Oryza Vol. 54 No. 4, 2017 (392-400)
DOI 10.5958/2249-5266.2017.00065.0

Grain yield performance and stability of rice variety mixtures and their component cultivars in monoculture

J Meher[1]* and SR Das[2]

[1]ICAR-National Rice Research Institute, Cuttack, Odisha, India

[2]College of Agriculture, OUAT, Bhubaneswar, Odisha, India

**Corresponding author e-mail: jmehercrri@gmail.com*

Received : 20 November 2017 Accepted : 15 December 2017 Published : 20 December 2017

ABSTRACT

It's usually presumed that variety mixtures perform better and are more stable than their component cultivars under diverse growing environments. Therefore, the grain yield performance and stability of six early rice varieties and their fifteen bi-varietal mixtures in all combination were assessed over four growing seasons in a tropical coastal Odisha climate. The mixture constituted equal proportion of both the varieties and were at same overall density as like the cultivar in monoculture. The grain yield stability based on regression model of Eberhart and Russel (1966) indicate that all the varieties including mixtures were stable in the trial environments as deviation from regressions were not significantly different from zero. Based on mean grain yield over environments Annapurna followed by Keshari and Parijat were the top yielder among the cultivars; while the mixture Annapurna+Annada produced highest yield followed by Annapurna+Parijat and Annapurna+Keshari. Further, mixture Annapurna+Keshari would perform well in favourable environment as indicated from higher grain yield from the grand mean with significantly higher bi value ; whereas cv Suphala would perform better in poorer environment, which had lesser yield from the grand mean with significantly lower bi value from unity. Rabi 2006 was the most productive, whereas kharif 2006 was the most stressful environment with overall high and low mean grain yield of entries respectively.

Key words: *Grain yield stability, upland rice, variety and variety mixture*

INTRODUCTION

Rice is an important crop of the world which is staple food for half of the population and that provides their calorie requirement. The crop is grown in around 158.8 million hectare (FAO, 2016) annually, in different parts of the world under diverse climatic conditions with a wide range of growing environments. Most often, the crop faces various biotic and abiotic stresses during its growth stages resulting in substantial yield loss in some unfavorable years creating uncertainty in production. During varietal development, adoptive strategies like evaluation of promising lines over diverse growing environments are usually followed to identify stable lines with minimum yield variability and are recommended for commercial cultivation to achieve the potential yield. Further, in such variable and stress prone environments, the cultivation of varietal mixture offer an opportunity to enhance functional diversity, thereby; can improve the stability in grain yield performance in mixtures than their component cultivars in monoculture. This is from the buffering ability against various biotic and abiotic stresses from the individual and population buffering (Allard and Bradshaw, 1964; Marshall and Brown, 1973). The individual buffering ability is the capability of the individuals to adjust to minor environmental changes and perform better as per its potential; whereas population buffering is the ability of population to adjust itself to change in environmental factors without affecting its performance by better performance of some genotypes in one environment while some other genotypes in a different environment of the population. The increase in yield stability is from the mechanism of compensation and/or complementation due to niche difference *i.e.,* the effective sharing of growth factors or resources or space by the component varieties in mixture as demonstrated in a numerous studies. Variety mixture conferring greater yield stability than their components may also be attributed to reduction in disease and pest progression in a heterogeneous population (Mundt et al., 1985; Finckh et al., 2000; Zhu et al., 2000). Variety mixtures with different characteristics has been demonstrated as a potential means of increasing as well as stabilizing crop yield over environments (Smithson and Lenne,´ 1996; Finckh et al., 2000; Kiær et al., 2009). There was a clear advantage of cultivar blends in winter wheat for stability of grain yield over component cultivars under diverse growing environments of Nebraska (Mengistu et al., 2010) with little or no reduction in grain yield.

Numerous studies indicated that genetic heterogenity led to more stable economic yields in a variety of crop. In rice, the yield and stability study on 3 *indica* varieties, 5 japonica varieties, 3 mixed populations of indica varieties and 4 mixed population of japonica varieties of equal proportion, and 3 hybrid and 4 hybrid F_2 populations respectively in indica and japonica varieties experimented over environments, growing seasons and locations indicated that the mean grain yield productivity was of order F_2 > mixed > pure stand in both indica and japonica varieties. The same order was also observed in the stability of yield as expressed by regression coefficient on environmental means in indica group, but the order was reversed in the japonica type *i.e.,* pure stand> mixed > F_2 populations(Chang and Wee, 1976). Evaluation of grain yield and its stability over seven growing environments in Lauisiana, USA of two rice cultivars and two hybrids and their six 1:1 equi proportional mixtures that included homozygous and homogeneous (variety), heterozygous and homogeneous (hybrid), homozygous and heterogeneous (variety mixture), heterozygous and heterogeneous (mixture of hybrids) suggested that both heterozygous and heterogeneous were more stable than homozygous heterogeneous followed by homozygous-homogeneous based on the stability parameters of principal component analysis of GGE bi plots (Blanche and Linscombe, 2006). Several studies have shown that variety mixtures have superior stability to pure stands (Aslam & Fischbeck, 1993; Sharma and Dubin, 1996; Helland and Holland, 2001; Cowger and Weisz, 2008; Mengistu et al., 2010; Kiaer et al., 2012). Since varieties behave differently in mixture than in monoculture, greater gain in stability would occur from systematic search for components that exhibit a high degree of buffering capacity when mixed, rather than composing variety mixture based on yield capability alone (Gupta and Virk, 1984). However, few contrasting results are also available where no evidence of increase in grain yield and grain yield stability was observed. In early duration rice some varieties showed high grain yield stability were reported by Subudhi et al. (2008) in coastal Odisha and in upland rice varieties grain yield stability was also reported by Bhakta and Das (2007) over four locations in Odisha, India. However, no report was available on the yield stability of rice variety mixture and their component cultivars in India so far.

Therefore, this study was undertaken to assess the grain yield performance and the stability of bi-varietal mixtures *vis-a-vis* their components in monoculture in four different growing environments and to identify the most productive stable variety(ies) and / or mixture(s) over the environments.

MATERIALS AND METHOD

Materials consisted of six photo-insensitive improved rice cultivars of 95-105 days duration adapted to upland direct seeding conditions and their fifteen resultant bi-varietal mixtures in all combination. These varieties were Annapurna, Parijat, Suphala, Keshari, Annada and Sidhant. These varieties along with their fifteen bi-varietal mixture were grown in four different growing seasons in one *kharif* (wet season) in 2006 (E2) and three *rabi* (dry season) in 2006 (E1), 2007 (E3) and 2009 (E4). The mixtures consisted of equal proportion of seeds and/or plants of both the varieties. Except wet season 2006, in all other seasons a line to line and a plant to plant spacing of 10 x 10 cm^2 was maintained with 12 rows of 2.7 m length and each hill was dibbled with 3-4 seeds. For bi-varietal mixture, each variety was sown in alternate hill in a row and starting with second variety in subsequent row such that each variety was surrounded by the other and vice versa and extended to all fifteen mixtures, keeping population of both the variety equal and constant. In mixture, the plants of same variety were arranged as like in a chess board representing either black or white squares. Both the varieties have equal stand and one was surrounded by other in all the directions that determine inter- varietal competition in mixture whereas it was intra-varietal competition in monoculture. A thinning was done at 10 days after sowing, from all the hills dibbled with seeds in monoculture and in mixtures by uprooting the other plants leaving only one healthy plant in a hill. In wet season 2006, line sowing was done for monocultures with 2080 freshly harvested viable seeds and for bi-varietal mixture with 1040 seeds from each variety based on seed rate and test weight of varieties in row spacing of 15cm with 7 rows. The trials were conducted at Rice Research Station, OUAT, Bhubaneswar in a randomized complete block design and all the entries (monoculture and bi varietal mixtures) were replicated thrice. The trial location situated in eastern coastal plain of 20.29^0 N latitude and 85.84^0 E longitude around 45m above msl, and soil type was lateritic sandy loam with PH 6.8. A uniform fertilizer dose of 80:40:40 NPK was applied in all the trials over the years. Entire P_2O_5 and half N and K_2O were applied as basal and rest N and K_2O in two equal splits at 30 and 60 days after sowing. All the trials were evaluated under recommended crop management practices including need based irrigation and plant protection to raise a normal crop.

Data collection and data analysis

At physiological maturity, whole plot was harvested leaving borders from *rabi* (dry season) 2006, 2008 and 2009 experiments replication wise from each entry and threshed properly. The grain was cleaned, sun dried for 7-8 days for 8 hours a day to bring grain moisture level to 14%. Grain weight was taken in a mechanical spring balance and recorded the weight and converted the grain yield into tonne/ha (t ha^{-1}). Similarly, the mixed sowing trial in line sown with seed mixture of the two component varieties and their constituent variety as monoculture in *kharif* (wet season) 2006 was harvested leaving the borders, threshed, cleaned and dried and taken grain yield and that were converted to t ha^{-1}. The grain yield expressed in t ha^{-1} from each entry i.e. variety and mixture replication wise were tabulated and subjected to analysis of variance for each trial representing an environment. The combined analysis of variances over the environments was carried out for grain yield. The stability parameters of entries over the environment were estimated based on the regression model proposed by Eberhart and Russel (1966) using statistical software for Plant Breeding data analysis using Indostat version 7.0. Based on the three parameters of stability, that is overall mean of the entry over environment (μ), its regression from the mean of the entry under different environment (bi) and deviation from regression (S^2_{di}) stability of entries were worked out

The linear model proposed by Eberhart and Russell (1966) was

$$Y_{ij} = \mu_i + b_i I_j + \sigma_{ij} + e_{ij}$$

Where, Y_{ij} = mean performance of the ith genotype in jth environment

μ_i = average performance of the ith genotype over all the environments.

b_i = regression coefficients that measures the response of ith genotype to the varying environments.

I_j = environmental index of the jth environment and is obtained as the deviation of the mean of all genotypes in the jth environment from grand mean.

σ_{ij} = deviation from regression of the ith genotype at jth environment

e_{ij} = random error

RESULTS AND DISCUSSION

Stability analysis of varieties and bi-varietal mixtures for grain yield

The most wide and popularly used regression model of stability was used to identify the stable genotypes (varieties and/or mixtures) by regressing the genotypic mean yield of a genotype on environmental index that is the genotypic mean of a particular genotype (varieties or mixtures) over the mean yield of all entries in that environment. The stable genotype can be defined as per the parameters suggested by the model is high varietal mean (μ) over the test environments above the grand mean ($\bar{X}$), regression coefficient (bi) tend to unity and the mean square deviation ($\overline{S^2d_i}$ or σe_j) from regression tend to zero *i.e.,* it should not deviate from zero significantly for a stable genotype. The pooled analysis of variance presented in Table 1showed significant differences among the entries (variety and the mixture), the environments and also the genotype x environment, as evident from the F test of the calculated F values at appropriate degree of freedom under the mentioned level of probability. The F values are calculated for MS due to variety (variety + mixture) and MS due to environment with respect to MS of genotype x environment and MS of genotype x environment with mean square of Standard error and were tested against by appropriate F test at respective degree of freedom at different level of probability mentioned against them.

The mean grain yield expressed in tonne/ha (t ha^{-1}) over replications for each variety and mixture in each environment and the mean over the environments, the regression coefficient (bis) and deviation from regression ($\overline{S^2d_i}$) for each entries, the grand mean of all entries (varieties and mixtures) along with other statistics like environmental index are depicted in Table 2.

The environment wise analysis of variance was also conducted to test the significant differences exists among the varieties including bi-varietal mixtures for their grain yield performance. The mean grain yield data expressed in (t ha^{-1}) of each environment for each variety and their bi-varietal mixtures were pooled and pooled analysis of variance was conducted to further partition the sum of square due to varieties including mixtures, sum of square due to environment + (environment x varieties) and pooled error. Suitable 'F' test was done to test the significant difference among the varieties (that include also the bi-varietal mixture) *i.e.,* to test the varieties including mixtures that did not differs for their regression on the environmental index and also to test the significance deviations from regression of individual variety including mixture. The estimation of mean bi and standard error of bi and S.E. (bi) of individual variety and mixture, population mean ($\overline{X}$) and S.E. (mean) was done using mean square due to pooled deviations.

The pooled ANOVA for stability performance of varieties and bi-varietal mixtures for grain yield (t ha^{-1}) is given in Table 1and stability parameters of varieties and bi-varietal mixtures for grain yield (t ha^{-1}) over four growing environment are given in Table 2. The bi value is the linear response of varieties and mixture to a change in environment that predict the performance of variety in a change environment and if bi is negative and less than unity (1) then the variety perform well in poor environment *e.g.,* low fertile soil and if it above unity (1) then it will perform well in rich environment. When the deviation from regression is not significantly deviating from zero indicate that the variety is more stable and when it significantly deviates from regression it is less stable. The most ideal conditions to determine a stable genotype is, the mean should be above grand mean over all environments, the regression coefficient bi of the variety should approach unity (≈ 1) and deviation from regression should be zero without a significant value.

Pooled ANOVA for stability performance of varieties and bi-varietal mixtures

The mean square from pooled ANOVA indicates significant difference observed among the entries (varieties + mixtures), among the environments and between genotype x environment. It further revealed that Env + (Var x Env) is highly significant, Environment (linear) and Var x Env (linear) are also significant indicates differences observed among them. The pooled deviations of each variety including mixtures also found to be highly significant when tested against pooled error indicates that the varieties responses to different environmental change were different and that responses were significant (Table 1). This indicate that enough variability among the entries for grain yield (t ha^{-1}), environments and also response of entries were different to environmental change, hence stability analysis by regression model to identify the stable varieties and/or mixture was undertaken. The genotype x environment was significant only at ($P < 9.0$) indicate that there was not much influence of environment on grain yield of these varieties and their bi-varietal mixtures probably because these varieties are well adapted to the local environmental conditions of the trials environment with high degree of buffering effect and the range of variability in trial environment were narrow although significant among themselves.

Performance of varieties and mixtures under different environments

The environment 1, *i.e.,* the mixed sown experiment during *rabi*, 2006 was the most favorable environment, where the mean grain yield (t ha^{-1}) is highest with 3.108 that is above the grand mean over the environments. Among the genotypes variety Annapurna performed

Table 1. Pooled ANOVA for stability performance of varieties and bi-varietal mixtures for grain yield.

Source of Variations	df	Sum of Squares	Mean Squares	F Ratio	Probability
Rep within Env.	8	0.55615	0.06952	1.624	0.14689
Varieties	20	6.40731	0.32037***	7.486	0.00000***
Env.+ (Var.x Env.)	63	60.01126	0.95256***	22.258	0.00000***
Environments	3	56.16681	18.72227***	437.479	0.00000***
Var.x Env.	60	3.84446	0.06407†	1.497	0.08471†
Environments(Lin.)	1	56.16681	56.16681***	1312.436	0.00001***
Var.x Env.(Lin.)	20	2.04704	0.10235**	2.392	0.00866**
Pooled Deviation	42	1.79743	0.04280**	1.889	0.00269**
Pooled Error	160	3.62574	0.02266		
Total	83	66.41857	0.80022		

†, *, **, *** Significant at 10%, 5%, 1% and 0.1% respectively, N.B. Varieties mentioned in the tables include bi-varietal mixture also.

very well with grain yield of 4.310 t ha^{-1} followed by mixture Annapurna+ Keshari and Annapurna +Annada both with grain yield of 3.857 t ha^{-1}. The poorest performer was Suphala followed by mixture Suphala + Keshari with the same grain yield of 2.383t ha^{-1}. The performances of varieties in different environment as revealed from Table 2 indicate that Annapurna followed by Sidhant produced highest yield under *rabi* 2006 environment (E1) although no significant difference was observed among other varieties except Suphala and Annapurna. The mixture Annapurna + Keshari, Annapurna + Annada and Annapurna + Parijat also produced higher yield that was comparable to Sidhant (3.570 tha^{-1}) but not better than Annapurna. There was a reduction in yield of Annapurna + Suphala mixture, may be because of poor contribution from Suphala. Other better yielder mixture were Keshari + Annada, Keshari + Sidhant, Annada + Sidhant, Parijat + Keshari and Parijat + Annada with no and/or minimal deviation from mean monoculture of component.

In environment 2 (*kharif*, 2006), the mean grain yield was 1.141t ha^{-1} and that was lowest among all the testing environments. The highest grain yield of 1.643 t ha^{-1} was obtained in variety Parijat followed by Keshari with 1.483 t ha^{-1} and mixture Keshari + Sidhant with 1.447 t ha^{-1}. The lowest grain yield of 0.897 kg/m^2 was realized both in mixtures Parijat + Suphala and Suphala + Annada. Among the varieties Suphala was lowest yielder with 0.940 t ha^{-1}. *Kharif*, 2006 (E2) was a poor environment because of its high rainfall at early vegetative stage of the crop that lead to water stagnation and was not desirable for upland varieties like this trial. In this environment, Parijat performed better followed by Keshari, Annapurna and Sidhant. The most affected varieties in monoculture were Suphala and Annada based on grain yield. A comparatively better grain yield were obtained in Keshari + Sidhant and Parijat + Keshari in mixture implies that these varieties *i.e.,* Parijat and Keshari also influence the mixture performance under such harsh environment when they were component; may be because of better mixing ability and compatibility between them that reflect in stability in performance.

The mean grain yield of 1.354 t ha^{-1} was obtained in environment 3. The highest yielders were Annapurna and Keshari in monoculture both with1.817 t ha^{-1} followed by1.773 t ha^{-1} in mixture Suphala + Keshari and with 1.727 t ha^{-1} in mixture Annapurna + Annada respectively. The lowest yielder is Parijat + Sidhant with grain yield of 0.907 t ha^{-1} preceded by Suphala + Sidhant with 0.920 t ha^{-1} and Parijat + Annada with 1.010 t ha^{-1}. The lowest yielder was Suphala among the varieties in monoculture with a grain yield of 1.063 t ha^{-1}. Also better yield in Keshari + Annada, Annapurna + Suphala and Parijat + Keshari than mean yield of this environment was obtained indicate that the grain yield of mixture was close to mean monoculture, when either Annapurna or Keshari was a component in mixture. Therefore, these cultivars had a positive effect on mixture performance although no increase from mean monocultures was obtained. On the contrary, Parijat, Suphala and Sidhant showed lower yield as monoculture and also in different mixture combinations like Parijat + Annada, Parijat + Sidhant and Suphala + Sidhant probably due to lower contribution of these varieties in mixture and also due to low mixing ability among them. The incompatibility because of competition also cannot be ruled out, as all of them like Parijat, Annada and Sidhant are of similar duration, T**able 2.** Stability parameters of varieties and bi-varietal mixtures for grain yield (t ha-1) over 4 environments (Eberhart and Russel, 1966).

Sl.No.	Variety and Mixtures	Env.1	Env.2	Env.3	Env.4	Mean(μ)	$\overline{S^2d_i}$	bi
1	Annapurna	4.310	1.290	1.817	3.140	2.639	0.024	1.426
2	Parijat	3.347	1.643	1.150	2.540	2.170	0.114	0.978
3	Suphala	2.383	0.940	1.063	2.030	1.604	-0.023	0.754*
4	Keshari	3.233	1.483	1.817	3.077	2.403	0.014	0.918
5	Annada	3.070	0.963	1.430	2.840	2.076	0.026	1.081
6	Sidhant	3.570	1.237	1.160	2.583	2.138	0.027	1.210
7	Annapurna+Parijat	3.553	1.300	1.167	2.967	2.247	0.020	1.253
8	Annapurna+Suphala	3.007	1.063	1.577	2.820	2.117	0.033	0.981
9	Annapurna+Keshari	3.587	1.140	1.323	2.753	2.201	-0.019	1.239*
10	Annapurna+Annada	3.587	1.277	1.727	2.987	2.394	-0.014	1.135
11	Annapurna+Sidhant	3.183	1.110	1.323	2.713	2.083	-0.020	1.080
12	Parijat+ Suphala	2.640	0.897	1.237	1.920	1.673	0.002	0.806
13	Parijat+ Keshari	2.997	1.407	1.450	2.543	2.099	-0.020	0.842
14	Parijat+ Annada	2.973	0.940	1.010	2.367	1.823	-0.019	1.067
15	Parijat+ Sidhant	2.450	0.907	0.907	2.153	1.604	-0.007	0.855
16	Suphala+ Keshari	2.383	1.150	1.773	2.343	1.913	0.058	0.561
17	Suphala+ Annada	2.867	0.897	1.347	1.903	1.753	0.055	0.865
18	Suphala+ Sidhant	2.793	0.947	0.920	1.790	1.613	0.050	0.907
19	Keshari+ Annada	3.250	0.970	1.630	2.797	2.162	0.027	1.091
20	Keshari+ Sidhant	3.020	1.447	1.240	2.843	2.138	0.053	0.948
21	Annada+Sidhant	3.073	0.960	1.367	2.330	1.933	-0.007	1.003
	Mean	**3.108**	**1.141**	**1.354**	**2.545**	**2.037**		**1.000**
	S.E.(±)	0.322	0.132	0.137	0.204			0.126
	Env. Index (Ij)	1.071	-0.896	-0.883	0.508			
	CD(0.05)	0.651	0.267	0.277	0.412			
	CD(0.01)	0.871	0.357	0.371	0.552			
	C.V. (%)	12.671	14.175	12.403	9.818			

* Significant at 5%

height and erect type that compete with each other.

The mean grain yield performance of varieties and their bi-varietal mixtures over replications expressed in t ha^{-1} for environment 4 (*rabi*, 2009) are presented in Table 2. From the table, it revealed that the general mean of the varieties and their bi-varietal mixtures in this environment is 2.545 t ha^{-1} which was the 2nd highest among the four growing environments. The varieties and mixtures that performed better were Annapurna with grain yield of 3.140 t ha^{-1} followed by Keshari with 3.077 t ha^{-1} and in mixtures Annapurna + Annada produced a gain yield of 2.987 t ha^{-1} followed by Annapurna + Parijat with 2.967 t ha^{-1}. The low yielders were Suphala + Sidhant with 1.790 kg/ m^2 followed by Suphala + Annada with 1.903 kg/m^2. It was observed that Annapurna enhances the mean grain yield in mixture, whereas Suphala decreases the mean grain yield whenever those were the constituents. The mixture Annapurna + Annada, Annapurna + Parijat, Annapurna + Keshari, Keshari + Sidhant, Annapurna + Suphala, Keshari + Annada, and Annapurna + Sidhant were out yielded the environmental mean for *rabi*, 2009. In mixture when Annapurna and /or Keshari was a component improves the mixture productivity close to the highest monoculture performance of Annapurna or Keshari and these combination can be exploited to achieve desirable mixture yield with genetic diversity that may be more resilient under various biotic and abiotic stresses. Keshari was found to be a more stable variety as it was having one of the highest yielder in normal as well as in stressful environment and under favourable environment Annapurna was the highest yielder because of its yielding ability and better plant characteristics.

In *rabi*, 2006 environment (E1) the varieties were line sown at recommended seed rate and in case of bi varietal mixture by mixing seeds based on test weight. Since the relative density was high in comparison to other environments *i.e., kharif*, 2006 (E2), *rabi* 2007 (E3) and *rabi* 2009 (E4), where varieties were grown at a spacing of 10 cm between and within row and maintained only with single plant per hill, the grain yield were marginally lower in these environments across the entries. In general, the grain yield of Annapurna was higher and Suphala was lower marginally than other four varieties *viz.,* Parijat, Keshari, Annada and Sidhant. The higher yielding ability of Annapurna may be due to better tillering, short bold grain with high spikelet fertility, whereas the low yield in Suphala relate to low test weight and biomass due to dwarf plant type. Other varieties like Parijat, Keshari, Annada and Sidhant had comparable yield in monoculture and all these six varieties were more or less of similar duration (95-105 days). The *kharif*, 2006 trial got enough rainfall at early vegetative stage as a result 15-20 cm water stagnation for a week leading to poor tillering and some mortality in some of the treatment, hence decrease in yield invariably for all entries. When the mixture yield performance compared with better constituent monoculture almost all mixture yielded less than the better constituent in monoculture which is observed in rice (Bastia et al., 2008).

Grain yield stability of varieties and bi-varietal mixtures

Based on the mean grain yield of entries (varieties as monoculture + bi-varietal mixtures) over environments, their regression coefficient (bis) and deviations from regression ($\overline{S^2d_i}$) for each entries; the stable genotypes are identified as per the stability model of Eberhart and Russel (1966). The most promising monoculture/mixture that gave highest yield over the environments which was above the grand mean of grain yield of all entries (varieties + mixtures) of 2.037 t ha^{-1} were Annapurna with 2.639 t ha^{-1} followed by Keshari with 2.403 t ha^{-1} and Annapurna + Annada with 2.394 t ha^{-1} where, bi $\approx$ 1 and $\overline{S^2d_i}$ tends to zero without any significant deviation from zero were the most stable genotypes. However, these entries were also found to be stable based on the aforesaid parameters which were Parijat (2.170 t ha^{-1}), Annada (2.067 t ha^{-1}), Sidhant (2.138 t ha^{-1}), Annapurna + Parijat (2.247 t ha^{-1}), Annapurna + Suphala (2.117 t ha^{-1}), Annapurna + Keshari (2.201 t ha^{-1}), Annapurna + Sidhant (2.083 t ha^{-1}), Parijat + Keshari (2.099 t ha^{-1}), Keshari + Annada (2.162 t ha^{-1}), and Keshari + Sidhant with 2.138 t ha^{-1} (Table 2). For any of the mixtures deviation from regression ($\overline{S^2d_i}$) tends to zero with regression coefficient (bi) tends to unity, which support the hypothesis and findings reported by many workers that heterogeneity imparts stability in mixtures.

In Annapurna where bi was not significantly different from 1 although with value above unity that is 1.426 indicates, Annapurna may not perform better in favorable environments. Since $\overline{S^2d_i}$ is not significantly deviated from regression i.e. zero for any of the varieties and/or mixtures, all are found to be stable over environments. The lowest yielding genotype (variety and /or mixture) were Suphala with 1.604 t ha^{-1} but bi significantly < 1, Parijat + Suphala with same level of yield as Suphala, followed by Suphala + Sidhant with 1.613 t ha^{-1} and Parijat + Suphala with1.673 t ha^{-1} over environments, suggest that these genotypes were less productive; hence not to be chosen for cultivation in any unfavorable environment except Suphala that perform well in a poorer environment with a low predicted yield as bi was significant with < 1.

The varieties/mixtures showing 'bi' values >1 are Annapurna with 1.426, Annapurna +Parijat with 1.253, Annapurna + Keshari with 1.239 and Sidhant with 1.210. But, only in Annapurna + Keshari with 1.239 is significantly different from unity (1) as evident from t test with standard error of the entry indicates this mixture will show a better response in their performance in a better (favourable) environment, whereas varieties or mixtures that have bi < 1 and significantly deviated from 1 would show good response in poorer environment. The only variety Suphala that show significant bi of 0.754 performed well in poorer environment.

Numerous studies indicated that generally the mixture were more stable than pure stands (Smithson and Lenne, 1996; Mengistu et al, 2010; Aslam and Fischbeek, 1993; Sharma and Dubin, 1996; Cowger and Weisz, 2008; Kaut et al., 2009; Ostergard et al., 2005; Kaier et al., 2012) in red hard winter wheat which support this findings as many mixture were stable on par with the component cultivar if not better than the component as evident from mixture of Annapurna + Parijat, Annapurna + Suphala, Annapurna + Keshari, Annapurna + Annada, Annapurna + Sidhant, Parijat+ Keshari, Keshari + Annada and Keshari +Sidhant. Likewise, the stability of cv Annapurna and Keshari as monoculture was better stable than any of the mixture from this study is in agreement with the results reported from earlier studies where the mixtures were not the most stable one among the plots were also reported in winter wheat by Dubin and Sharma (1993); Bebawi and Nayler (1978) from Oat and barley mixture with their components, and not necessarily all hanfets (blend of barley and wheat) were more stable than pure crop (Woldeamlak et al., 2008). The yield stability of rice cultivars and cultivar mixture didn't differs significantly in this study is also supported from similar study in late season oat cultivar and cultivar mixture that did not differs in stability (Helland and Holland, 2001); and no evidence of increase in grain yield and stability of mixture in this study as all mixture showed poor yield and stability than Annapurna and Keshari that was also reported by Paynter and Hills (2008) in barley.

The overall mean grain yield of entries over all the growing environments showed Annapurna as the most productive entries followed by Keshari and none of the mixtures performed better than these two varieties. Some of the productive mixture and cultivar that outyielded from the grand mean yield of entries over environments were Annapurna + Annada, Annapurna + Parijat, Annapurna + Keshari, Keshari + Annada, Sidhant, Keshari + Sidhant, Annapurna + Suphala, Annapurna + Sidhant, Parijat and Annda. Also none of them show significant deviation from regression, hence they can be termed as the stable entries based on regression model of Eberhart and Russel (1966) on three stability parameters as indicated earlier. The stability of mixture was improved where Annapurna or Keshari was a component that usually enhances the mixture productivity except in Suphala + Keshari as evident from Table 2. This is due to better yielding ability of these entries that contributes better for mixture productivity and probably these two are better compatible with other component varieties because of their plant architecture like height, tillering ability, larger LAI and grain test weight with better mixing ability and least fluctuation in grain yield over the environments. Annapurna + Keshari showed a significant bi value above unity indicate it respond better to favourable environment. This was also evident from the better and stable yield of the mixture where either of these two cultivar was the component and less variable performance in yield of these varieties in various environment when grown as monoculture as well as least fluctuation of its performance in combination with other in mixture. Suphala on the other hand showed a better performance in comparison to other varieties as monoculture that deviate less in grain yield among the environments, although the yield level was lowest among the varieties. Therefore, it will show a better response to poorer environment because of its adaptability as it showed less fluctuation and bi value significantly less than unity and therefore, it may be act as a component with better compatibility in mixture for poorer environment. On the contrary, Parijat, Annada and Sidhant showed better yield as monoculture in various environment and were more stable, but in different mixture combinations like Parijat + Annada, Parijat + Sidhant and Annada + Sidhant they showed lower yield in mixture as a result showed poor in stability based the aforesaid parameters which may be due to low mixing ability among them. The incompatibility because of competition also cannot be ruled out, as all of them like Parijat, Annada and Sidhant are of similar duration, height and erect type that compete with each other.

From Table 2, it revealed that most of the mixture with Annapurna and/or Keshari as a component improve yield stability except in Suphala + Keshari as these varieties are higher yielding with better plant type, compatible well with other component varieties in mixture with better mixing ability and with least fluctuation over the environments. However, none of the mixture was better productive than Annapurna and Keshari mean over the environments and also for stability, probably because these varieties have high yield, better plant type and buffering ability or plasticity. Cultivars Annapurna, Keshari, Parijat, Sidhant, Annada were also stable on the aforesaid stability parameters. It support the views that yielding ability of mixture hardly exceed the yield of better component as reported from many studies and contradict the notion that yield stability is better in mixture than the component cultivar. Similar results were also found in four two row barley cultivar in eleven mixture combination tested over eleven sites in Australia (Paynter and Hills, 2008). But the stability of some of the mixture like Annapurna + Annada, Annapurna +Parijat, Annapurna +Keshari, and Keshari+ Annada (Table 2) are comparable to Annapurna and Keshari also support the view that mixture are more stable as reported in many cases.

Generally, yielding ability of the varieties, their mixing ability and compatibility improve yield stability in mixture as revealed from this study.

CONCLUSION

Therefore, it can be concluded that cv Annapurna and Keshari followed by mixture Annapurna + Annada were the most stable. Both Annapurna and Keshari contribute positively for yield and stability of mixture while Suphala and Parijat contribute negatively. The stability of mixture is depends on the components yielding ability and stability, and their compatibility or mixing ability. It goes against the notion that all the mixture are better stable than the components, but most of the components as well as some of the mixture were better stable and stability in mixture depend on positive interaction of the components which were not competing for resources.

REFERENCES

Allard RW and Bradshaw AD (1964). Implications of genotype-environment interactions in applied plant breeding. Crop Science 4: 503-508

Annonymous (2016). FAO Statistics 2015-16

Aslam M and Fischbeck G (1993). Development of stripe and leaf rusts in wheat cultivar mixtures. Journal of Agronomy and Crop Science 171: 49-57

Bastia DN, Das SR and Mishra TK (2008). Studies on inter-genotypic competition in upland rice. Oryza 45(2): 88-93

Bhakta N and Das SR (2008). Phenotypic stability for grain yield in rice. Oryza 45(1): 115-119

Bebawi FF and Naylor REL (1978). Yield performance of mixtures of oats and barley. New Phytologist 81: 705-710

Eberhart SA and Russell WA (1966). Stability parameters for comparing varieties. Crop Science, 6:36-40.

Finckh MR, Gacek ES, Goyeau H, Lannou C, Merz U, Mundt CC, Munk L, Nadziak J, Newton AC, Vallavieille-Pope C and Wolfe MS (2000). Cereal variety and species mixtures in practice, with emphasis on disease resistance. Agronomie 20(7): 813-837

Gupta AK and Virk DS (1984). Intergenotypic competition in mechanical mixture of bread wheat. Crop Improvement 11: 25-29

Kiær LP, Skovgaard IM and Østergaard H (2009). Grain yield increase in cereal variety mixtures: A meta-analysis of field trials. Field Crops Research 114: 361-373

Marshall DR and Brown AHD (1973). Stability performance in mixtures and multilines. Euphytica 22: 405-412

Mundt CC, Brophy LS and Schmitt MS (1995a). Disease severity and yield of pureline wheat cultivars and mixtures in the presence of eyespot, yellow rust, and their combination. Plant Pathololgy 44: 173-182

Ostergard H, Kristensen K and Jensen JW (2005). Stability of variety mixtures of spring barley. In E.T. Lammerts van Bueren et al. (ed.) Proc., Workshop on Organic Plant Breeding Strategies and the Use of Molecular Markers. Driebergen, The Netherlands 17-19 th Jan. 2005

Paynter BH and Hills AL (2008). Mixing feed barley cultivars did not decrease leaf disease or increase grain yield. Australasian Plant Patholoy. 37(6) : 626- 636

Sharma RC and Dubin HJ (1996). Effect of wheat cultivar mixture on spot bloch (Bipolaris sorokiniana) and grain yield. Field Crop Research 48: 95-101

Smithson JB, Lenee JM (1996). Varietal mixtures: a viable strategy for sustainable productivity in subsistence agriculture. Annals of Applied Biology 128: 127-158

Subudhi HN, Meher J and Bose LK (2008). Stability analysis for grain yield in some rice varieties. Ecology and Environment 26(4): 2199-2201

Woldeamlak A, Sharmam JK and Struik PC (2009). Yield advantage analysis and competition on barley - wheat intercropping in the central highlands of Eritrea. Progressive Agriculture 9(1): 1-5

Zhu Y, Chen H, Fan J, Wang Y, Li Y, Chen J, Fan JX, Yang S, Hu L, Leung H, Mew TW, Teng PS, Wang Z and Mundt CC (2000). Genetic diversity and disease control in rice. Nature (London) 406: 718-722