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Assessment of Multiple Tolerance Indices to Identify Rice Lines Suitable for the Aerobic System of Cultivation

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Authors' contributions

This work was carried out in collaboration among all authors. The study was conceived and planned by author KMB. Phenotyping of the panel was executed by authors RP, Honappa, YMR and NDM. Phenotypic and genotypic data analysis were done by authors RP, VR, DB, YMR, KMB, CG and AMS. The critical editing was done by authors KMB, PS, MSM, RL, JRD and RMS. All authors read and approved the final manuscript.

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ABSTRACT

Climate resilience is the most concentrated subject in the current scenario for rice improvement. The aerobic system of rice cultivation involving direct seeding with need-based irrigation in non-puddled soil is gaining ground with respect to a current scenario of water scarcity. The selection of lines suitable and stable under aerobic along with irrigated conditions without any yield penalty is one of the focus areas of the breeding programme for resource use efficiency. In the present study, we have screened a panel of 118 rice lines under aerobic i.e. limited water conditions and irrigated conditions at ARS Dhadesugur Karnataka to identify ideal selection indices viz. STI, TOL, SSI, YSI, YR, YI, PYR, MP and GMP for selecting the best high-yielding and stable lines under both rice cultivation methods. The deployment of selection indices here only pertains to finding the differences in yield per plant under aerobic and irrigated conditions. According to the results of multivariate analysis (correlation and PCA), STI, YI, MP and GMP exhibited a strong correlation with Y_P and Y_S. Therefore, they appear to be the most effective stress indices for the selection of lines with good yield potential under water-limited and irrigated conditions. These indices serve as valuable selection criteria for the identification of aerobic-tolerant cultivars from both water-limited and normal conditions. These indices identified lines, DB 5 (Swarna × *Oryza nivara* (IRGC 81848)) and NPK-40 (Swarna × *Oryza nivara* (IRGC81832)) wild introgression lines. GNV-14-96-1 (BPT-5204 × Nerica line) Advanced breeding line. JBB 631-1 ((Swarna*2/ IRGC 4105) (RP 5405-JBB-631-1-1-1-1-1-1)) *Tropical japonica* × *indica* introgression line. KR-209 (Wazuhophek × ISM) and KR-262 (Wazuhophek × ISM) recombinant introgression lines. TI-36 and TI-124 Ethyl Methane Sulfonate (EMS) mutants of BPT-5204. WB-10 (Langphou) and WB-16 (Phouoibi) North-Eastern Landraces were promising for both environments. These lines are suitable because of low grain yield loss under aerobic conditions and can be further considered for cultivation.

Keywords: Multivariate analysis; selection indices; tolerance index; geometric mean productivity.

1. INTRODUCTION

Rice is a staple food for more than half of the world's population [1], and about 90% of rice is grown in the Asian region. The global population and the demand for food are expanding. In order to meet the global food demand by 2050, food output must therefore be boosted by 70% [2]. The horizontal expansion of rice area is limited in the near future along with an increase in adverse climatic conditions, scarcity of water and labour, increased wage rates and production cost, and soil and environmental degradation poses a major challenge to shift in rice cultivation system [3].

The primary method of rice cultivation in many parts of the world is puddled transplanting. A high and reliable yield is provided by the transplanting system, but it requires a significant quantity of labour and irrigation water (1500 mm to 2000 mm). Increasing scarcity of labour and irrigation water is a major driver to the aerobic system of rice cultivation or dry direct-seeded rice in many Asian countries including India, dry direct seeded even has an advantage over wet direct-seeded rice by utilizing minimum water resources [3]. Aerobic rice is a method of rice cultivation that has the potential to save both water and labour by 50%, wherein seedling nursery raising, puddling and transplanting were omitted, rather primed seeds are directly sown on the dry cultivated field by hand or seeder [2]. Cultivation of aerobic rice is an eco-friendly approach which reduces greenhouse gas emissions and improves soil health compared with the conventional system. The development of aerobic dry direct seeding adapted rice varieties is immensely needed and underlies the government policy of more crop per drop to double farmer income and livelihood with low input costs [4].

Climate resilience is the most concentrated subject in the current scenario for rice improvement. The aerobic system of rice cultivation involving direct seeding with need-based irrigation in non-puddled soil is gaining ground with respect to water scarcity [5,3]. The development of aerobic dry direct seeding adapted rice varieties is immensely needed and underlies the government policy of more crop per drop to double farmer income and livelihood with low input costs. The selection of lines suitable and stable under aerobic along with irrigated conditions without any yield penalty is one of the focus areas of the breeding program for resource use efficiency. In breeding programs, selection should be based on the tolerance indices calculated from the grain yield under both conditions to develop cultivars having aerobic tolerance (without any yield penalty). In the present study, we have screened a panel of rice lines under aerobic i.e. limited water conditions and irrigated conditions to identify ideal selection indices for selecting the best high-yielding and stable lines under both rice cultivation methods. The deployment of selection indices here only pertains to finding the differences in yield-related parameters under aerobic and irrigated conditions. We have used the selection indices that are commonly deployed to find the stress-related indices under nutrient stress and normal conditions.

2. MATERIALS AND METHODS

2.1 Plant Material

The experimental material comprised 118 diverse rice lines including landraces, popular varieties, aerobic released varieties, BPT-5204 and Nagina 22 (N22) Ethyl Methane Sulfonate (EMS) mutants, aromatic lines, introgression lines, and advanced breeding lines.

2.2 Phenotyping for Yield under Irrigated and Aerobic Conditions

The experiment was carried out under irrigated and aerobic conditions during *Kharif* 2020 for yield-related traits, at ARS Dhadesugur, Raichur, Karnataka in augmented block design with six blocks, wherein, each block consists of 23 diverse rice lines along with checks (BPT-5204, Swarna, MTU-1010 and RNR-15048). Each line was sown in two rows of two-meter length at a spacing of 20 cm × 15 cm, seeds were direct sown in the nursery beds and 30 days after sowing, the seedlings were transplanted under irrigated conditions. Agronomic practices were followed as recommended for irrigated rice cultivation. For the aerobic condition, the experiment was laid out in an augmented block design with five blocks, where, each block consists of 30 rice lines along with checks (*viz*., Sabita, Sahbhagidhan, MAS 946-1, DRR-Dhan-41, DRR-Dhan-42, DRR-Dhan-44, CR-Dhan-201 and CR-Dhan-202). Each line was sown in two rows of two-meter length at a spacing of 20 cm×15 cm. Agronomic practices were followed as recommended for aerobic rice cultivation. The seeds were dry and direct sown, and extra seedling were thinned to a single plant per hill after 15 days and was maintained. Timely weeding was performed, and the field was maintained per agronomic practices with need-based irrigation.

The following observations were recorded for the traits, plant height (PH), panicle length (PL), number of tillers per plant (NTP), number of panicles per plant (NPP), the total number of grains per plant (TNG), per cent spikelet fertility (SF), test weight (TW), grain yield per plant (GYP), straw weight (SW). Spikelet fertility (%) was calculated as the ratio of the number of filled spikelets per panicle to the total number of spikelets per panicle and expressed in percentage and harvest index was calculated as the ratio of economic yield to the biological yield and expressed in percentage. Grain yield per plant was determined under irrigated and aerobic conditions and indicated as Y_p and Y_s respectively.

2.3 Statistical Analysis

Stress indices were estimated using a formulae at Table 1 and combined analysis of variance (ANOVA) was calculated between stress indices and grain yield, Correlation coefficients were estimated between stress tolerance indices and grain yield The biplots of principal component analysis (PCA) were analyzed using R studio (*version* 4.0.2) (https://cloud.r-project.org/ package=augmented RCBD) using the R script.

3. RESULTS AND DISCUSSION

The aerobic system of cultivation with direct seeding is gaining popularity on account of its water-saving nature, and economy. The purpose of our study was to find the rice line without any yield penalty under aerobic conditions as compared to irrigated conditions. So, here we deployed multiple selection indices that are commonly used to assess the differences in yield and yield-related parameters under two contrasting conditions. The indices for irrigated and aerobic conditions were calculated and represented in Table 2. Analysis of variance showed highly significant differences for most of the indices of the lines (Table 3). The mean sum of squares due to treatment, Check and test lines, were significant for all the indices for grain yield under aerobic and irrigated conditions except for STI and YRR). The mean sum of squares due to Test vs. Check was significant for all the indices for grain yield under aerobic and irrigated conditions except YRR. We have identified the high yielding rice lines under both aerobic and irrigated field conditions [6].

3.1 Correlation between Grain Yield and Different Selection Indices

The correlation coefficient between grain yield under irrigated and aerobic conditions and other indices was calculated to determine the most desirable selection criterion (Table 2). A positive significant correlation was observed between Y_p and Y_s (r = 0.537) suggesting that high-yielding lines can be selected based on them under both irrigated and aerobic conditions. Thus, indirect selection for an aerobic condition based on the results of normal conditions will be efficient. Aghaei et al. [7] revealed that rice cultivars with high yield potential were more productive under aerobic conditions. Grain yield per plant had a significant positive correlation with STI, TOL, YRR, SSI, PYR, MP and GMP under both irrigated conditions except YSI. Grain yield per plant had a significant positive correlation with STI, YSI, YI, MP and GMP under aerobic conditions, except TOL, YRR, SSI and PYR. Therefore, these indices are most appropriate in screening high-yielding rice lines in both conditions. Similar results were reported by Dorostkar et al. [8] and Kamrani et al. [9] in wheat. According to Fernandez [10], lines with higher yield potential and tolerance selection index would be identified by selection based on STI, GMP, and MP selection indices. In the present study, grain yield and the YSI index exhibited a significant positive correlation under aerobic conditions (Fig. 1). YSI was a more useful index to discriminate water limited from normal lines [11]. Nouri et al. [12] reported that YSI can be a useful parameter for discriminating lines that have higher stability and lower susceptibility to stress conditions.

3.2 Principal Component Analysis (PCA)

The PCA was performed to discern the per cent contribution of major components and indices towards the total variance using grain yield under both conditions and selection indices (Table 4 and Fig. 2). Biplot analysis confirmed correlation analysis between the studied criteria. Principal component analysis (PCA) using the selection indices and grain yield under both conditions (aerobic and irrigated) resulted in a number of linear combinations of these indices that account for most of the variability in the data. Considering Eigen values greater than or equal to 1.0, the first two components in total, explained more than 99% of the variation of the selection indices. The first component (PC1) explained 62.45% of the total variation and exhibited a high positive correlation with YI, YS, YSI, GMP, STI and MP (Table 4), thus the variables belong to the component one was named as yield potential components with aerobic adaption as explained by Fernandez [10] group A and group C components as stable performing lines under water-limited (aerobic) and normal (irrigated) condition. The second component (PC2) explained 36.72% of the total variation and had the highest positive correlation with TOL, MP, STI, GMP, and SSI except for YRR and PYR thus it was called aerobic stress susceptibility components. Likewise, Bahrami et al. [13] and Dorostkar et al. [8] Yan W used the same approach to name PC1 and PC2 based on their correlation with Y_s, Y_p and stress tolerance indices. In the biplot, indices are positively correlated if the angle between their vectors is 90°, and independent if the angle is 90° (Yan and Kang 2003); [1]. Thus, Y_p and Y_s positively correlated with the MP, GMP and STI indices, as indicated by the acute angles between their vectors. The obtuse angle between the vectors of Y_s, TOL and SSI indicates a substantial negative association between these variables. TOL had a near zero correlation with GMP and STI, as indicated by their nearly perpendicular vectors.

3.3 Grouping of the Selected Lines based on Their Yield Response to Aerobic Conditions Using Different Selection Indices

Achieving drought tolerance solely based on grain yield is difficult because of its complex heritability and similarly, selecting lines with tolerant genes is also a difficult task [14]. Alternatively, some breeders have employed parameters to compare grain yield changes under water-limited (aerobic) and normal (irrigated) conditions for the selection of tolerant lines as suggested by Rosielle and Hamblin [15]. In addition, selection indices and their correlation with grain yield have been also used to select high-yielding lines [15,16]. So according to Fernandez, [10], lines can be divided into four groups based on their yield response to selection conditions as groups A, B, C and D. The lines belonging to 'group A' were selected from selection indices like, stress tolerance index (STI), mean productivity (MP) and geometric mean productivity (GMP). Among the 118 rice rice lines such as DB 5 (Swarna × *Oryza nivara* (IRGC 81848)) and NPK-40 (Swarna × *Oryza nivara* (IRGC81832)) wild introgression lines. GNV-14-96-1 (BPT-5204 × Nerica line) advanced breeding line. JBB 631-1 ((Swarna*2/ IRGC 4105) (RP 5405-JBB-631-1-1-1-1-1-1)) *tropical japonica* × *indica* introgression line. KR-209 (Wazuhophek × ISM) and KR-262 (Wazuhophek × ISM) recombinant introgression lines. TI-36 and TI-124 EMS mutants of BPT-5204. WB-10 (Langphou) and WB-16 (Phouoibi) North-Eastern landraces belong to the group 'A' these lines are suitable for both conditions (aerobic and irrigated) and reported to produce high yield under both conditions and in other words, these lines showed low grain yield loss in both the conditions. From a practical point of view, the lines which fall into 'group A' are efficient and responsive to the use of available soil water and nutrient and are the most desirable, with a robust root system.

The lines belonging to the 'group B' were selected from selection indices like stress tolerance (TOL) and stress susceptibility index (SSI), and it includes ten lines such as Rasi, ATR-486 (Azucena × Dular), CG-228 (Dissi), CG-242 (Mow), CG-243 (Mouli), CR-Dhan-201, DRR Dhan-41, MTU-1010, NPK-40 (Swarna × *Oryza nivara* (IRGC81832)) and NPK-43 (Swarna × *Oryza nivara* (IRGC81832)) and these lines reported producing yield under irrigated conditions. Therefore, the lines are high yielding under irrigated ecosystem, The lines belonging to' group C' were selected from indices like, stress susceptibility index (SSI), yield stability index (YSI), per cent yield reduction (PYR), yield index (YI) and yield reduction ratio (YRR) this group includes nine rice lines such as NPK-40 (Swarna × *Oryza nivara* (IRGC81832)), Rasi, Swarna, TI-124 (BPT-5204 mutant), WB-24 (Pat-Phou), WB-26 (Taothabi), along with the positive checks for aerobic rice ecosystem such as MAS 946-1, CR-Dhan-202, DRR Dhan-44, indicating their suitability for cultivation under aerobic condition, This is due to contributed traits of higher root biomass and length, seedling vigour. The lines belonging to the 'group D' were selected based on tolerance index (TOL) indices consisting of five lines (TI-44 EMS mutant of BPT-5204), NPS-53 (Swarna × *Oryza nivara* (IRGC81848)), DB-7 (Swarna**Oryza nivara*), RP-Bio and CG-219 (Saali)). These have poor performance under both aerobic and irrigated conditions. These were the most undesirable lines and were the non-efficient and non-responsive type for both under water-limited and normal conditions. Fageria and Santos, [17] grouped the lines into four categories based on the yield under stress and non-stress conditions. Similar work of grouping genotypes from different stress indices has been reported [10,18,9].

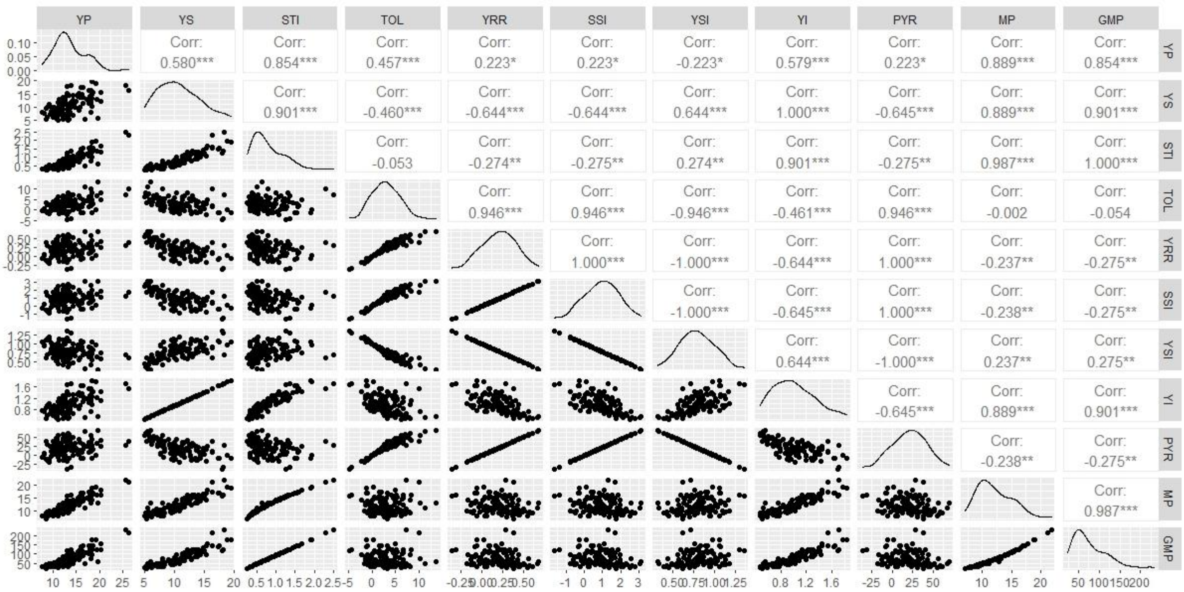

Fig. 1. Correlation for multiple indices of rice panel under irrigated and aerobic conditions

Table 1. Selection indices were calculated using the following relationship

Sl. No.	Index Name	Formula	Reference
1	Stress tolerance index (STI)	$STI=\frac{Y_{P}Y_{S}}{(\bar{Y}_P)^2}$	Fernandez, [10]
2	Tolerance index (TOI)	$TOI = Y_P - Y_S$	Rosielle and Hamblin, [15]
3	Stress susceptibility index (SSI)	$SSI= \frac{1-Y_S/Y_P}{1-\overline{Y_S/Y_P}}$	Fisher and Maurer, [19]
4	Yield stability index (YSI)	$YSI= \frac{Y_S}{Y_P}$	Bouslama and Schapaugh,[20]
5	Yield reduction ratio (YR)	$YR = 1 - (\frac{Y_S}{Y_S})$	Araghi, G. and Assad, [21]
6	Yield index (YI)	$YI= \frac{Y_S}{\bar{Y}_S}$	Gavuzzi et al. [22]
7	Percent yield reduction (PYR)	$YR= \frac{Y_{P-Y_S}}{Y_P}\times100$	Yaseen and Malhi, [18]
8	Mean Productivity (MP)	$(Y_p+Ys)/2$	Rosielle and Hamblin, [15]
9	Geometric Mean Productivity (GMP)	$\sqrt{(Y_p)}(Ys)$	Kristin et al. [23]; Fernandez, [10]

Table 2. Multiple selection indices of rice panel under irrigated and aerobic conditions

Sl. No.	Rice lines	Biological status of Accession	Y_p	Y_s	STI	TOL	YRR	SSI	YSI	YI	PYR	MP	GMP
1	KJ-214	Tropical *japonica* accessions	12.99	9.25	0.64	3.74	0.29	1.31	0.71	0.87	28.77	11.12	60.10
2	KJ-216		19.70	6.02	0.64	13.68	0.69	3.16	0.31	0.56	69.43	12.86	59.34
3	KJ-219		13.60	10.59	0.77	3.01	0.22	1.01	0.78	0.99	22.13	12.10	72.01
4	KJ-221		15.07	12.22	0.99	2.85	0.19	0.86	0.81	1.15	18.89	13.64	92.06
5	KJ-222		10.36	6.29	0.35	4.07	0.39	1.79	0.61	0.59	39.25	8.33	32.60
6	KJ-226		15.88	10.00	0.85	5.87	0.37	1.69	0.63	0.94	36.99	12.94	79.41
7	WB-3 (Wangoo-Phou)	North-Eastern Landraces	11.65	9.80	0.61	1.85	0.16	0.72	0.84	0.92	15.86	10.72	57.07
8	WB-5 (Phouren)		18.18	16.30	1.59	1.88	0.10	0.47	0.90	1.53	10.34	17.24	148.17
9	WB-6 (Chakhao)		12.28	13.75	0.90	-1.48	-0.12	-0.55	1.12	1.29	-12.03	13.02	84.42
10	WB-8 (Moirangphou-Yenthik)		18.34	10.33	1.01	8.01	0.44	1.99	0.56	0.97	43.66	14.34	94.76
11	WB-10 (Langphou)		19.20	18.83	1.94	0.37	0.02	0.09	0.98	1.77	1.91	19.02	180.80
12	WB-12 (Langphou-Chakao)		13.63	10.38	0.76	3.26	0.24	1.09	0.76	0.97	23.89	12.01	70.73
13	WB-14 (Ayangleima)		11.78	10.27	0.65	1.51	0.13	0.58	0.87	0.96	12.81	11.03	60.53
14	WB-15 (Heimang-Phou)		11.89	8.19	0.52	3.69	0.31	1.42	0.69	0.77	31.07	10.04	48.70
15	WB-16 (Phouoibi)		16.28	14.74	1.28	1.54	0.09	0.43	0.91	1.38	9.46	15.51	119.98
16	WB-22 (Moirang-Phou-Khokngangbi)		15.83	13.68	1.16	2.15	0.14	0.62	0.86	1.28	13.60	14.75	108.25
17	WB-23 (Kakcheng-Phou)		17.74	11.29	1.07	6.46	0.36	1.66	0.64	1.06	36.39	14.52	100.13
18	WB-24 (Pat-Phou)		18.33	19.49	1.91	-1.17	-0.06	-0.29	1.06	1.83	-6.37	18.91	178.62
19	WB-26 (Taothabi)		13.42	14.33	1.03	-0.92	-0.07	-0.31	1.07	1.34	-6.83	13.88	96.15
20	WB-27 (Langmanbi)		18.10	12.69	1.23	5.41	0.30	1.36	0.70	1.19	29.89	15.40	114.84
21	WB-29 (Akut-Phou)		20.36	12.10	1.32	8.26	0.41	1.85	0.59	1.13	40.59	16.23	123.14

Sl. No.	Rice lines	Biological status of Accession	Y_p	Y_s	STI	TOL	YRR	SSI	YSI	YI	PYR	MP	GMP
22	WB-30 (MoirangPhou-Angouba)		15.62	15.08	1.26	0.54	0.03	0.16	0.97	1.41	3.48	15.35	117.75
23	WB-32 (Keibi-Phou)		19.56	12.98	1.36	6.58	0.34	1.53	0.66	1.22	33.62	16.27	126.98
24	WB-39 (Phouren-Amubi)		17.82	16.31	1.56	1.51	0.08	0.39	0.92	1.53	8.49	17.06	145.29
25	GNV-1109	Advanced breeding line	11.30	11.09	0.67	0.21	0.02	0.08	0.98	1.04	1.83	11.19	62.64
26	GNV-1089		10.64	8.09	0.46	2.54	0.24	1.09	0.76	0.76	23.91	9.37	43.04
27	RNR-15048	Popular mega variety	10.74	9.56	0.55	1.18	0.11	0.50	0.89	0.90	10.98	10.15	51.30
28	Pokkali	Cultivated variety	9.27	10.92	0.54	-1.65	-0.18	-0.81	1.18	1.02	-17.81	10.09	50.58
29	Siri-1253	Cultivated variety	11.72	9.38	0.59	2.35	0.20	0.91	0.80	0.88	20.02	10.55	54.96
30	GNV-14-96-1	Advanced breeding lines	18.62	15.41	1.54	3.21	0.17	0.79	0.83	1.44	17.26	17.01	143.44
31	RP-Bio-226	Cultivated variety	8.09	7.73	0.33	0.36	0.04	0.20	0.96	0.72	4.41	7.91	31.25
32	Tellahamsa	Popular mega variety	11.67	10.84	0.68	0.83	0.07	0.33	0.93	1.02	7.14	11.25	63.23
33	FL-478	Cultivated variety	10.36	7.20	0.40	3.16	0.31	1.39	0.69	0.67	30.53	8.78	37.28
34	Ratnamudi	Karnataka landraces	10.01	6.26	0.34	3.75	0.37	1.71	0.63	0.59	37.48	8.13	31.30
35	Ratnachudi		8.64	5.36	0.25	3.28	0.38	1.73	0.62	0.50	37.92	7.00	23.17
36	Tanu	Popular mega varieties	11.28	7.50	0.45	3.79	0.34	1.53	0.66	0.70	33.56	9.39	42.29
37	Rasi		13.18	17.98	1.27	-4.80	-0.36	-1.66	1.36	1.69	-36.41	15.58	118.54
38	Swarna Sub-1		10.31	8.29	0.46	2.02	0.20	0.89	0.80	0.78	19.56	9.30	42.75
39	MTU-1010		8.80	9.91	0.47	-1.11	-0.13	-0.58	1.13	0.93	-12.65	9.36	43.62
40	BPT-5204		15.68	8.95	0.75	6.72	0.43	1.95	0.57	0.84	42.89	12.32	70.18
41	Jaya		16.58	13.60	1.21	2.98	0.18	0.82	0.82	1.27	17.99	15.09	112.72
42	MTU-1001		11.22	8.12	0.49	3.10	0.28	1.26	0.72	0.76	27.64	9.67	45.52
43	TI-3	Ethyl Methane Sulfonate (EMS) mutants of BPT-5204	11.18	11.65	0.70	-0.47	-0.04	-0.19	1.04	1.09	-4.20	11.42	65.12
44	TI-4		10.36	10.15	0.56	0.21	0.02	0.09	0.98	0.95	2.06	10.25	52.56
45	TI-8		12.36	7.34	0.49	5.02	0.41	1.85	0.59	0.69	40.59	9.85	45.38
46	TI-11		9.60	9.80	0.50	-0.20	-0.02	-0.09	1.02	0.92	-2.08	9.70	47.01
47	TI-12		13.15	7.24	0.51	5.91	0.45	2.05	0.55	0.68	44.96	10.20	47.62
48	TI-15		10.81	5.81	0.34	5.00	0.46	2.11	0.54	0.54	46.27	8.31	31.41
49	TI-16		11.12	4.99	0.30	6.13	0.55	2.51	0.45	0.47	55.10	8.06	27.76
50	TI-17		11.50	10.52	0.65	0.98	0.09	0.39	0.91	0.99	8.55	11.01	60.47
51	TI-18		12.30	9.40	0.62	2.90	0.24	1.08	0.76	0.88	23.60	10.85	57.79
52	TI-19		10.93	6.14	0.36	4.79	0.44	2.00	0.56	0.58	43.84	8.53	33.53
53	TI-23		12.08	9.62	0.62	2.46	0.20	0.93	0.80	0.90	20.37	10.85	58.07
54	TI 24		13.27	7.53	0.53	5.73	0.43	1.97	0.57	0.71	43.22	10.40	49.97
55	TI-25		12.30	6.65	0.44	5.65	0.46	2.09	0.54	0.62	45.95	9.47	40.87
56	TI 35		16.39	11.39	1.00	5.00	0.30	1.39	0.70	1.07	30.49	13.89	93.37
57	TI 36		20.36	15.42	1.68	4.94	0.24	1.11	0.76	1.44	24.28	17.89	156.94
58	TI-37		13.14	7.80	0.55	5.34	0.41	1.85	0.59	0.73	40.63	10.47	51.28

Sl. No.	Rice lines	Biological status of Accession	Y_p	Y_s	STI	TOL	YRR	SSI	YSI	YI	PYR	MP	GMP
59	TI-44		18.28	8.03	0.79	10.25	0.56	2.56	0.44	0.75	56.07	13.16	73.39
60	TI-87		13.47	5.62	0.40	7.86	0.58	2.66	0.42	0.53	58.31	9.55	37.84
61	TI-112		13.11	9.19	0.64	3.92	0.30	1.36	0.70	0.86	29.88	11.15	60.23
62	TI-128		12.61	12.70	0.86	-0.09	-0.01	-0.03	1.01	1.19	-0.69	12.66	80.09
63	TI-166		12.40	13.86	0.92	-1.46	-0.12	-0.54	1.12	1.30	-11.80	13.13	85.95
64	TI-124		13.90	18.22	1.36	-4.32	-0.31	-1.42	1.31	1.71	-31.07	16.06	126.68
65	Swarna	Cultivated varieties	16.09	17.35	1.49	-1.26	-0.08	-0.36	1.08	1.63	-7.83	16.72	139.64
66	Vandana		13.27	11.09	0.79	2.17	0.16	0.75	0.84	1.04	16.38	12.18	73.59
67	Wazuhophek	Landrace	12.70	6.73	0.46	5.97	0.47	2.14	0.53	0.63	47.02	9.71	42.70
68	Improved Samba Mahsuri (ISM)	Cultivated variety	18.29	14.83	1.45	3.46	0.19	0.86	0.81	1.39	18.90	16.56	135.60
69	PUP-225 (ISM × VANDANA)	Near isogenic lines	14.78	11.96	0.95	2.82	0.19	0.87	0.81	1.12	19.06	13.37	88.36
70	PUP-229 (MTU1010 × Vandana)		18.28	11.60	1.13	6.68	0.37	1.67	0.63	1.09	36.54	14.94	106.02
71	PUP-230 (MTU1010 × Vandana)		16.86	5.54	0.50	11.32	0.67	3.06	0.33	0.52	67.15	11.20	46.66
72	KR-209 (ISM × Wazuhophek)	Recombinant inbred lines	26.23	16.30	2.29	9.93	0.38	1.72	0.62	1.53	37.84	21.27	213.82
73	KR-262 (ISM × Wazuhophek)		18.46	13.33	1.32	5.13	0.28	1.27	0.72	1.25	27.77	15.90	123.07
74	CR Dhan-202	Aerobic adapted cultivar	13.40	11.04	0.79	2.36	0.18	0.80	0.82	1.03	17.59	12.22	73.99
75	SR-50	Short rice, landrace from Nagaon, Assam	13.37	6.44	0.46	6.94	0.52	2.36	0.48	0.60	51.87	9.91	43.04
76	MAS 946-1	Aerobic adapted cultivar	15.39	14.71	1.21	0.68	0.04	0.20	0.96	1.38	4.42	15.05	113.14
77	PB-3	Pusa basmati	17.92	13.63	1.31	4.30	0.24	1.09	0.76	1.28	23.97	15.78	122.12
78	CR Dhan-201	Aerobic adapted cultivar	13.07	15.30	1.07	-2.23	-0.17	-0.78	1.17	1.43	-17.04	14.18	99.96
79	DRR Dhan-42	First Drought tolerant MAS derived variety	14.02	11.99	0.90	2.03	0.14	0.66	0.86	1.12	14.48	13.00	84.01
80	DRR Dhan-44	Aerobic adapted cultivar	14.15	11.15	0.84	3.01	0.21	0.97	0.79	1.04	21.24	12.65	78.88
81	NPS-24	Wild introgression lines (Swarna× *Oryza nivara)*	13.65	8.28	0.61	5.37	0.39	1.79	0.61	0.78	39.33	10.97	56.55
82	NPS-53		9.53	7.24	0.37	2.29	0.24	1.09	0.76	0.68	23.99	8.39	34.51
83	NPS-25		11.14	7.94	0.47	3.20	0.29	1.31	0.71	0.74	28.75	9.54	44.24
84	DB-5		17.96	13.98	1.34	3.98	0.22	1.01	0.78	1.31	22.16	15.97	125.59
85	DB-6		14.69	9.90	0.78	4.80	0.33	1.49	0.67	0.93	32.65	12.30	72.71
86	DB-7		14.38	7.07	0.54	7.31	0.51	2.32	0.49	0.66	50.85	10.72	50.80
87	DB-9		17.99	12.54	1.21	5.45	0.30	1.38	0.70	1.17	30.31	15.26	112.77
88	NPK-13		12.08	11.46	0.74	0.62	0.05	0.23	0.95	1.07	5.13	11.77	69.26
89	NPK-27		12.64	6.44	0.44	6.21	0.49	2.24	0.51	0.60	49.09	9.54	40.69
90	NPK-40		16.47	17.54	1.55	-1.07	-0.06	-0.30	1.06	1.64	-6.48	17.01	144.47
91	NPK-41		11.54	8.17	0.50	3.37	0.29	1.33	0.71	0.77	29.21	9.85	47.11

Sl. No.	Rice lines	Biological status of Accession	Y_p	Y_s	STI	TOL	YRR	SSI	YSI	YI	PYR	MP	GMP
92	NPK-43		12.48	12.70	0.85	-0.22	-0.02	-0.08	1.02	1.19	-1.74	12.59	79.27
93	NPK-45		9.91	9.28	0.49	0.62	0.06	0.29	0.94	0.87	6.29	9.60	45.98
94	SM-363	Ethyl Methane Sulfonate (EMS) mutants of N22	12.91	10.97	0.76	1.94	0.15	0.68	0.85	1.03	15.03	11.94	70.77
95	SM-669		12.51	7.50	0.50	5.01	0.40	1.82	0.60	0.70	40.03	10.00	46.90
96	SM-686		10.97	9.55	0.56	1.42	0.13	0.59	0.87	0.89	12.97	10.26	52.36
97	PB-4	Pusa basmati	12.09	9.90	0.64	2.19	0.18	0.83	0.82	0.93	18.11	11.00	59.85
98	PB-5		11.99	11.15	0.72	0.84	0.07	0.32	0.93	1.04	7.01	11.57	66.84
99	Sahbhagidhan	Drought tolerant variety	17.24	12.80	1.18	4.44	0.26	1.17	0.74	1.20	25.74	15.02	110.31
100	Sabita	*Oryza sativa* cultivar	13.71	11.20	0.82	2.51	0.18	0.83	0.82	1.05	18.29	12.45	76.76
101	DRR Dhan-41	Drought tolerant variety	12.61	13.57	0.92	-0.96	-0.08	-0.35	1.08	1.27	-7.62	13.09	85.52
102	KMR-3	Variety	13.26	5.17	0.37	8.10	0.61	2.78	0.39	0.48	61.05	9.22	34.26
103	IR-64	Cultivated Mega variety	15.49	14.23	1.18	1.26	0.08	0.37	0.92	1.33	8.11	14.86	110.19
104	ATR-486	Introgression line (Azucena × Dular)	11.33	12.85	0.78	-1.52	-0.13	-0.61	1.13	1.20	-13.38	12.09	72.82
105	ASG-73	Landrace from West Bengal	11.57	8.03	0.50	3.54	0.31	1.39	0.69	0.75	30.57	9.80	46.47
106	ASG-126	Landrace collected from Uttar Pradesh	13.71	9.53	0.70	4.17	0.30	1.39	0.70	0.89	30.45	11.62	65.34
107	Saali	*Oryza glaberrima* accessions	8.80	6.14	0.29	2.65	0.30	1.37	0.70	0.58	30.16	7.47	27.02
108	Dissi		8.53	9.50	0.43	-0.97	-0.11	-0.52	1.11	0.89	-11.33	9.02	40.53
109	Mow		9.36	10.25	0.51	-0.89	-0.10	-0.44	1.10	0.96	-9.55	9.80	47.95
110	Mouli		7.71	8.17	0.34	-0.45	-0.06	-0.27	1.06	0.77	-5.88	7.94	31.50
111	Basmathi-370	Traditional Bamati cultivar	11.90	9.43	0.60	2.46	0.21	0.94	0.79	0.88	20.71	10.67	56.11
112	Thurur Bhog	Landrace	12.32	7.57	0.50	4.75	0.39	1.76	0.61	0.71	38.57	9.94	46.60
113	D-92	North-Eastern Landrace	12.29	5.30	0.35	6.99	0.57	2.59	0.43	0.50	56.88	8.80	32.57
114	JBB-661	*Tropical japonica* × *indica* introgressed lines	8.25	7.75	0.34	0.50	0.06	0.28	0.94	0.73	6.10	8.00	31.96
115	JBB-610		14.26	12.47	0.95	1.79	0.13	0.57	0.87	1.17	12.53	13.37	88.93
116	JBB-684		9.63	8.40	0.43	1.23	0.13	0.58	0.87	0.79	12.74	9.02	40.46
117	JBB-1325		14.36	14.27	1.10	0.09	0.01	0.03	0.99	1.34	0.63	14.32	102.46
118	JBB-631-1		25.61	18.25	2.50	7.36	0.29	1.31	0.71	1.71	28.74	21.93	233.69

Y_p-Yield under irrigated condition, Y_s- Yield under aerobic condition

Table 3. Combined analysis of variance for grain yield under irrigated and aerobic conditions and selection tolerance indices for 118 rice lines

Source of variation	Mean sum of square											
	df	**Y_P**	**Y_S**	**STI**	**TOL**	**YRR**	**SSI**	**YSI**	**YI**	**PYR**	**MP**	**GMP**
Treatment	117	11.96 **	11.93 **	0.23 ns	10.47 **	0.05 ns	0.95 **	0.05 **	0.11 **	458.6 **	9.71 **	1680.52 **
Check	7	4.41 **	5.28 **	0.27 ns	13.32 **	0.14 ns	1.02 **	0.05 **	0.08 **	480.16 **	2.67 **	471.67 **
Test vs. Check	1	15.72 **	38.58 **	3.04 **	30.61 **	0.03 ns	3.75 **	0.35 **	0.99 **	1913.89 **	55.92 **	3363.2 **
Test genotypes	109	12.41 **	12.12 **	0.2 ns	10.11 **	0.04 ns	0.92 **	0.04 **	0.11 **	443.86 **	9.74 **	1742.71 **
Block	1	3.96 **	4.53 **	1.51 **	0.35 ns	0.09 ns	0.01 ns	0.02 **	0.06 *	0.94 ns	6.25 **	4.55 **
Residuals	7	0.05	0.16	0.12	0.39	0.05	0.0024	0.00037	0.01	0.48	0.03	0.15

**, ** Significant at 0.05 and 0.01 levels of probability, respectively; ns = not significant, Y_p-Yield under irrigated condition, Y_s- Yield under aerobic condition*

Table 4. Principal components for selection indices under irrigated and aerobic conditions for 118 rice lines

Variables	**Y_P**	**Y_S**	**STI**	**TOL**	**YRR**	**SSI**	**YSI**	**YI**	**PYR**	**MP**	**GMP**	**Eigenvalue**	**% variance**
PC 1	0.13048	0.36595	0.28931	-0.2574	-0.3175	-0.3176	0.31749	0.36598	-0.3176	0.27941	0.28942	6.87	62.45
PC 2	0.46451	0.13569	0.32081	0.35793	0.2738	0.27367	-0.2738	0.13555	0.2736	0.33753	0.32063	4.03	36.72

Y_p-Yield under irrigated condition, Y_s- Yield under aerobic condition

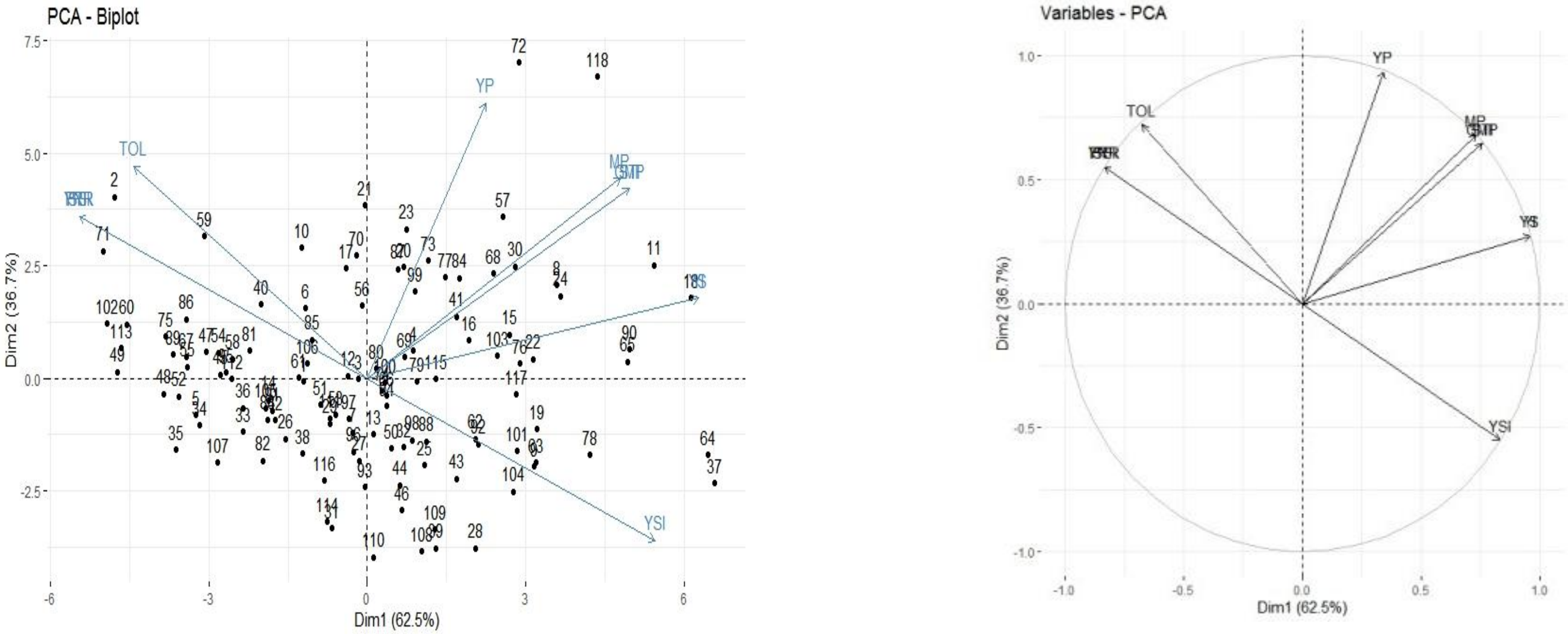

Fig. 2. PCA-Biplot and variable plot for selection tolerance indices under irrigated and aerobic conditions for 118 rice lines

4. CONCLUSION

The indices STI, YI, MP, and GMP exhibited a strong correlation with Y_P and Y_S and serve as valuable selection criteria for the identification of aerobic-tolerant cultivars from both stress and normal conditions. These indices identified lines *viz*. DB 5 (Swarna × *Oryza nivara* (IRGC 81848)), NPK-40 (Swarna × *Oryza nivara* (IRGC81832)) wild introgression lines, GNV-14-96-1 (BPT-5204 × Nerica line) advanced breeding line, JBB 631-1 ((Swarna*2/ IRGC 4105) (RP 5405-JBB-631-1-1-1-1-1-1)) *tropical japonica* × *indica* introgression line, KR-209 (Wazuhophek × ISM) and KR-262 (Wazuhophek × ISM) recombinant introgression lines, TI-36, TI-124 EMS mutants of BPT-5204, WB-10 (Langphou) and WB-16 (Phouoibi) North-Eastern landraces as promising for both environments. The lines are suitable for aerobic condition because of low grain yield loss and can be further considered for evaluation under aerobic conditions at multiple locations.

CONFERENCE DISCLAIMER

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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