

Isolating higher yielding and more stable rice genotypes in stress environments: fine-tuning a selection method using production and resilience score indices

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Supplementary materials

A: Consistency of the score indices over different seasons

To demonstrate their consistency, the same selection process was repeated on another set of 36 genotypes, from Verulkar et al.^[1], using both selection methods (1) YPSI-YSSI selection method (using the local cultivar as a reference) and (2) selecting genotypes directly with PCI-RCI value superior to seven in both indices (corresponding to the A genotype area, Fig. 3(b) in this paper). These 36 genotypes included the six genotypes this manuscript highlights, and the same two local cultivars (IR64 and MTU1010).

For yield performance selection, using the YPSI-YSSI selection adjusted with fine-tuning on PCI-RCI, four genotypes with consistent yield performance between moderate and severe stress were identified: IR 69515-6-KKN-4-UBN-4-2-1-1-1, IR 70213-10-CPA-4-2-2-2, DGI 75, IR 74371-70-1-1 (Table S2). Common selections to Raman et al.^[2] were DGI 75, IR 74371-70-1-1. These four genotypes had high production capacity but poor resilience under moderate stress (RCI = 4) which improved under severe stress (RCI = 6) (Table S2).

All three selections (Verulkar et al.^[1], Raman et al.^[2] and this paper) agree that DGI 75 and IR 74371-70-1-1 yield better than the local cultivar under a range of environments. However, as with Raman et al.^[2], the selected genotypes using this method are not the best performing under stress conditions, but they can be identified using the PCI-RCI selection method.

Selection using PCI and RCI identified two common genotypes under moderate and severe stress environments in both Verulkar et al.^[1] and Raman et al.^[2]: ARB 8 and ARB7 (Table S3) that were stable high yielding genotypes under moderate to severe stress conditions compared to the population (36 genotypes and 39 genotypes). Finally, IR 55419-04, identified as resilient and productive using the data set of Raman et al.^[2] was also highlighted in this set from Verulkar et al.^[1] under severe stress but not under moderate stress due to a lower RCI (RCI = 5) (Table S3). This second analysis confirmed that genotypes selected using PCI and RCI directly are the better options, within these populations, to ensure yield under unpredictable stresses as in rainfed lowland, upland, and aerobic conditions.

Ideally, the same set of 39 genotypes would have been trialled over different years and stress intensities to be more comparable. However, having another set including the six highlighted from Raman et al.'s

analysis^[2] and the same two reference cultivars (IR64 and MTU1010) under a similar environment was sufficient to demonstrate the consistency of the score index selection method. In fact, discovering the same genotypes between two different sets and years clearly shows it is feasible to select genotypes under stress conditions by comparing their yield responses in terms of resilience and productivity to the response of the whole population (PCI-RCI). Identifying two of the three selected genotypes with each selection method is an excellent result.

Table S1 List of the 36 rice lines showing the yield value under irrigated conditions (Yp), moderate stress (Yms), severe stress (Yss) (data from Verulkar et al.^[1])

Genotype ID	Yp (T·ha ⁻¹)	Yms, SI: 0.33					Yss, SI: 0.67				
		Yms (T·ha ⁻¹)	YPSI	YSSI	PCI	RCI	Yss (T·ha ⁻¹)	YPSI	YSSI	PCI	RCI
NDR 1045-2	5.3	3.9	4	8	10	6	1.4	4	5.5	7	4
IR 79906-B-5-3-3	5.8	3.1	8	5.5	9	2	1.6	6.5	7.5	10	5
IR 69515-6-KKN-4-UBN-4-2-1-1-1	5.5	3.4	6	6.5	9	4	1.6	4.5	7.5	9	6
IR 70213-10-CPA-4-2-2-2	5.5	3.4	6	6.5	9	4	1.6	4.5	7.5	9	6
ARB 8	4.5	3.8	0.5	8	8	8	1.9	-1	9.5	9	10
IR 70215-70-CPA-3-4-1-3	4.8	3.2	3	6.5	8	5	1.9	1	9.5	10	9
IR 74371-54-1-1	5.2	3.4	5	6.5	9	4	1.5	3.5	6.5	8	5
IR 78937-B-4-B-B-B	5.5	2.7	6.5	4.5	7	2	1.7	5.5	8	10	6
DGI 75	5.2	3.2	4.5	6	8	4	1.6	3.5	7.5	9	6
IR 74371-70-1-1	5.2	3.2	4.5	6	8	4	1.6	3.5	7.5	9	6
IR 79913-B-399-B-2	5.2	3.1	5.5	5.5	8	3	1.7	3.5	8	9	7
IR 70844-10-SRN-43-1-B-B-1-1	5.1	3.3	4.5	6	8	4	1.6	3	7	8	6
IR 69502-6-SRN-3-UBN-2-B-2-2-2	5.8	2.9	7.5	5	8	2	1.3	6	5	7	3
IR 78908-80-B-3-B	5.0	3.5	4	7	9	5	1.5	2	6.5	7	6
IR 55419-04	4.7	3.3	2.5	6.5	8	5	1.8	0	9	9	9
IR 78875-23-B-2-B	5.3	2.6	6	4.5	7	2	1.8	4	8.5	10	7
ARB 3	5.0	3.1	4.5	6	8	4	1.7	2.5	8	9	7
IR 74371-46-1-1	5.1	3.0	5	5	7	3	1.7	2.5	8	9	7
DGI 307	5.0	3.1	4.5	6	8	4	1.6	1.5	7.5	8	7
IR 74371-78-1-1	5.1	3.0	5	5	7	3	1.6	3	7	8	6
ARB 7	4.5	3.5	1	7.5	8	7	1.7	-1	8.5	8	9
PMK 3	5.0	3.7	3.5	7.5	9	6	1.2	2	4.5	5	4
Poornima 79	3.8	3.8	-2.5	8.5	7	10	1.5	-2.5	7	6	8
IR 78908-39-B-2-B	5.4	3.3	6	6.5	9	4	1.1	4.5	3.5	5	2
Tripuradhan 81	3.4	3.4	-4.5	7.5	5	10	1.7	-1	8.5	8	9
Kallurundkar 82	3.2	3.2	-4.5	7.5	5	10	1.6	0	7	7	7
APO 90	3.1	3.1	-5.5	7	4	10	1.3	2	5	6	4
MTU 1010	5.1	2.8	4.5	5	7	3	1.4	2.5	6	7	5
Baranideep 82	2.9	2.9	-5.5	7	4	10	1.5	-0.5	6.5	6	7
Annada 81	3.0	3.0	-5.5	7	4	10	1.6	-3.5	7.5	6	9
Jonga 88	2.5	2.5	-7.5	6	2	10	1.6	-3	7.5	6	9
IR 64	5.1	2.6	5	4	6	2	0.9	2.5	2	3	1
Lalmati 79	2.9	2.9	-5.5	7	4	10	1.4	-8	6.5	3	10
Kalamkati 90	1.7	1.7	-9	5.5	1	10	1.1	1	3.5	4	3
IR 36	4.4	2.3	3	3.5	5	2	0.7	-1	1	1	1
IR 79956-B-60-2-3	4.2	1.8	2.5	2	3	1	1	-3	3	2	4

Note: The yield potential score index (YPSI), the yield score stress index (YSSI), the production capacity index (PCI), the resilient capacity index (RCI) were calculated from the yield data following the scoring method developed by Thiry et al.^[3] and the stress intensity (SI) was calculated following the method of Fischer and Maurer^[4]. Genotypes ID highlighted in yellow are the selected genotypes from the method of this paper on Raman et al yield data^[2]. The color scale from red to green represents the lowest to highest values (YPSI scale is going from -4.5 (red) to 4.5 (green) and all the other indices are scaled from 1 (red) to 10 (green)).

Table S2 List of selected rice genotypes using YPSI, YSSI + fine-tuning on PCI-RCI

Genotype ID	Moderate stress					
	Yp (T·ha ⁻¹)	Yms (T·ha ⁻¹)	YPSI	YSSI	PCI	RCI
IR 69515-6-KKN-4-UBN-4-2-1-1-1	5.50	3.40	6	6.5	9	4
IR 70213-10-CPA-4-2-2-2	5.50	3.40	6	6.5	9	4
IR 74371-54-1-1	5.20	3.40	5	6.5	9	4
DGI 75	5.20	3.20	4.5	6	8	4
IR 74371-70-1-1	5.20	3.20	4.5	6	8	4
IR 70844-10-SRN-43-1-B-B-1-1	5.10	3.30	4.5	6	8	4
ARB 3	5.00	3.10	4.5	6	8	4
DGI 307	5.00	3.10	4.5	6	8	4
IR 78908-39-B-2-B	5.40	3.30	6	6.5	9	4
IR 64	5.10	2.60	5	4	6	2
MTU 1010	5.10	2.80	4.5	5	7	3

Genotype ID	Severe stress					
	Yp (T·ha ⁻¹)	Yss (T·ha ⁻¹)	YPSI	YSSI	PCI	RCI
IR 69515-6-KKN-4-UBN-4-2-1-1-1	5.50	1.60	4.5	7.5	9	6
IR 70213-10-CPA-4-2-2-2	5.50	1.60	4.5	7.5	9	6
IR 78937-B-4-B-B-B	5.50	1.70	5.5	8	10	6
DGI 75	5.20	1.60	3.5	7.5	9	6
IR 74371-70-1-1	5.20	1.60	3.5	7.5	9	6
IR 79913-B-399-B-2	5.20	1.70	3.5	8	9	7
IR 78875-23-B-2-B	5.30	1.80	4	8.5	10	7
IR 64	5.10	0.90	2.5	2	3	1
MTU 1010	5.10	1.40	2.5	6	7	5

Note: Yp, yield potential (yield value under irrigated conditions); Yms, yield under moderate stress; Yss, yield under severe stress; YPSI, yield potential score index; YSSI, yield stress score index; RCI, resilient capacity index; PCI, production capacity index calculated for two environments (moderate stress and severe stress). Genotypes ID highlighted in purple show the four common genotypes between stress intensity, while those highlighted in light blue show the reference genotypes. Yield data of 36 rice genotypes was sourced from Verulkar et al.^[1]. The indices were calculated following the method of Thiry et al.^[3]. The color scale from red to green represents the lowest to highest values (YPSI scale is going from -4.5 (red) to 4.5 (green) and all the other indices are scaled from 1 (red) to 10 (green)).

Table S3 List of the genotypes with responses superior to the 70% of the population in moderate and severe stress environments in terms of PCI and RCI

Genotype ID	Moderate stress					
	Y _p (T·ha ⁻¹)	Y _{ms} (T·ha ⁻¹)	YPSI	YSSI	PCI	RCI
ARB 8	4.50	3.80	0.5	8	8	8
ARB 7	4.50	3.50	1	7.5	8	7
Poornima 79	3.80	3.80	-2.5	8.5	7	10
IR 64	5.10	2.60	5	4	6	2
MTU 1010	5.10	2.80	4.5	5	7	3
Genotype ID	Severe stress					
	Y _p (T·ha ⁻¹)	Y _{ss} (T·ha ⁻¹)	YPSI	YSSI	PCI	RCI
ARB 8	4.50	1.90	-1	9.5	9	10
IR 70215-70-CPA-3-4-1-3	4.80	1.90	1	9.5	10	9
IR 79913-B-399-B-2	5.20	1.70	3.5	8	9	7
IR 55419-04	4.70	1.80	0	9	9	9
IR 78875-23-B-2-B	5.30	1.80	4	8.5	10	7
ARB 3	5.00	1.70	2.5	8	9	7
IR 74371-46-1-1	5.10	1.70	2.5	8	9	7
DGI 307	5.00	1.60	1.5	7.5	8	7
ARB 7	4.50	1.70	-1	8.5	8	9
Tripuradhan 81	3.40	1.70	-1	8.5	8	9
Kallurundkar 82	3.20	1.60	0	7	7	7
IR 64	5.10	0.90	2.5	2	3	1
MTU 1010	5.10	1.40	2.5	6	7	5

Note: Y_p, yield value under irrigated conditions; Y_{ms}, yield under moderate stress; Y_{ss}, yield under severe stress; YPSI, yield potential score index; YSSI, yield stress score index; PCI, production capacity index; RCI, resilient capacity index. Genotypes ID highlighted in purple show the two common genotypes between stress intensity into this set of 36 rice genotypes, while those highlighted in light blue show the reference genotypes and the ones highlighted in pink are common to the main study of this manuscript (from data set of Raman et al.^[2]) observed under severe stress condition. Yield data of 36 rice genotypes is sourced from Verulkar et al.^[1]. The indices were calculated following the method of Thiry et al.^[3]. The color scale from red to green represents the lowest to highest values (YPSI scale is going from -4.5 (red) to 4.5 (green) and all the other indices are scaled from 1 (red) to 10 (green)).

B: Linear regression reporting Pearson correlation coefficient (R) and significance

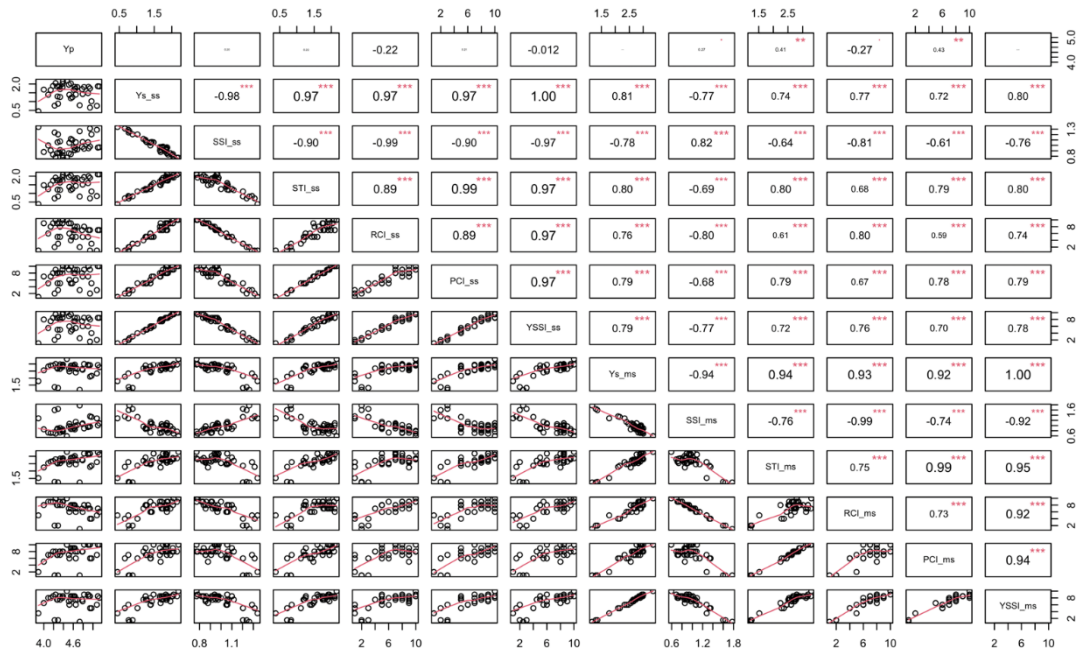


Fig. S1 Linear regression reporting Pearson correlation coefficient (R) and significance ($***P < 0.0001$, $**P < 0.001$, $*P < 0.01$, $\cdot P < 0.05$) between each variables: the yield value under irrigated conditions (Y_p), yield under moderate and severe stress (Y_{ms} and Y_{ss} , respectively), stress susceptibility index under moderate and severe stress (SSI_{ss} and SSI_{ms} , respectively), stress tolerance index under moderate and severe stress (STI_{ms} and STI_{ss} , respectively), resilient capacity index under moderate and severe stress (RCI_{ms} and RCI_{ss} , respectively), production capacity index under moderate and severe stress (PCI_{ms} and PCI_{ss} , respectively) and yield score stress index under moderate and severe stress ($YSSI_{ss}$ and $YSSI_{ms}$, respectively).

C: Limitation of the selection method to identify A genotypes

To confirm the need to have at least one representative genotype A to properly classified and identify genotypes following the distribution in Fig. 3(b), we compared both distributions as a function of RCI and PCI of the 39 genotypes^[2] under both stress intensities (Fig. S2(a,c)) and when a hypothetical pure A-genotype is introduced into these trials, generating Fig. S2(b,d).

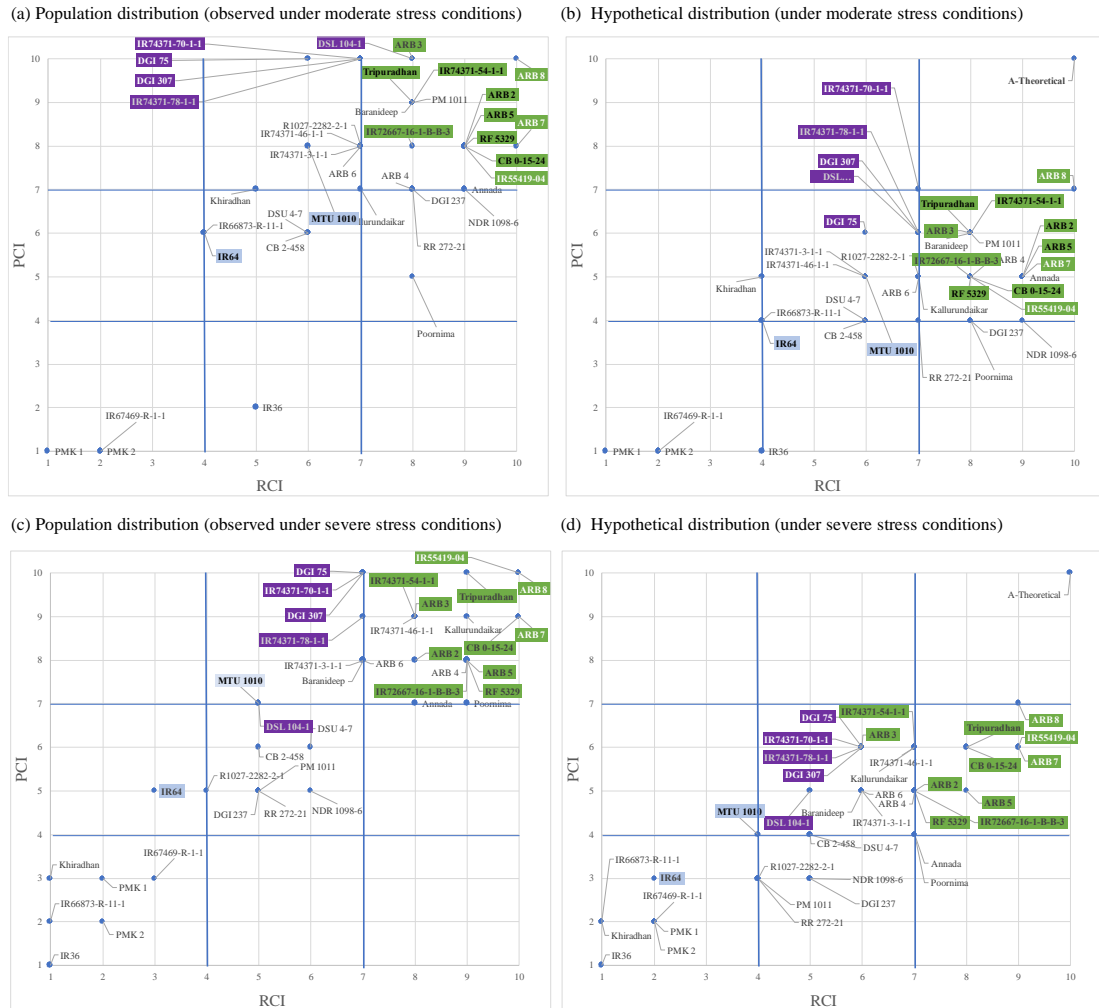


Fig. S2 Distributing genotypes into four classes based on RCI and PCI under moderate (a) and severe stress (c). (b) and (d) Show the redistribution of the genotypes based on RCI and PCI when a theoretical A genotype was inserted into the panel, corresponds to moderate stress (b) and to severe stress (d). Genotypes highlighted in green represent the 11 genotypes in common between both stress intensities using the selection base on RCI and PCI only, genotypes highlighted in purple represent the five genotypes in common between both stress intensities using the indices YSSI and YPSI selection + fine-tuning on RCI-PCI, genotypes highlighted in light blue represent the two reference cultivars. Genotype ID which are written in white color represents the selected ones.

Looking at Raman et al. yield data^[2], the genotype distribution as a function of RCI and PCI under both stress intensities (Fig. S2(a,c)) indicates the 11 common genotypes classified as A-genotypes (Fig. 3(a,c), Fig. S2(a,c)). As these score indices (RCI and PCI) depend on the response of whole population, if no pure A genotypes are present then genotypes with the best performance in terms of RCI and PCI will be distributed into the A genotypes area but are not true A genotypes. While this selection identifies genotypes with high stable yield in stress environments, they will not yield the best under non-stress conditions as they are not A genotypes. These 11 genotypes highlighted green in Fig. S2 should be better considered as C genotypes.

To create an A-theoretical genotype, the maximum Y_p observed in the trial for yield potential value was used and a theoretical Y_s derived by subtracting the minimum observed differences between Y_p

and Ys that Yp (max), for each stress intensity (Fig. S2(b,d)). This redistributes the genotypes towards the theoretical model (Fig. 3(b)). The three genotypes selected using RCI and PCI are located in the best C genotypes area (Genotypes' ID written in white on a green background in Fig. S2) and the three genotypes selected by YSSI and YPSI are located in the best B genotypes area (Genotypes' ID written in white on a purple background in Fig. S2).

This indicates that RCI and PCI allow the breeder to easily identify A genotypes as suggested by Thiry et al.^[3] but we are highlighting here the importance of having at least one A genotype in the panel to differentiate A from B and C genotypes otherwise the use of PCI and RCI will differentiate C from B.

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