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Identification of drought tolerant, high yielding rice genotypes for rainfed upland ecosystem of Uttarakhand hills through different drought tolerance indices

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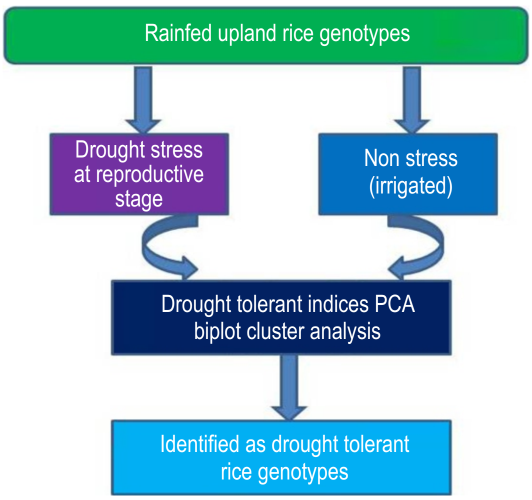
Abstract

Aim: To identify drought tolerant rice genotypes for rainfed upland hills at reproductive stage through different drought tolerance indices, PCA Biplot Analysis and Cluster Analysis.

Methodology: Forty eight rainfed upland genotypes were evaluated under drought stress at reproductive stage and non-stress (irrigated) conditions. Different drought tolerance indices *viz.,* drought tolerance efficiency (DTE), mean productivity index (MPI), relative efficiency (REI), mean relative performance (MRP), stress tolerance index (STI), drought yield index(DYI), stress tolerance (TOL), stress susceptibility index (SSI) and Schneider's stress susceptibility index (SSSI)were used for screening genotypes.



Results: The reduction in grain yield was observed in all the genotypes grown under drought stress condition and the per cent reduction in grain yield between stress and non-stress trial varied from 23.62% to 67.69%. The highest value of DTE was recorded in VL 20541 (76.38%) whereas VL 20441 showed the highest value for MPI (2656), REI (1.478), MRP (2.44) and STI (0.79). The lowest value of DYI (1.31), TOL (625), SSI (0.51) and SSSI (-0.23) was observed in VL 20541. Highest value for DTE, MPI, REI, MRP, STI and lowest value for DYI, TOL, SSI, SSSI are preferred and desirable as it indicate drought tolerance. A positive and highly significant correlation was exhibited by grain yield under stress (YS) with DTE, MPI, REI, MRP, STI and highly negative significant with DYI, TOL, SSI SSSI indicating that selection of low DYI, TOL, SSI, SSSI value and high DTE, MPI, REI, MRP, STI for screening of rice genotypes under drought stresses condition. Principal component analysis revealed that PC1 and PC2 accounted for 80.05% and 19.40% of the total variations, respectively. Cluster analysis grouped the 48 rice genotypes into two main clusters.

Interpretation: On the basis of drought tolerant indices, PCA Biplot analysis and Cluster analysis six genotypes *viz.,* VL 20441, VL 20225, VL 20541, VL 20468, VL 8549, and VL 20316 were identified as drought tolerant.

Key words: Cluster Analysis, Drought tolerant indices, Hill rice, PCA Biplot

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Introduction

Rice (*Oryza sativa* L.) is an important cereal for one-third of the world's population (Brar and Singh, 2011) particularly, in Asia where around 90% of rice is grown and consumed (Kumar *et al.,* 2014). Rice is popularly cultivated in both irrigated and rainfed conditions and 50% of rice cultivation is under rainfed condition in Asia (Raman *et al.,* 2012). Among Asian countries, India is the second largest producer of rice where, out of the total 20.4 m ha area of rainfed rice, approximately 64% (6.3 m ha upland and 7.3 m ha lowland rice) is drought-prone (Pandey and Bhandari, 2008). However, upland rice gets more affected due to drought stress because there is no water retention in the field due to lack of bunds, unleveled and sloppy terrains (Bernier *et al.,* 2008). Upland rice ecosystem (12% of global rice production area) although being the lowest yielding (<1 ton/ha) ecosystem (Khush, 1997) but serves as an important source of food security for poorest of poor masses in India. Drought stress is the major constraint which adversely affect the upland rice at the seedling, vegetative and reproductive stages, however, drought at the reproductive stage found most detrimental (O'Toole, 1982) which causes severe yield loss (up to 58 %)(Ouk *et al.,* 2006) and also severely affect the quality of the produce (Bartwal *et al.,* 2016).

Therefore, drought tolerance is more urgent for upland rice than lowland and fully irrigated rice (Mau *et al.,* 2019). So far little efforts have been made to address the problem of drought stress in rainfed upland rice ecosystem. The efforts of yield improvement through high yielding varieties (HYV) and technological interventions in many cases were found unrewarding in farmer's field probably due to the reason that most of the HYV grown in rainfed areas are varieties bred exclusively for irrigated ecosystems and never screened and/or selected for drought tolerance hence, suffer heavy yield losses even under mild stress conditions (Kumar *et al.,* 2014). Further, lack of practical methods of screening of a large number of genotypes (Zeigler and Puckridge, 1995), managed drought stress not represent farmers' fields (Kamoshita *et al.,* 2008), adverse growing conditions and limited resources available to the farmers as well as the lack of development of suitable cultivars (Fukai *et al.,* 1999) also rendered the problem of drought stress under rainfed upland rice ecosystem unaddressed. The best option to improve crop yield under drought stress is to develop drought-tolerant crop varieties (Manju *et al.,* 2019).

The drought vulnerability of upland rice is likely to worsen in the future with predicted climate change scenarios due to more complex interactions of drought with other abiotic and biotic stresses (Serraj *et al.,* 2011). Therefore, for stability of rice production in upland ecosystem, the ability of crop cultivars to perform reasonably well in drought-stressed environments is of paramount importance. In this regard, several drought indices have been suggested for the identification of lines with significantly higher performance over current cultivated varieties under moderate to severe drought situations. These indices are based on the estimation of mean yield and relative yield performance of genotypes under drought-stressed and non-stressed environments and considered as an effective approach for selecting genotypes that combine drought tolerance with general high yield potential (Garg and Bhattacharya, 2017). In the present investigation efforts have been made to identify drought tolerant and stable high yielding rice genotypes suitable for cultivation in the upland ecosystem of Himalayan state Uttarakhand situated in the North-Western region of India.

Materials and Methods

Forty-eight rice genotypes comprising of forty six advance lines and two check varieties viz.,Vivek Dhan 154 and VL Dhan 157 of rainfed upland were evaluated under drought stress at reproductive stage and non-stress (irrigated) conditions at the Experimental Farm of ICAR-Vivekananda Parvatiya Krishi Anusandhan Sansthan (VPKAS), Almora during kharif 2017. The experiment was laid out in RBD with two replications in two row plots with 3 m row length and 20 cm row to row distance. Genotypes were sown on 30.06.2017 by direct seeding in both stress and non-stress experiments. Sowing was delayed for 20-30 days so that it coincides with the withdrawal of monsoon at reproductive stage. Nitrogen, phosphorus and potassium (NPK) were applied @ 60:30:20kg ha^{-1}. P and K were applied as basal and nitrogen was applied in three splits, first as basal, second at maximum tillering and third at panicle initiation stage.

In non-stress experiment, soil moisture was maintained from sowing to 10 days before maturity by providing water by supplementary irrigation as and when required. The drought-stress experiment was like irrigated non-stress experiment up to 60 days after sowing (DAS) after that stress was created by withholding irrigation for a week (IRRI, 2002) or till most lines wilted and exhibited leaf drying then plot was irrigated. The observation of leaf rolling and leaf drying were taken on a 0 to 9 scale as per SES method (IRRI, 2002). The observations on grain yield and other two yield contributing traits were recorded on five randomly selected plants per genotype per replication and mean grain yield data were used to calculate different drought tolerance indices. Several drought tolerance indices have been suggested on the basis of a mathematical relationship between yield under drought stress conditions and non-stress conditions. Let (Yi)S denote the yield of the i^{th} genotype under stress, (Yi) NS is the yield of the i^{th} genotype under non-stress (irrigated) conditions and yS and yNS are the mean yields of all genotypes evaluated under stress and non-stress conditions, respectively.

The relative yield performance of genotypes in drought-stressed and non-stressed environments can be used as an indicator to identify drought tolerance genotypes for drought-prone environments (Raman *et al.,* 2012). Drought tolerance efficiency (DTE) is estimated by the equation of Fischer and Wood (1979). Higher values of DTE indicates higher drought tolerance ability of genotypes. Other drought indices mentioned are as follows: Rosielle and Hamblin (1981) defined stress tolerance (TOL) as difference in yield between the stress and non-stress environments. Higher values of TOL indicate susceptibility of a given cultivar. Hossain *et al.* (1990) defined mean productivity index (MPI) as the average of (Yi)NS and (Yi)S. Mean relative performance (MRP) and Relative efficiency(RE) were calculated. Fernandez (1992) defined a stress tolerance index (STI) which can be used to identify genotypes that produce high yield under both stress and non-stress conditions. A high value of STI implies higher tolerance to stress. A stress susceptibility index (SSI) assesses the reduction in yield caused by unfavorable compared with favorable environments was suggested by Fischer and Maurer (1978). Lower SSI values indicate lower differences in yield across stress levels, in other words, more resistance to drought. A modified formula for Schneider's stress severity index (SSSI) is defined by Singh *et al.* (2011). Schneider's stress susceptibility index estimates the relative tolerance for yield reduction of a genotype relative to the population mean reduction in grain yield response due to stress. Drought yield index (DYI) determines the ranking of genotypes. Cluster analysis and Principal Component Analysis (PCA) were performed using XLSTAT software (version 2020.4.1.1018).

Results and Discussion

The results related to grain yield, plant height, days to 50% flowering and days to maturity of rice genotypes evaluated under stress (drought at reproductive stage) and non-stress (irrigated) conditions are presented in Table 1. Genotypes grown under stress condition showed significantly lower grain yield compared to non-stress condition. The reduction in grain yield was observed in all the genotypes grown under drought stress condition. The grain yield ranged from 2,646 kg ha^{-1} (VL 20541) to 3,229 kg ha^{-1} (VL 20441) under non-stress and 875 kg ha^{-1} (VL 20254) to 2,208 kg ha^{-1} (VL 20468) under stress condition, respectively.

The per cent reduction in grain yield between stress and non-stress trial varied from 23.62% to 67.69% with the mean grain yield reduction of 46.58%. Based on grain yield reduction, stress trial fell under moderate stress category as per classification for upland trial suggested by Dixit *et al.* (2014). The crop experienced natural drought during reproductive stage as 18 days (64-82days of crop growth) was rainless day and it may be considered significant as a general guideline for upland 7 days without significant (>5mm) rainfall during critical stage (reproductive/flowering stage) decrease yield by about 10% for each additional day without rainfall (Fischer *et al.,* 2003). Singh *et al.* (2018) reported grain yield reduction ranged from 37.39 to 56.62% in rice. VL 20441, VL 20149, VL 8726, VL 20238 and VL 20095 were the best performers under non-stress trial whereas VL 20468, VL 20441, VL 20541, VL 20225 and VL 20316 were the best performers under stress trial based on grain yield potential.

Genotypes *viz.,* VL 20254, VL 8717 and VL 20318 had shown maximum yield reduction (≥ 60%). The effect of drought was found to be minimum in genotypes VL 20541, 20468, VL 8549, VL 20316 and VL 20225 as per cent yield reduction in these genotypes was minimum. VL 20441, VL 20468 and VL 20225 yielded well under both non-stress and stress condition. The response among rice genotypes for days to 50% flowering and days to maturity varied under stress and non-stress condition, however, the variations observed was low and non-significant. Most genotypes exhibited either equal or one to two days early 50% flowering under stress trial, except for genotypes VL 20222, VL 31153 and VL 8717 where flowering was delayed. Delayed flowering in drought is a strong indication of drought susceptibility of genotypes and longer delay will tend to produce less grain yield due to retarded growth during the drying cycle and upon recovery (Hanamaratti and Salimath, 2012).

Plant height was reduced in all the rice genotypes grown under drought stress trial as compared to non stress trial. This primarily occurs due to reduction in metabolic activities related to cell division and cell elongation process (Maurya *et al.,* 2021) and physiological activities like gas exchange, water use efficiency and biomass production (Saraswathi and Paliwal, 2011) which consequently reduces the plant height. The mean grain yield of all rice entries differed significantly between non-stress and stress conditions which indicate that the performance under non-stress and stress was considerably different (Fig. 1). Drought tolerance efficiency (DTE) was recorded highest in VL 20541 (76.38%) followed by VL 20468 (75.18%), VL 8549 (68.75%), VL 20316 (67.65%), VL 20225 (66.90%) and VL 20554 (66.67%) which indicates higher drought tolerance ability of these genotypes. DTE is a measure of drought resistance mechanism and determines the consistency of selected genotypes in response to drought stress thus may be helpful in identifying genotypes that possess drought resistance capability in rainfed ecosystem of rice (Kumar *et al.,* 2013). With respect to MPI, genotype VL 20441 showed the highest value followed by VL 20468, VL 20225, VL 20558, VL 20568 and VL 20238.

Genotype with highest value of MPI is more desirable, therefore, VL 20441 was found to be more drought tolerant. MPI is often used by breeders interested in relative performance, since drought stress can vary in severity in field environments over years and considered to be effective for selection of drought tolerant rice genotypes (Bhandari *et al.,* 2020). Relative efficiency index (REI) was observed highest in VL 20441 (1.478) followed by VL 20468 (1.426), VL 20225(1.287), VL 20568 (1.245) and VL 20558 (1.230). The highest value of REI is desirable and useful in identifying genotypes with high yield potential (Kamarudin et al., 2020). Genotypes VL 20441 (2.44 and 0.79) recorded the highest MRP and STI value followed by VL 20468 (2.42 and 0.762), VL 20225 (2.28 and 0.687), VL 20568 (2.23 and 0.665) and VL 20558 (2.22 and 0.657) indicating tolerance of these genotypes toward moisture stress. Drought tolerance indices MRP and STI have been found effective in distinguishing genotypes with higher yield under drought stress in upland rice (Mau *et al*., 2019).

Drought Yield Index (DYI) was relatively low for genotypes where small difference was observed between mean yield of non-stress and stress trial. Rice genotypes with lower value of DYI are preferred and more desirable as they indicate

Table 1: Yield and its attribute of rice genotypes in response to stress and non-stress condition in rainfed upland ecosystem of Uttarakhand hills

Genotypes	Days to 50 % flowering		Plant height (cm)		Grain yield (kg ha^{-1})		% reduction in yield under stress
	Non- stress	Stress	Non- stress	Stress	Non- stress	Stress	
Vivek Dhan 154	80	79	95	90	2838	1292	54.48
VL Dhan 157	80	79	106	101	2833	1208	57.35
VL 20222	81	84	128	125	2858	1438	49.71
VL 20224	81	79	107	105	2854	1292	54.74
VL 20225	81	79	111	109	2958	1979	33.10
VL 20229	80	78	110	109	3104	1583	48.99
VL 20238	79	79	108	100	3179	1646	48.23
VL 20250	83	83	106	104	2771	1417	48.87
VL 20252	81	79	90	90	2958	1417	52.11
VL 20254	79	78	89	89	2708	875	67.69
VL 20305	79	77	93	90	3083	1375	55.41
VL 20310	79	78	100	97	2896	1563	46.04
VL 20316	80	79	104	100	2833	1917	32.35
VL 20318	81	80	105	101	2746	1104	59.79
VL 20325	83	81	103	101	2750	1708	37.88
VL 20348	80	79	99	98	2646	1667	37.01
VL 20356	80	79	98	97	2896	1417	51.08
VL 20364	80	79	92	90	3021	1583	47.59
VL 20432	83	82	110	106	2854	1375	51.82
VL 20433	81	80	112	110	3167	1500	52.63
VL 20434	83	81	116	112	3104	1542	50.34
VL 20441	83	82	118	117	3229	2083	35.48
VL 20444	82	79	95	93	2833	1708	39.71
VL 20466	81	80	95	93	2875	1500	47.83
VL 20468	81	80	117	116	2938	2208	24.82
VL 20541	82	80	114	113	2646	2021	23.62
VL 20549	78	78	93	90	2792	1813	35.07
VL 20554	78	77	93	90	2750	1833	33.33
VL 20558	80	79	93	90	3125	1792	42.67
VL 20559	79	78	93	90	3083	1646	46.62
VL 20561	78	77	90	88	2958	1479	50.00
VL 20568	79	78	108	104	3125	1813	42.00
VL 20070	81	80	102	100	2917	1542	47.14
VL 20071	80	79	104	101	2750	1667	39.39
VL 20072	78	78	96	93	3092	1667	46.09
VL 20073	82	80	93	91	2833	1500	47.06
VL 20086	81	80	111	107	3000	1708	43.06
VL 20089	81	80	111	108	3042	1646	45.89
VL 20091	84	84	114	111	2750	1500	45.45
VL 20095	81	80	113	108	3167	1563	50.66
VL 20149	79	78	113	110	3213	1708	46.82
VL 20150	80	79	113	107	2833	1458	48.53
VL 20078	81	80	104	100	2958	1258	57.46
VL 31153	83	85	110	106	2750	1167	57.58
VL 8717	79	82	110	108	2750	1021	62.88
VL 8549	83	81	101	100	2667	1833	31.25
VL 8726	81	80	119	108	3208	1563	51.30
VL 8747	80	79	109	107	2750	1250	54.55

drought tolerance. VL 20541(1.31) showed the lowest DYI value followed by VL 20468(1.33), VL 8549(1.45), VL 20316(1.48) and VL 20225(1.49). DYI may be used for identification of genotypes with high yield under stress condition but not very high yield under non-stress (normal irrigated) condition. DYI can also be useful for areas where stress is a recurring phenomenon (Raman *et al.,* 2012). Lower value of stress tolerance (TOL) indicates high stress tolerance ability of a genotype. VL 20541 exhibited the lowest

Table 2: Drought response indices of rice genotypes tested under stress and non-stress conditions in rainfed upland ecosystem of Uttarakhand hills

Genotypes	DTE	MPI	REI	MRP	STI	DYI	TOL	SSI	SSSI	R	SDR	RS
Vivek Dhan 154	45.52(39)	2065(42)	0.805(42)	1.80(42)	0.430(42)	2.20(39)	1546(36)	1.17(39)	0.079(39)	40.00	2.12	42.12
VL Dhan 157	42.65(43)	2021(43)	0.752(44)	1.75(43)	0.402(44)	2.34(43)	1625(41)	1.23(43)	0.108(43)	43.00	0.87	43.87
VL 20222	50.29(30)	2148(35)	0.903(36)	1.90(35)	0.482(36)	1.99(30)	1421(24)	1.07(30)	0.031(30)	31.78	4.02	35.80
VL 20224	45.26(41)	2073(41)	0.810(41)	1.81(41)	0.433(41)	2.21(41)	1563(37)	1.18(41)	0.082(41)	40.56	1.33	41.89
VL 20225	66.90(5)	2469(3)	1.287(3)	2.28(3)	0.687(3)	1.49(5)	979(6)	0.71(5)	-0.135(5)	4.22	1.20	5.42
VL 20229	51.01(29)	2344(14)	1.080(18)	2.08(19)	0.577(18)	1.96(28)	1521(33)	1.05(28)	0.024(29)	24.00	6.71	30.71
VL 20238	51.77(26)	2413(7)	1.150(9)	2.14(9)	0.614(9)	1.93(26)	1533(34)	1.04(26)	0.017(26)	19.11	10.40	29.51
VL 20250	51.13(28)	2094(40)	0.863(38)	1.86(38)	0.461(38)	1.96(28)	1354(19)	1.05(28)	0.023(28)	31.67	7.11	38.77
VL 20252	47.89(37)	2188(30)	0.921(33)	1.92(33)	0.492(33)	2.09(37)	1542(35)	1.12(37)	0.055(37)	34.67	2.55	37.22
VL 20254	32.31(48)	1792(48)	0.521(48)	1.49(48)	0.278(48)	3.10(48)	1833(48)	1.45(48)	0.211(48)	48.00	0.00	48.00
VL 20305	44.59(42)	2229(24)	0.932(32)	1.94(31)	0.498(32)	2.24(42)	1708(46)	1.19(42)	0.088(42)	37.00	7.38	44.38
VL 20310	53.96(18)	2229(24)	0.994(26)	1.99(26)	0.531(26)	1.85(17)	1333(16)	0.99(17)	-0.005(18)	20.89	4.46	25.35
VL 20316	67.65(4)	2375(10)	1.193(7)	2.20(6)	0.638(7)	1.48(4)	917(4)	0.69(4)	-0.142(4)	5.56	2.13	7.68
VL 20318	40.21(46)	1925(46)	0.666(46)	1.65(46)	0.356(46)	2.49(46)	1642(42)	1.28(46)	0.132(46)	45.56	1.33	46.89
VL 20325	62.12(10)	2229(24)	1.032(24)	2.04(24)	0.552(24)	1.61(10)	1042(9)	0.81(10)	-0.087(10)	16.11	7.49	23.60
VL 20348	62.99(9)	2156(33)	0.969(28)	1.98(28)	0.518(28)	1.59(9)	979(6)	0.79(9)	-0.096(9)	17.67	11.14	28.80
VL 20356	48.92(34)	2156(33)	0.902(37)	1.90(35)	0.482(36)	2.04(34)	1479(28)	1.10(34)	0.045(34)	33.89	2.52	36.41
VL 20364	52.41(24)	2302(19)	1.051(22)	2.05(21)	0.562(21)	1.91(24)	1438(26)	1.02(24)	0.010(24)	22.78	2.17	24.94
VL 20432	48.18(36)	2115(38)	0.862(39)	1.86(38)	0.461(38)	2.08(36)	1479(28)	1.11(36)	0.052(36)	36.11	3.26	39.37
VL 20433	47.37(38)	2333(16)	1.044(23)	2.05(21)	0.558(23)	2.11(38)	1667(44)	1.13(38)	0.061(38)	31.00	10.11	41.11
VL 20434	49.66(32)	2323(18)	1.052(21)	2.05(21)	0.562(21)	2.01(32)	1563(37)	1.08(32)	0.038(32)	27.33	6.96	34.30
VL 20441	64.52(8)	2656(1)	1.478(1)	2.44(1)	0.790(1)	1.55(8)	1146(12)	0.76(8)	-0.111(8)	5.33	4.30	9.63
VL 20444	60.29(12)	2271(22)	1.064(20)	2.07(20)	0.568(20)	1.66(12)	1125(11)	0.85(11)	-0.069(12)	15.56	4.75	20.30
VL 20466	52.17(25)	2188(30)	0.948(30)	1.95(30)	0.506(30)	1.92(25)	1375(20)	1.03(25)	0.012(25)	26.67	3.54	30.20
VL 20468	75.18(2)	2573(2)	1.426(2)	2.42(2)	0.762(2)	1.33(2)	729(2)	0.53(2)	-0.218(2)	2.00	0.00	2.00

Table continued

Table 2: Drought response indices of rice genotypes tested under stress and non-stress conditions in rainfed upland ecosystem of Uttarakhand hills

Genotypes	DTE	MPI	REI	MRP	STI	DYI	TOL	SSI	SSSI	R	SDR	RS
VL 20541	76.38(1)	2333(16)	1.175(8)	2.20(6)	0.628(8)	1.31(1)	625(1)	0.51(1)	-0.230(1)	4.78	5.24	10.02
VL 20549	64.93(7)	2302(19)	1.112(13)	2.12(11)	0.594(13)	1.54(7)	979(6)	0.75(7)	-0.115(7)	10.00	4.36	14.36
VL 20554	66.67(6)	2292(21)	1.108(14)	2.12(11)	0.592(14)	1.50(6)	917(4)	0.72(6)	-0.132(6)	9.78	5.63	15.41
VL 20558	57.33(14)	2458(6)	1.230(5)	2.22(5)	0.657(5)	1.74(14)	1333(16)	0.92(14)	-0.039(14)	10.33	4.87	15.21
VL 20559	53.38(20)	2365(11)	1.115(12)	2.11(14)	0.596(12)	1.87(20)	1438(26)	1.00(20)	0.000(20)	17.22	5.14	22.36
VL 20561	50.00(31)	2219(28)	0.962(29)	1.96(29)	0.514(29)	2.00(31)	1479(28)	1.07(30)	0.034(31)	29.56	1.24	30.79
VL 20568	58.00(13)	2469(3)	1.245(4)	2.23(4)	0.665(4)	1.72(13)	1313(15)	0.90(13)	-0.046(13)	9.11	5.13	14.25
VL 20070	52.86(23)	2229(24)	0.988(27)	1.99(26)	0.528(27)	1.89(22)	1375(20)	1.01(21)	0.006(23)	23.67	2.55	26.22
VL 20071	60.61(11)	2208(29)	1.007(25)	2.01(25)	0.538(25)	1.65(11)	1083(10)	0.85(11)	-0.072(11)	17.56	8.11	25.67
VL 20072	53.91(19)	2379(9)	1.132(10)	2.13(10)	0.605(10)	1.86(19)	1425(25)	0.99(17)	-0.005(18)	15.22	5.65	20.87
VL 20073	52.94(22)	2167(32)	0.934(31)	1.93(32)	0.499(31)	1.89(22)	1333(16)	1.01(21)	0.005(22)	25.44	6.04	31.49
VL 20086	56.94(15)	2354(13)	1.126(11)	2.12(11)	0.602(11)	1.76(15)	1292(14)	0.92(14)	-0.035(15)	13.22	1.79	15.01
VL 20089	54.11(17)	2344(14)	1.100(16)	2.10(15)	0.588(16)	1.85(17)	1396(23)	0.99(17)	-0.007(17)	16.89	2.52	19.41
VL 20091	54.55(16)	2125(37)	0.906(35)	1.90(35)	0.484(35)	1.83(16)	1250(13)	0.98(16)	-0.011(16)	24.33	10.65	34.99
VL 20095	49.34(33)	2365(11)	1.087(17)	2.09(17)	0.581(17)	2.03(33)	1604(40)	1.09(33)	0.041(33)	26.00	10.37	36.37
VL 20149	53.18(21)	2460(5)	1.206(6)	2.20(6)	0.644(6)	1.88(21)	1504(32)	1.01(21)	0.002(21)	15.44	9.84	25.28
VL 20150	51.47(27)	2146(36)	0.908(34)	1.91(34)	0.485(34)	1.94(27)	1375(20)	1.04(26)	0.020(27)	29.44	5.29	34.74
VL 20078	42.54(44)	2108(39)	0.818(40)	1.82(40)	0.437(40)	2.35(44)	1700(45)	1.23(43)	0.109(44)	42.11	2.32	44.43
VL 31153	42.42(45)	1958(45)	0.705(45)	1.69(45)	0.377(45)	2.36(45)	1583(39)	1.24(45)	0.110(45)	44.33	2.00	46.33
VL 8717	37.12(47)	1885(47)	0.617(47)	1.60(47)	0.330(47)	2.69(47)	1729(47)	1.35(47)	0.163(47)	47.00	0.00	47.00
VL 8549	68.75(3)	2250(23)	1.074(19)	2.09(17)	0.574(19)	1.45(3)	833(3)	0.67(3)	-0.153(3)	10.33	8.83	19.17
VL 8726	48.70(35)	2385(8)	1.102(15)	2.10(15)	0.589(15)	2.05(35)	1646(43)	1.10(34)	0.047(35)	26.11	12.66	38.77
VL 8747	45.45(40)	2000(44)	0.755(43)	1.74(44)	0.404(43)	2.20(39)	1500(31)	1.17(39)	0.080(40)	40.33	4.06	44.40
Mean	53.47	2238.92	1.00	2.00	0.54	1.93	1359.40	1.00	0.00	24.35	4.84	29.18

Values in the parentheses refer to the ranks of the genotype for each index, DTE= drought tolerance efficiency, MPI= mean productivity index, REI=relative efficiency, MRP= mean relative performance, STI= stress tolerance index, DYI= drought yield index, TOL=stress tolerance, SSI= stress susceptibility index, SSSI =Schneider's stress susceptibility index, R= Rank mean, SDR= Standard deviation of rank, RS= Rank sum.

Table 3: Correlation coefficients between drought tolerance indices under stress and non stress conditions in rainfed upland ecosystem of Uttarakhand hills

Variables	YS	YNS	DTE	MPI	REI	MRP	STI	DYI	TOL	SSI	SSSI
YS	1										
YNS	0.25	1									
DTE	0.94**	-0.09	1								
MPI	0.89**	0.67**	0.68**	1							
REI	0.95**	0.53**	0.79**	0.99**	1						
MRP	0.96**	0.52**	0.81**	0.98**	0.99**	1					
STI	0.95**	0.53**	0.79**	0.99**	1.00**	0.99**	1				
DYI	-0.95**	-0.03	-0.97**	-0.74**	-0.83**	-0.85**	-0.83**	1			
TOL	-0.82**	0.36	-0.96**	-0.46**	-0.60**	-0.62**	-0.60**	0.89**	1		
SSI	-0.94**	0.09	-1.00**	-0.68**	-0.79**	-0.81**	-0.79**	0.97**	0.96**	1	
SSSI	-0.94**	0.09	-1.00**	-0.68**	-0.79**	-0.81**	-0.79**	0.97**	0.96**	1.00**	1

** Significant at 1% levels of probability

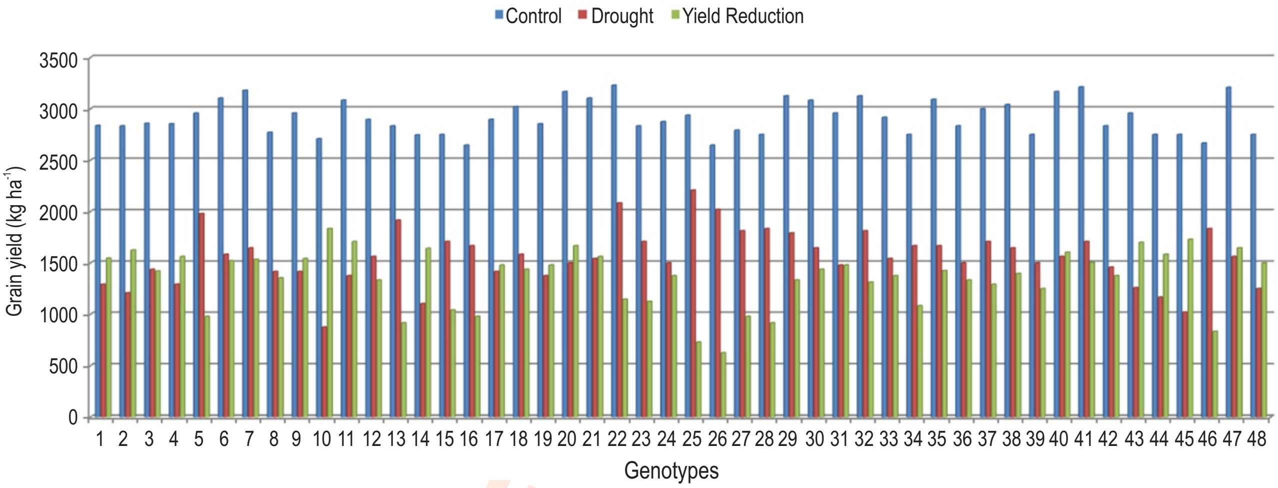

Fig. 1: Performance of rice genotypes under control and drought stress at reproductive stage of crop in rainfed upland ecosystem of Uttarakhand hills.

TOL value followed by VL 20468 and VL 8549. Drought indices TOL favor genotypes with good yield under drought stress condition (Kumar *et al.,* 2014). Based on TOL, low-yield potential genotypes can be identified under non-stress conditions whereas high-yield potential genotypes can be selected under stress conditions (Negarestani *et al.,* 2019). Stress susceptibility index (SSI) and Schneider's stress severity index are measure of yield stability. Lower SSI and SSSI values indicate lower difference in yield between non-stress and stress condition; in other words, more resistance to drought. SSI and SSSI assess the reduction in yield caused by unfavorable environment compared with favorable environment. The lowest value of SSI and SSSI were recorded in VL 20541 followed by VL 20466, VL 8549, VL 20316 and VL 20225. Broadly, genotypes are classified either drought tolerant (SSI <1.00) or drought susceptible (SSI > 1.00).

Drought tolerance genotypes showed smaller grain yield reduction whereas drought susceptible genotypes showed large grain yield reduction between stress and non-stress condition. Genotype classification may further be elaborated as highly drought tolerant (SSI < 0.50), drought tolerant (SSI 0.51-0.75), moderately drought tolerant (SSI 0.76-1.00) and drought susceptible (SSI > 1.00). Based on this classification, seven genotypes were found to be drought tolerant, thirteen genotypes as moderately drought tolerant and twenty-eight genotypes were susceptible.

SSSI estimates the relative tolerance for yield reduction of a genotype relative to the population mean reduction in grain yield response due to stress (Farhad *et al.,* 2014). Mean rank, Standard deviation of ranks and rank sum of all indices were estimated to identify desirable drought tolerant genotypes because single drought indices provide exclusive result as different indices identified different genotypes as drought tolerance. Genotypes VL 20225, VL 20316, VL 20441, VL 20469, VL 20541, VL 20554 and VL 20568 were identified as the

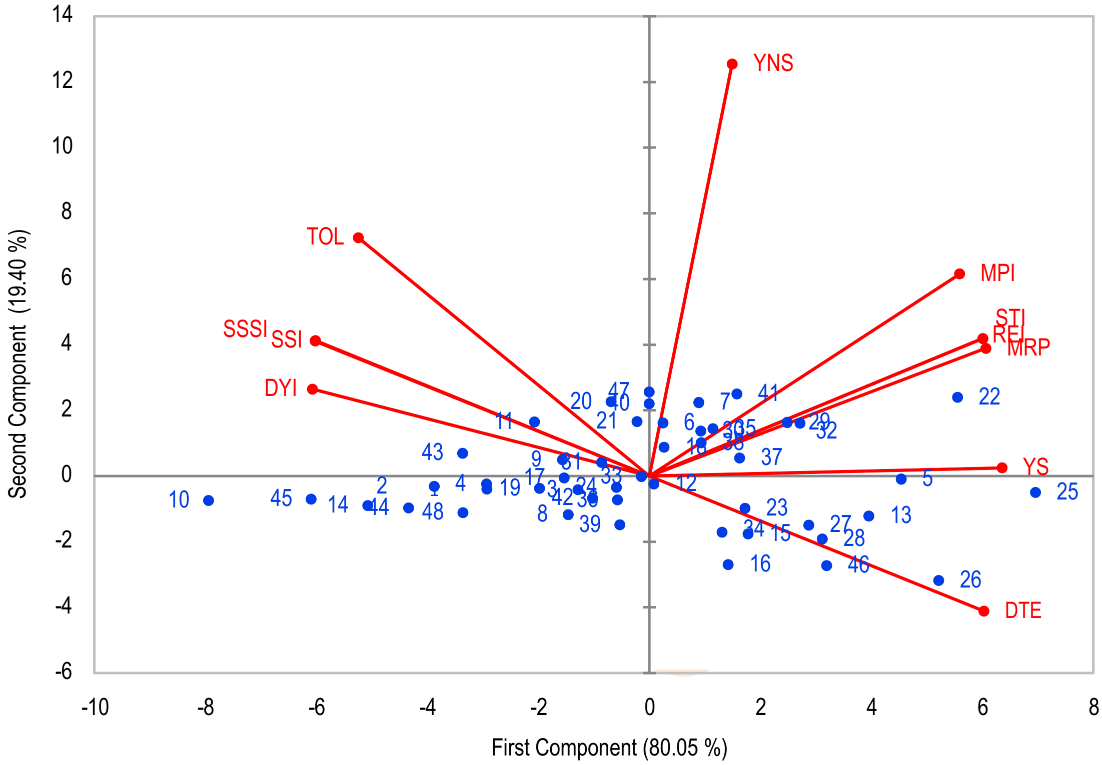

Fig. 2: Biplot for drought tolerance indices based on the first and second principal components axes (PC1 and PC2) for 48 rice genotypes in rainfed upland ecosystem of Uttarakhand hills under moisture stress (YS) and non-stress (YNS) conditions. The indices are indicated using uppercase letters and each genotype is represented with numbers (see Table 2, for abbreviations and genotypes code).

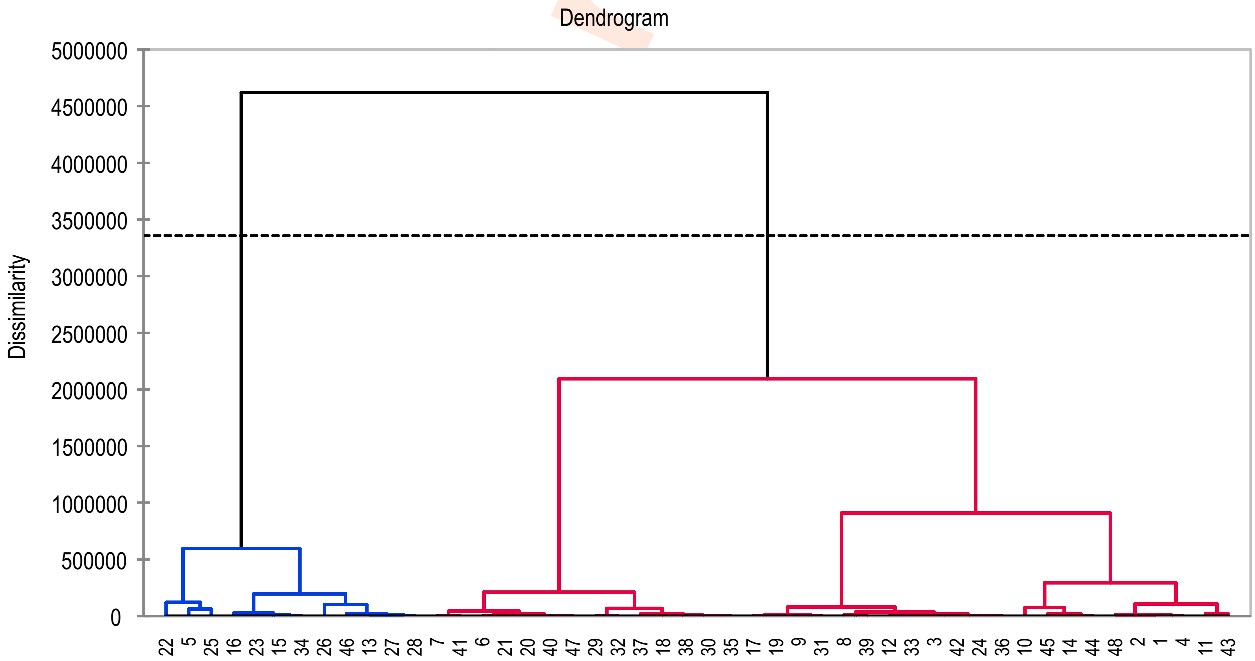

Fig. 3: Dendrogram of rice genotypes in rainfed upland ecosystem of Uttarakhand hills using average linkage method (between groups) based on drought tolerance indices. Each genotype is represented with numbers (see Table 1, for genotypes code).

highest drought tolerant genotypes, based on all drought indices these genotypes had the best mean rank, rank sum and low standard deviation of ranks. Correlation coefficients between YS, YNS and nine drought tolerance indices were estimated (Table 3) to determine the most desirable drought tolerant selection criteria.

A positive non-significant correlation was observed between YS and YNS which indicates that selection under drought stressed condition are independent of the performance in non-stressed condition and vice versa. A positive and highly significant correlation was exhibited by mean grain yield under stress (YS) with DTE, MPI, REI, MRP, STI whereas it was negative and highly significant with DYI, TOL, SSI and SSSI. This indicates that selection of low DYI, TOL, SSI, SSSI value and high DTE, MPI, REI, MRP, STI value enable selection for high grain yield under drought stresses condition. Ferede *et al.* (2020) observed significant positive correlation of grain yield under stress with STI, GMP, MP and negative correlation with SSI in tef crop. The positive and significant correlation of yield under stress with STI and MP was also reported by Naghavi *et al.* (2013) in maize. MPI, REI, MRP and STI were found to be highly significant and positively correlated with grain yield under both stress and non stress condition indicating that these indices would be useful for selecting of genotypes with high grain yield under drought stressed and non-stressed conditions (Table 3).

The findings of Ferede *et al.* (2020) and Yasir *et al.* (2013) also indicate the usefulness of significantly correlated drought indices for selecting genotypes. Principal component analysis revealed that PC1 and PC2 explained 80.05% and 19.40% of the total variations, respectively. PCA1 had high and positive coefficients for YS, MRP, STI, REI, MPI, DTE and YNS (Fig. 2) therefore; it may be called as a component of yield potential and tolerance of drought stress. MRP, STI, REI, MPI and DTE were strongly correlated with yield under stress and non-stress conditions. Therefore, consideration may be given to these indices for screening high yielding and drought tolerant genotypes under both stress and non stress conditions because of high and positive values on biplot (Ali and El-Sadek 2016; Ferede *et al.* 2020; Subhani *et al.* 2015). Genotypes *viz.,* VL 20468, VL 20541, VL 20441 and VL 20225 falling near these indices would be assumed to be high yielding under both stress and non stress conditions. These two PCA were related to yield potential and sensitivity to stress, and genotypes with high PC1 and low PC2 were found to be high yielding and drought tolerant whereas low PC1 and high PC2 performed poorly under drought condition (Shiri *et al.,* 2010).

Drought tolerant varieties impart better yield levels under stress conditions generally due to a deep, well-developed root system to extract water from deep soil layers or reducing water loss through physiological responses like leaf rolling, decreased stomatal conductance. Drought tolerant varieties also have mechanism to regulate metabolism even at low leaf water potential by retaining of green leaves, maintaining cell membrane stability (CMS), epicuticular wax, partitioning and stem reserve mobilization.

Based on nine drought tolerance indices and grain yield under drought stress and non-stress conditions rice genotypes were classified into two main clusters (Fig. 3). The first cluster consisted of twelve genotypes and these genotypes were characterized by higher performance and high grain yield under both moisture stress and non-moisture conditions and also have high values of drought tolerant STI, DTE, MRP, REI and MPI indices. Thus, they were considered as tolerant to drought stress and more reliable for both stress and non-stress conditions. The second cluster contained 36 genotypes that either had drought susceptible genotypes or genotypes suitable for non stress conditions only. Earlier, Ferede *et al.* (2020), Aliakbari *et al.* (2014), Mursalova *et al.* (2015) and Subhani *et al.* (2015) also reported selection of drought tolerant genotypes in different crops based on cluster analysis for drought tolerance indices and grain yield under both drought stress and non-stress conditions. Among 48 genotypes, six genotypes *viz.,* VL 20441, VL 20225, VL 20541, VL 20468, VL 8549, and VL 20316 were identified as drought tolerant based on the results related to grain yield and a combination of drought stress indices.

These drought tolerance genotypes may further be evaluated under multi-location testing of SVT or AICRP programme for release as a variety and may also be included in rainfed upland rice breeding programme.

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Authors' contribution: J.P. Aditya: Conduction of trial, data recording, compilation and preparation of research manuscript; **A. Bhartiya:** Data analysis, interpratation and manuscript preparation; **R.S. Pal:** Assistance in research manuscript preparation; **L. Kant:** Intellectual input in the improvement of manuscript; **A. Pattanayak:** Conceptualization and intellectual input for the improvement of the manuscript.

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