawe, and Fogera National Rice Research Training Center (FNRRTC) were evaluated as experimental materials. These varieties were randomly assigned to the experimental block, and the experiment was laid out in a Randomized Complete Block Design (RCBD) with three replications. The spacing 980ko between blocks and plots was 1m and 0.5m, respectively. The gross size of each plot was 4.5 m^2 (3m × 1.5m), with six rows and a row-to-row spacing of 25cm. The total area of the experimental field was 247.5 m^2 (38m × 6.5m). Planting was done by drilling seeds in rows with a seed rate of 85 kg ha^{-1}. NPS fertilizer was applied at the rate of 100 kg ha^{-1} (30g per plot) at the time of planting, and Urea was also applied at vegetative stage at the rate of 150 kg ha^{-1}.

2.6 Data collected

Data were recorded on a plot and a single plant basis and taken from the central rows of the plot. Individual plant-based data were taken from five plants in each plot, taken randomly from the central rows of each plot.

Data collected on plot basis

Days to heading (DH): The number of days from 50% of the plots showing emergence of seedlings up to the emergence of the tips of the panicles

Table 1: Description of upland rice varieties used for the experiment

Variety Name	Year of Release	Releasing center	Yield Potential (ton ha^{-1})		Production Ecosystem
			Research	Farmers	
Selam	2020	FNRRTC	5.2	4.8	Upland
Shega	2017	FNRRTC	4.9-6.8	3.9-5.0	Upland
Fogera-1	2016	FNRRTC	4.2-5.0	3.2-3.9	Upland
Pawe-2	2020	PARC	5.1	4.8	Upland
Azmera	2019	FNRRTC	4.8	NI	Upland
Adet	2014	AARC	4.2	2.4	Upland
Nerica-4	2006	PARC	4.8	3.0	Upland
Fogera-2	2016	FNRRTC	4.2-6.1	NI	Upland
Kokit	2000	FNRRTC	3.6	2.8	Upland
Nerica-12	2013	AARC	3.5-4.1	2.3-3.4	Upland
Chewaka	2013	BARC	4.2	3.3	Upland

Seed source = FNRRTC = Fogera National Rice Research and Training Center, BARC = Bako Agricultural Research Center, PARC = Pawe Agricultural Research Center, AARC = Adet Agricultural Research Center, NI = not identified.

from the flag leaf sheath in 50% of the plot stands.

Days to Maturity (DM): The number of days from 75% of the plots showing emergence of seedlings up to the

Disease and insect pest score: will be recorded using (1-9) rating scale where 1 = No visible disease symptom, 3 = resistant, 5 = moderately tolerant, 7 = susceptible and 9 = highly susceptible. The disease will be scored at weekly intervals starting from the first disease spot symptom appearance and will continue k/ until the final stage when the disease attained maximum (Villegas *et al.*, 2012).

Grain yield (g/plot): The weight of grain for all the central row plants, including tillers harvested at the level of the ground

Data collected on a plant basis

Plant height (cm): Measured as the distance from the base of the stem of the main tiller to the tip of the panicle at maturity

Panicle length (cm): The length from the node where the first panicle branch starts up to the tip of the main spike at maturity

Data Analyses

Genstat 18th edition software was used to analyze all the collected data from individual farmers and the combined data over locations. Mean separations were carried out using least significant difference (LSD) at 5% probability level. ANOVA model for a single location as: $Yijk = \mu + Gi + Rj + Bkj + Eijk$ was used.

ANOVA model for the combined over locations as: $Yijkr = \mu + Gi + Lj + Rk(Lj) + Br(LjRk) + GiLj + Eijkr$., Where Y is the performance of genotype i in jth location, kth replication, and rth incomplete block, μ is the mean effect, Lj is the effect of jth location, Rk (Lj) is the effect of the kth replication in location J, Br (LjRk) is the effect of rth incomplete block in jth location and kth replication, GiLj is the interaction effect of genotype i and location j, and εijkr is the error associated with the ith genotype, jth location, kth replication, rth incomplete block

Stability Analysis

Yield stability of the varieties was evaluated using different models: the Additive Main Effect and Multiplicative Interaction (AMMI) model, and Genotype Main Effect and Genotype × Environment Interaction Effect (GGE) biplot analysis were used to determine the effects of GEI, Yield stability index (YSI), and AMMI Stability Value (ASV), on yields.

2.7 Additive main effect and multiplicative interaction (AMMI) model

Additive Main Effect and Multiplicative Interaction (AMMI) is one of the most widely used models to explain G×E interaction of multi-environment genotype trial and categorizing the genotypes into narrow or wider adaptation (Crossa *et al.*, 1990). The AMMI analysis uses analysis of variance (ANOVA) followed by a principal component analysis applied to the sums of squares allocated by the ANOVA to the GEI (Kempton *et al.*, 1984).

The AMMI Model Equation is: $\bar{Y}ijk = \mu + Gi + Ej + \Sigma mk{=}1\ \lambda k\alpha ik\gamma jk + Pij$

Where: $\bar{Y}ijk.$ = the yield of the i^{th} genotype in the j^{th} environment, Gi = the mean of the i^{th} genotype minus the grand mean, Ej = the mean of the j^{th} environment minus the grand mean, λk = the square root of the eigen value of the k^{th} IPCA axis, αik and γjk = the principal component scores for IPCA axis k of the i^{th} genotypes and the j^{th} environment, Pij = the deviation from the model

2.8 Genotype main effect and genotype by environment interaction (GGE) biplot

The GGE biplot (Purchase, 1997) model is: $Yij - \mu - \beta j = \lambda 1 \mathcal{E} i1 \eta j1 + \lambda 2 \mathcal{E} i2 \eta j2 + \mathcal{E} ij$

where: Yij= the performance of the i^{th} genotype in the j^{th} environment; μ = the grand mean; βj = the main effect of the environment j: λl and λ2 = Singular value for IPCA1 and IPCA2 respectively: Ɛi1 and Ɛi2 = Eigen vectors of genotype i IPCA1 and IPCA2 respectively: ηj1 and ηj2 = Eigen vectors of environment j for IPCA1 and IPCA2 respectively; Ɛij = Residual associated with genotype i and environment j.

2.9 Yield stability index (YSI)

This measurement was developed by Farshadfar *et al*. (2011). Stability by itself should not be the only measurement for selection, because the most stable genotypes would not necessarily give the best yield performance. This method is vital to measure and rank genotypes based on grain yield stability. The summation of rank of ASV and rank of yield are used to calculate YSI. The genotype with least YSI is considered as the most stable with high grain yield

YSI was calculated as: $YSI = RASV + RY$,

Where: RASV is the rank of AMMI stability value, RY is the rank of mean yield of genotypes across environments.

2.10 AMMI stability value (ASV)

The ASV is the distance from the coordinate point to the origin in a two-dimensional scatter length of IPCA1 scores against IPCA2 scores in the AMMI model (Purchase, 1997). AMMI Stability Value (ASV), length of genotype and environment markers of the origin in a two-dimensional plot of IPCA1 scores against IPCA2 scores was calculated as follows (Purchase, 1997).

$$\boldsymbol{ASV} = \sqrt{\left[\frac{\text{IPCA1 Sum Squares}}{\text{IPCA2 Sum Squares}}(\text{IPCA1 Score})\right]2 + [\text{IPCA2 Score}]2}$$

Where: IPCA1= interaction principal component axis 1; IPCA2 = interaction principal component axis 2. Genotypes with lower values of the ASV are considered to be more stable

3. Results and Discussion

The combined analysis of variance for mean square values of yield and other agronomic characteristics is presented in **Table 2**. The result revealed that the main effects, varieties, locations, and year showed a highly significant ($P \leq 0.001$) difference for grain yield and other agronomic traits. The variety × year had a significant difference ($P \leq 0.05$) for all yield-related traits and yields. Variety × location had also shown a significant difference ($P<0.05$) for days to heading, days to maturity and thousand seed weight, while plant height and number of fertile tillers per plant were non-significant. This is in agreement with the findings of Sewagegne *et al*. (2013).

Table 2: Combined Mean square values on phonological and yield components of upland rice varieties 2023-2024/2025 cropping season

Source of Variation	DF	DH (days)	DM (days)	PH (cm)	NFTPP (No)	PL (cm)	TSW (gm)	SY (Qt ha^{-1})
Replications	2	0.442*	13.21^{ns}	320.99*	4.60*	7.74*	0.76*	5963499^{ns}
Varieties	10	796.459**	404.24**	1843.18**	41.29**	20.23**	31.36**	13047053**
Years	1	29.87**	61.43**	472.43**	12.050**	85.44**	6.45**	1207**
Locations	2	3175.052**	5806.87**	9862.39**	312.076**	319.94**	2.67**	26205124**
Variety×Year	10	23.67*	11.32*	9.87*	6.70*	13.02*	0.89*	3050*
Variety×location	20	57.038*	40.05**	113.91^{ns}	9.124^{ns}	4.077**	0.75*	3824531**
Variety×location×year	20	68.75**	27.87*	12.89^{ns}	15.50*	45.08^{ns}	20.68^{ns}	58600**
Pooled Error	108	2.739	17.89	77.00	9.88	3.158	11.59	1656383
LSD (0.05)		2.68	6.84	14.20	5.08	2.88	5.79	2082.94
CV %		4.50	7.90	10.30	27.4	9.10	11.50	26.40

DF= Degree of freedom, DH= Days to heading, DM= Days to maturity, PH= Plant height, NFTPP= Number of fertile tiller per plant, PL= Panicle length, TSW= Thousand seed weight, SY= Seed yield, LSD=Least Significant Difference, CV=Coefficient of Variation.

On the other hand, the three-way interaction of Variety × Location × Year effects was highly significant ($P \leq 0.001$) only for days to heading and non-significant for number of plant height, panicle length, and thousand seed weight. The non-significant response of varieties across years, across locations and years indicated that the varieties would respond in a similar manner, while a significant ($P \leq 0.05$) three-way interaction leads to further analysis to determine the magnitude of G×E and separate into component multiplicative terms, and to estimate the yield stability of the varieties.

The mean performances across the two years for seed yield-related traits are presented in **Table 3**.

Table 3: Combined mean yield related traits data of upland rice varieties over locations and year

Sr. No	Varieties	DH (days)	DM (days)	PH (cm)	PL (cm)	NFTPP (No)	TSW (gm)
1	Selam	91.67^{d}	126.7^{b}	83.76^{bc}	18.62^{de}	10.87^{bcd}	30.00^{a-d}
2	Shega	85.07^{f}	117.6^{e}	100.37^{a}	19.26^{cde}	13.51^{a}	25.00^{d}
3	Fogera -1	81.47^{h}	117.9^{de}	80.71^{cd}	19.82^{bcd}	10.47^{cd}	30.00^{a-d}
4	Pawe-2	93.87^{c}	126.7^{b}	81.28^{c}	19.68^{bcd}	8.64^{d}	30.00^{a-d}
5	Azmera	87.87^{e}	120.9^{cd}	88.06^{b}	19.52^{bcd}	10.67^{cd}	31.67^{abc}
6	Adet	83.20^{g}	116.5^{e}	83.47^{bc}	19.11^{cde}	10.27^{cd}	28.33^{bcd}
7	Nerica-4	82.00^{h}	121.3^{c}	85.07^{bc}	20.36^{bc}	13.62^{a}	25.00^{d}
8	Fogera-2	104.27^{a}	131.1^{a}	64.83^{e}	18.60^{de}	13.04^{ab}	31.67^{abc}
9	Kokit	88.87^{e}	116.5^{e}	74.87^{d}	18.04^{e}	10.02^{cd}	35.00^{a}
10	Nerica-12	88.27^{e}	117.8^{e}	89.47^{b}	20.79^{b}	12.18^{abc}	33.33^{ab}
11	Chewaka	99.73^{b}	127.2^{b}	105.44^{a}	22.19^{a}	12.96^{ab}	26.67^{cd}
	GM	89.66	121.82	85.21	19.63	11.48	29.70
	LSD (0.05)	2.68	6.84	14.20	2.88	5.08	5.79
	CV%	4.50	7.90	10.30	9.10	27.4	11.50
	P-value	**	**	*	**	**	*

DF= days to flowering, DM = days to maturity, PH = plant height, PL= Panicle length, NFTPP = Number of fertile tillers per plant, TSW = Thousand seed weight, GM = grand mean, LSD=least significant difference, CV = coefficient of variation, * = significant, ** = highly significant

Days to heading ranged from 81.47-104.27 days, and Fogera-1 was early to heading, whereas Fogera-2 was too late to head. It takes 131.1 days to reach physiological maturity for Fogera-2 and 116.5 days for Kokit and Adet varieties. Osman *et al.* (2012) and Mulugeta *et al.* (2016) evaluated 13 and 22 rice genotypes, respectively, and found that genotypes had variation in days to maturity in the range between 88 and 110 and 104 to115 days, respectively. Maximum plant height (105.44 cm) was recorded for Chewaka, while the minimum (64.83 cm) was for Fogera-2. The maximum panicle length (22.19cm) was recorded for the Chewaka variety, while the lowest (18.04cm) was recorded for the Kokit variety. The maximum Productive tiller per plant (13.62) was recorded for Narica-4 variety, while the lowest (8.64) was recorded for Pawe-2 variety. The maximum thousand-seed weight (35 gm) was recorded for the Kokit variety, while the lowest (25 gm) was recorded for Shega and Narica-4 varieties (**Table 3**). This finding is in line with the previous finding of Tefera *et al.* (2017) and Girma (2018). Disease reactions were recorded, and the most economically important diseases recorded were bacterial leaf blight and brown spot, and the reaction for varieties ranged from resistant to moderately susceptible (**Table 4**).

The mean grain yield ranged from 3229 kg ha^{-1} to 6612 kg ha^{-1} per hectare. The highest grain yield (6612 kg ha^{-1}) was recorded by Chewaka, followed by Adet (5525 kg ha^{-1}), while the lowest was recorded by Kokit (3229 kg ha^{-1}) (**Table 5**). The best-yielding ability of the Chewaka variety might be attributed to larger panicle length per plant. Many authors reported differential performances of rice genotypes across environments (Bose *et al.*, 2014; Krishnamurthy *et al.*, 2015; Mulugeta *et al.*, 2016; Taddesse *et al.*, 2017; Girma, 2018).

Table 4: Summary of disease reactions data of Upland rice varieties over locations and years

Sr. No	Varieties	Bacterial Leaf Blight		Brown Spot	
		PSI	HR	PSI	HR
1	Selam	24	MR	22	MR
2	Shega	10	R	20	MR
3	Fogera -1	24.9	MR	21.5	MR
4	Pawe-2	22.4	MR	23.3	MR
5	Azmera	9.2	R	22.5	MR
6	Adet	8.56	R	9.78	R
7	Nerica-4	23.9	MR	22.5	MR
8	Fogera-2	29.5	MS	30.0	MS
9	Kokit	31.3	MS	32.3	MS
10	Nerica-12	23.6	MR	31.6	MS
11	Chewaka	10	R	20.5	MR

PSI = Mean percentage severity index, HR = Host reactions, MR = moderately resistant, MS = Moderately Susceptible, R = Resistant.

3.1 Stability analysis

Before pooling the data, homogeneity of error variance was tested using Bartlett's test of homogeneity of error variances (Steel and Torrie, 1986). Bartlett's test of homogeneity of error variances ($P<0.01$) illustrated that grain yield data obtained from the five environments were homogeneous. Thus, it indicates the possibility of combining the data for analysis. Pooled analysis of variance (ANOVA) depicted highly significant variation ($P<0.01$) among Upland rice varieties for grain yield (**Table 2**).

3.2 AMMI analysis for grain yield

The combined AMMI analysis (**Table 5**) showed that the mean square for genotype, environment, and the interaction was highly significant ($P< 0.01$) for grain yield. The result indicated the

Table 5: Combined mean grain yield (kg ha^{-1}) of upland rice varieties tested at Bedele, Gechi, and Dabo Hana

Sr. No	Varieties	Dabo Hana District			Bedele District			Gechi	Over all
		2023	2024	Combined	2023	2024	combined		
1	Selam	5981^{abc}	2939^{bcd}	4460^{bcd}	6363^{a}	3832^{bc}	5098^{a}	6256^{bc}	5074^{bc}
2	Shega	7302^{a}	3878^{bcd}	5590^{ab}	5071^{ab}	3987^{bc}	4529^{ab}	7091^{ab}	5466^{abc}
3	Fogera-1	7075^{a}	3157^{bcd}	5116^{abc}	5018^{ab}	3939^{bc}	4478^{ab}	4632^{cd}	4764^{bcd}
4	Pawe-2	3651^{cd}	4817^{b}	4234^{bcd}	4703^{ab}	3867^{bc}	4285^{ab}	4350^{cd}	4278^{cde}
5	Azmera	6472^{abc}	4533^{bc}	5503^{ab}	4792^{ab}	4509^{abc}	4651^{ab}	6072^{bc}	5276^{bc}
6	Adet	8063^{a}	2572^{bcd}	5318^{ab}	6367^{a}	4532^{abc}	5450^{a}	6089^{bc}	5525^{ab}
7	Nerica-4	6783^{b}	2941^{bcd}	4862^{a-d}	3382^{b}	6193^{a}	4787^{ab}	3753^{d}	4611^{bcd}
8	Fogera-2	2875^{d}	2313^{cd}	2594^{d}	5244^{ab}	3540^{c}	4392^{ab}	4390^{cd}	3672de
9	Kokit	4050^{bcd}	1648^{d}	2849^{cd}	3460^{b}	3115^{c}	3288^{b}	3871^{d}	3229^{e}
10	Nerica-12	6046^{abc}	4062^{bc}	5054^{abc}	6175^{ab}	5329^{ab}	5752^{a}	4466^{cd}	5215^{bc}
11	Chewaka	6815^{a}	7625^{a}	7220^{a}	5645^{ab}	4512^{abc}	5079^{a}	8460^{a}	6612^{a}
	GM	5568	3680.56	4800.01	5111	4305.07	4707.96	5402.93	4883.78
	LSD (0.05)	2935	2284.07	2404.46	2862	908.07	1610.69	2017.17	1222.79
	CV%	30.90	30.4	29.90	29.90	12.40	29.50	21.90	25.60
	P-value	**	**	**	*	*	*	**	**

GM = grand mean, LSD = least significant difference, CV = coefficient of variation, * = significant, ** = highly significant.

inconsistent performance of genotypes across the test environments for yield, suggesting the need to conduct further GEI and thereby stability analyses to understand the nature of GEI and stability of the performance of genotypes across environments. Many researchers reported the presence of significant GEI effect on grain yield of rice genotypes that implied the need to conduct GEI and stability analyses (Ramezani and Torabi, 2014; Luguterh *et al*., 2016; Oladosu *et al*., 2017; Taddesse *et al*., 2017; Girma, 2018; Akter *et al*., 2019). The significant mean squares of genotype, environment + (genotype × environment), and environment linear indicated the presence of significant differences among varieties and environments for mean grain yield. Girma (2018) observed that mean squares due to genotypes and interaction of genotype × environment (linear) were highly significant (P < 0.01) by evaluated eleven rice genotypes at six environments in Western Ethiopia, and he suggested the differences in yield performance among the genotypes. Mosavi *et al*. (2013) also observed significant yield differences among rice genotypes, environment, and genotype-by-environment interaction.

The GEI reduces the association between phenotypic and genotypic values and leads to bias in the estimates of gene effects less amenable to selection (Farshadfar *et al*., 2011). In the presence of a significant GEI effect, the identification of superior genotypes for a range of environments is difficult because GEI is complicated to determine their true genetic potential (Yaghotipoor and Farshadar, 2007). It was reported that the contribution of environmental effect was large to total variation (Blanche *et al*., 2009). The results from AMMI model analysis revealed highly significant (P<0.01) mean squares for genotype, environment and G × E interaction effects for grain yield. The highest percentage (65.54%) of the total variation for grain yield was explained by environment, followed by GEI (26.42%), and the least was due to varieties (22.53%) of the total sum square of yield. The large sum of squares for the environment indicated that the environment was diverse, with a large difference among environmental mean and caused variation in the performance of the varieties. This result is in line with the previous findings of Zerihun (2011). The AMMI analysis of variance (for multiplicative) was further exploited by decomposing into Interaction principal component analysis (**Table 6**). The first Interaction Principal Component Analysis (IPCA1) captured 65.06 % of the interaction sum of squares of the multiplicative interactions component, and the second principal component (IPCA2) further explained 27.46% of the multiplicative interaction component, and cumulatively the two principal components explained 92.52%.

3.3 AMMI stability value (ASV) and Yield Stability Index (YSI)

Varieties Chewaka, Adet, and Azmera in the AMMI stability value model had reduced ASV, indicating good stability as well as high yielding. Compared to other varieties, these three varieties exhibit comparatively higher yield performance and stability (**Table 7**). Varieties with high grain yield and the lowest YSI values are thought to be the most stable (Bose *et al.*, 2014; Hebbache *et al.*, 2021; Alemayehu, 2023). Consequently, Chewaka and Adet varieties with great adaptation and high grain production were distinguished by the stability index. Similarly, Roostaei *et al.* (2022) discovered that the genotypes with the highest mean yield were also the most stable. Farshadfar *et al.* (2013) in chickpea and Alemayehu (2023) in Upland rice, in agreement with the current finding. However, the most unstable varieties with significant ASV were Selam, Shega, and Narica-12. Even though these varieties were not stable across the environments, they are adapted to specific niches.

3.4 GGE biplot evaluation of Upland rice varieties for grain yield

Stable and high-yielding genotype is regarded as an ideal genotype, which is represented by the concentric circle (Yan *et al.*, 2007). In reality, an ideal genotype may not exist, but it can be used as a benchmark for genotypic evaluation (Yan and

Table 6: Additive main effect and multiplicative interaction analysis of variances (AMMI) for seed yield of upland rice varieties

Source	D.F.	S.S.	M.S.	TSS %	GEI %	%Cumulative
Environments	4	384820497	96205124**	66.54		
Block (Env't)	10	17897223	1789722^{ns}			
Genotypes	10	130470531	13047053**	22.53		
Interactions (G × E)	40	152981254	3824531**	26.42		
IPCA1	13	99540676	7656975**		65.06	65.06
IPCA2	11	42010129	3819103*		27.46	92.52
Error	80	42430449	19.7			
Total	134	579088593	3531028			

IPCA = Interaction Principal Component Analysis, D.F = Degree of freedom, S.S = Sum of squares, M.S = Mean of squares, TSS = Total sum of squares, GEI = Genotype by Environment Interaction.

Table 7: Mean grain yield (kg ha^{-1}), AMMI Stability Values, and genotype selection index for upland rice varieties tested

Sr. No	Varieties	IPCA1	IPCA2	ASV	ASV Rank	Yield	Yield Rank	GSI	GSI Rank
1	Selam	2.006	14.293	22.69	5	5074	6	11	4
2	Shega	0.879	27.878	42.86	10	5466	3	13	5
3	Fogera-1	16.776	6.993	27.97	6	4764	7	13	5
4	Pawe-2	-27.958	-24.165	36.95	9	4278	9	18	8
5	Azmera	-5.493	5.068	11.50	3	5276	4	7	3
6	Adet	4.749	5.872	11.13	2	5525	2	4	2
7	Nerica-4	30.179	-24.474	59.82	11	4611	8	19	9
8	Fogera-2	-12.592	-17.163	32.77	7	3672	10	17	7
9	Kokit	5.338	-6.045	12.41	4	3229	11	15	6
10	Nerica-12	7.286	-21.901	35.53	8	5215	5	13	5
11	Chewaka	-2.169	6.644	10.75	1	6612	1	2	1
GM						4883.7			

GM= grand mean, IPCA1=Interaction Principal Component Axis 1, IPCA2=Interaction Principal Component Axis 2, ASV= Ammi Stability Value, GSI = Genotype stability index.

Tinker, 2006). The closer a genotype is to the concentric circle is the more favorable. Accordingly, Chewaka was plotted near the concentric circle, followed by Shega and Adet (**Fig. 2**), denoting their yielding potential and relative stability to the fluctuating seasonal and location variability. Therefore, based on grain yield and stability, Chewaka and Adet were found to be desirable upland rice varieties for the studied areas of Buno Bedele Zone.

3.5 Discriminating and representative environments

The GGE bi-plot environment view for grain yield (**Fig. 3**) indicated that each environment was connected to the bi-plot origin using a vector to determine the discriminating ability of the test environments. Environments with longer vectors are known to be more discriminative of the genotypes than those with short vectors (Yan and Tinker, 2006; Sharma *et al*., 2013). In this particular study, Gechi 2024 and Bedele 2023 were found closer to concentric circles, implying that they were the most ideal environments for the tested upland rice varieties. Whereas D/Hana 2023 and D/Hana 2024 were found far from the concentric circle, implying that they were not an ideal environment for the tested varieties.

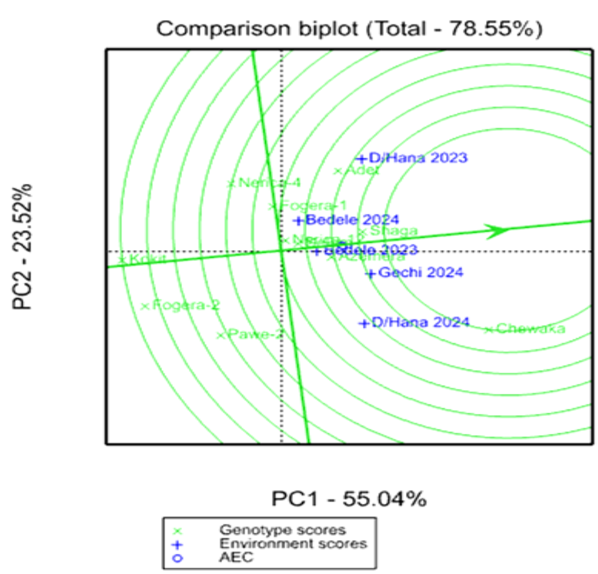

Fig. 2: GGE-biplot based on the ranking of varieties for grain yield relative to stable genotype

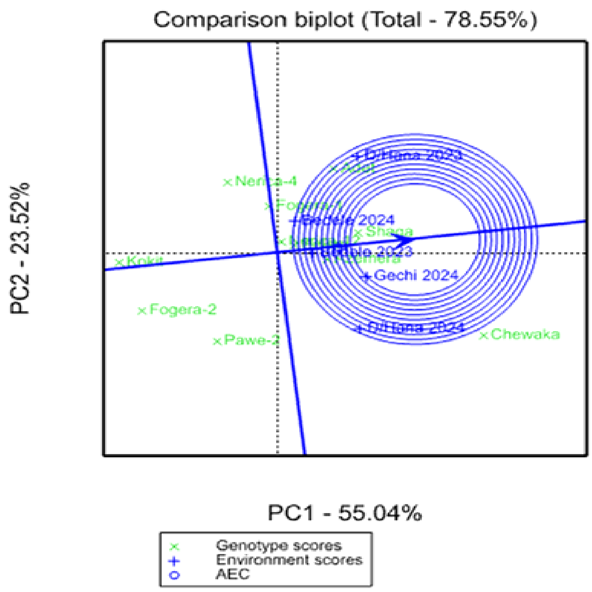

Fig. 3: GGE-biplot based on environment-focused scaling for comparison of the environments with the ideal environment

3.6 Comparison of environments

An environment with a small angle to the average environment axis (AEA) is more representative than other test environments. Being representative is the ability of the environment to allow the genotypes to perform more or less the same as they would in any other environment in the study. Any two environments can be positively, negatively or not correlated if the angles between their vectors are less than 90°, more than 90° or equal to 90°, respectively (Yan and Tinker, 2006; Vishakha, 2017). In this study, the vector view of the GGE biplot (**Fig. 4**) gives a succinct summary of the correlation among the environments. Thus, all the environments (Bedele 2023 with Bedele 2024, Bedele 2023/2024 and D/Hana 2023, D/Hana 2023 with Gechi 2024), were positively correlated to each other as the angle between them was less than 90° (*i.e.* acute angle). While Bedele 2024 with D/Hana 2023 was not correlated from due to the angle between the two closed to right angle (90°) indicated that this two environment significantly different from each other.

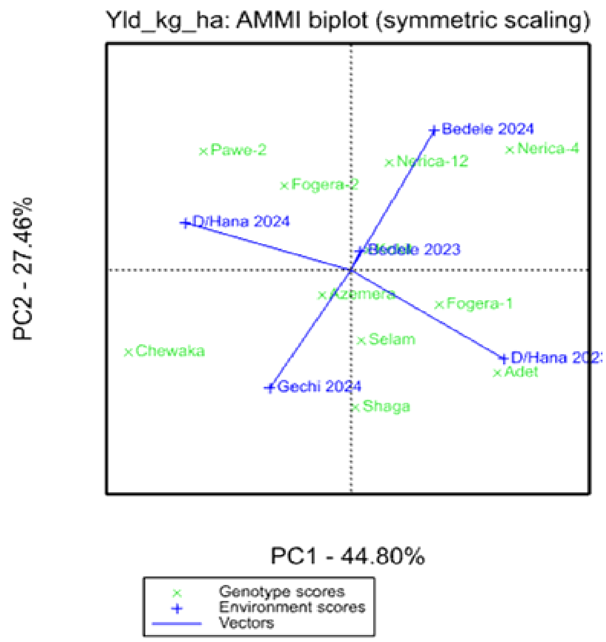

Fig. 4: Average genotype axis (AGA) in view of GGE bi-plot graph for grain yield

4. Conclusion

The Government of Ethiopia has developed national strategy for rice research understanding the role of the crop for food security. The crop is cultivated in most of the regional states in Ethiopia. Since, the mid-1990s, considerable number of upland rice varieties has been recommended for production in regions where rain-fed rice is cultivated in Ethiopia. The recommendation of varieties and introduction of new genotypes alone might not be important to increase the yield of rice in the country rather, the distribution and availability of varieties in rice growing areas is important to identify varieties of wide adaptable or adaptable to specific area which is one of the critical steps in breeding. This research was conducted with the objectives of evaluating, selecting and recommending high yielder and disease tolerant upland rice varieties to the study areas and other similar agro-ecologies. Eleven upland rice varieties were tested at five environments; all important data were collected and analyzed as well. The findings generated from the investigation discovered the presence of significant difference among the varieties, years' locations and their interactions for most parameters studied. On the bases of two years results of the study Chewaka and Adet performed best and maintains consistency in yielding potential in both years (6612 kg ha^{-1} and 5525 kg ha^{-1}) respectively. These varieties were also stable across years and locations for stability studied. Therefore, these two varieties are recommended to be demonstrated for mass production on farmers' fields; as a result small-scale farmers can boost their income.

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