



# Characterization of Rice (*Oryza sativa* L.) Germplasm for Early Seedling Vigour-related Traits under Direct Seeded Condition

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## **Authors' contributions**

*This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.*

## **Article Information**

DOI: 10.9734/IJPSS/2023/v35i193762

## **Open Peer Review History:**

This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: <https://www.sdiarticle5.com/review-history/106358>

**Original Research Article**

**Received: 05/07/2023**

**Accepted: 09/09/2023**

**Published: 13/09/2023**

## **ABSTRACT**

In pursuit of boosting rice production while maintaining economic feasibility within resource constraints, the shift from the traditional puddled-transplanted rice system to direct-seeded rice is gaining significance. Early seedling vigour (ESV) is an important character crucial for direct-seeded rice to outcompete and suppress weed growth. This study evaluated hundred rice germplasm accessions for their early seedling vigour-related traits. Mesocotyl and coleoptile lengths,

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chlorophyll content, alpha-amylase, speed of emergence, shoot and root characteristics, and vigour indices exhibited notable variability as indicated by their high PCV and GCV. Moreover, they were predominantly under the influence of additive gene effects, as illustrated by their high heritability and genetic advance as per cent of mean. This suggests that these traits are heritable and could be effectively exploited through selective breeding efforts. Positive correlations were found between seedling vigour and traits like emergence (%), speed of emergence, chlorophyll content, and alpha-amylase activity. Based on PCA, Vigour index-I, II, total seedling length, and chlorophyll contents were regarded as major discriminators in rice germplasm for direct seeded traits. The superior genotypes for seedling vigour such as *Honduras* and *Gharib*, could be used as donors in the rice breeding programs to develop direct seeded rice cultivars.

**Keywords:** Direct seeded rice; seedling vigour; correlation; variability; PCA.

## 1. INTRODUCTION

Rice (*Oryza sativa* L.) is one of the most important crops, serving as the primary dietary staple for half of the global population [1]. With the ever-increasing global demand for rice, maintaining rice production is of utmost importance. Worldwide, different systems of rice cultivation are in vogue, among which the puddled-transplanted rice (TPR) has led to an increase in rice crop productivity [2]. Apart from the benefits of TPR, it consumes enormous water, labour and energy. As these resources are becoming scarce, rice production has become less profitable [3]. Consequently, it is important to enhance crop productivity while ensuring economic viability. Thus, the situation calls for a substantial change in the rice cultivation system, shifting from puddled-transplanted rice to direct-seeded rice.

Rice is extensively grown under irrigated as well as rainfed conditions. Among the rice ecosystems, irrigated rice holds the dominant position in terms of both cultivated area and production [1]. By 2025, approximately 17 million hectares of irrigated rice fields in Asia could face physical water scarcity, while 22 million hectares might encounter economic water scarcity [4]. Hence, optimizing water use in rice cultivation is imperative. As an alternative to the traditional transplanted system, direct-seeded rice (DSR) offers advantages such as reduced labour and water needs, enables crops to mature 7–14 days earlier, and results in reduced methane emissions from the field [5].

Despite these advantages, one of the major devastating threats associated with DSR is weed growth [6], and more than 20 % of attainable yield or even total losses occur when the situation is not controlled [7]. A crop plant exhibiting faster growth holds a competitive

advantage over weed plants, leading to the inhibition of weed growth. The advancement of DSR continues to be impeded by challenges, and a significant one among them is the limited presence of suitable cultivars [8]. In practice, DSR cultivation employs cultivars that were originally developed and chosen for transplanting methods, which are semi dwarf and having poor early vigour. This mismatch leads to yield inconsistencies across diverse cultivation sites, primarily due to inadequate crop establishment and a high infestation of weeds [9]. The evaluation of appropriate characters for DSR cultivars becomes indispensable for the strategic development of future rice breeding programs. Thus, it is important for rice breeders to exploit the genetic variability present among the rice germplasm in terms of seedling vigor. In this scenario, the present study was conducted to evaluate hundred rice germplasm accessions for their early seedling vigour-related characters.

## 2. MATERIALS AND METHODS

A total of one hundred rice germplasm accessions (Table 1), obtained from Dr. Ramiah Gene bank, Department of Plant Genetic Resources, TNAU, Coimbatore, along with four check varieties suitable for irrigated ecosystem were evaluated for early seedling vigour-related traits under direct-seeded conditions at the Department of Plant Genetic Resources, TNAU, Coimbatore. The experiment was laid out in a completely randomized design with three replications. Polybags of size 30x28x25cm were filled with field soil and recommended basal dose of fertilizer was applied. Ten seeds of each genotype were direct sown in it, at a spacing of 10x5 cm and maintained weed free throughout the growing period by hand weeding. To investigate the variability among genotypes for early seedling vigour-related traits, various vegetative characteristics were examined. The

**Table 1. List of rice germplasm evaluated under the present study**

<b>S. No.</b>	<b>Breeder assigned name</b>	<b>Vernacular name</b>	<b>S. No.</b>	<b>Breeder assigned name</b>	<b>Vernacular name</b>
1	T 3446	Malagit	51	T 3985	Sang Do
2	T 3448	Milyang 23	52	T 3986	Sayllebon
3	T 3477	Mehr	53	T 3999	Sunbonnet
4	T 3488	Arabi	54	T 4014	Tox 1011-4-4
5	T 3489	Assey Y Pung	55	T 4023	Victoria
6	T 3497	Boa Vista	56	T 4030	WIR 1372-1
7	T 3501	British Honduras crede	57	T 4040	Yu nong 1
8	T 3508	Carolina gold	58	T 4046	Calady 40
9	T 3509	Caucasica	59	T 4054	Labelle
10	T 3523	Cuba 65	60	T 4058	Matuyama omachi
11	T 3546	Gharib	61	T 4078	Bico torto
12	T 3552	Honduras	62	T 4086	EL Paso L227
13	T 3580	Lemont	63	T 4092	Jing XI17
14	T 3598	Osogovka	64	T 4098	Lumbini
15	T 3615	Rathuwee	65	T 4100	Navolato
16	T 3631	Sufaid	66	T 4114	K.Hao pahk maw
17	T 3649	Vavilovi	67	T 4125	Sambegeury
18	T 3658	Yodanya	68	T 4187	Sahelika
19	T 3667	Agami M1	69	T 4191	Tokambany
20	T 3738	Pihatuwee	70	T 4199	WAB 706-3-4-K4-KB1
21	T 3747	Seenetti	71	T 4207	WAS 207-B-B-3-I-I
22	T 3764	Weda heenati	72	T 4215	Malagkit
23	T 3778	Assay-Pung	73	T 4254	Jorge valladres
24	T 3787	Gunja	74	T 4256	Kaduma
25	T 3790	Khao Do ngoi	75	T 4319	Harbhoondi
26	T 3804	Jagli Boro	76	T 4331	Surmaniya
27	T 3821	Aus jhari	77	T 4350	ARC 12451
28	T 3822	Baganan asalao	78	T 4372	Ram Tulasi
29	T 3829	Belle patna	79	T 4392	ARC 15872
30	T 3836	Calrose	80	CB-T 1509	Kuruva 24. valasumundon
31	T 3844	Cirad	81	CB-T 1351	Cheera champam
32	T 3855	Drago	82	CB-T 1399	Puthu vithu
33	T 3858	Elvo	83	CB-T 1405	Thovan brown
34	T 3868	Guatemala 1021	84	CB-T 1770	Kalar palai
35	T 3875	Hong jeong	85	CB-T 7	Chirumalairayan
36	T 3885	IRAT 170	86	CB-T 34	Krishna neela bhatta
37	T 3889	Jamaica 3	87	CB-T 51	Sakulathi sanna bhatta
38	T 3892	Jibo ya	88	CB-T 1464	Thekkan
39	T 3900	K. Hao kap sang	89	CB-T 1929	Kinthu samba
40	T 3904	Komal bhog	90	CB-T 1937	Kanaka samba
41	T 3911	Kullu	91	ADT-T 216	White sirumani
42	T 3912	Kuruwee	92	ADT-T 355	Nalla konamani
43	T 3922	Lichuan Da Bai Gu	93	ADT-T 366	Omachi
44	T 3928	Mahsuri	94	ADT-T 1157	Perunkar
45	T 3935	Mat merah	95	ADT-T 1915	BT 154 Baramani
46	T 3948	Muttu samba	96	ADT-T 1967	Jaypore sannam
47	T 3957	Nungyu 1511	97	ADT-T 2060	Radhuri pagal
48	T 3964	Pecos	98	ADT-T 2221	Bhasamanick

S. No.	Breeder assigned name	Vernacular name	S. No.	Breeder assigned name	Vernacular name
49	T 3969	Popong	99	ADT-T 183	Kodai kulathan
50.	T 3976	Rikuto norin 264	100	ADT-T 1340	Rajah kazhama
101.	CO 52				
102.	CO 54				
103.	ADT 54				
104.	CR1009 Sub 1				

emerged seedlings were counted from second day of sowing till the fourteenth day and emergence (%) and speed of emergence [10] were calculated.

$$\text{Speed of emergence} = \frac{X_1}{Y_1} + \frac{X_2 - X_1}{Y_2} + \dots + \frac{X_n - X_{n-1}}{Y_n}$$

Where  $X_n$  is the number of germinated seeds on nth day and  $Y_n$  is the number of days from the first experimental day.

On 15 DAS (days after sowing), five seedlings from each replication were chosen for analyzing traits such as number of leaves, shoot length (cm), root length (cm), total seedling length (cm), number of nodal roots, shoot fresh and dry weights (g), root fresh and dry weights (g). Root network area (cm<sup>2</sup>) and network volume (cm<sup>3</sup>) were recorded through GiA Roots software (General Image Analysis of Roots) [11]. The same set of traits was also recorded on the 30th DAS, along with parameters like the number of tillers per plant and seedling vigour [12] (scoring based on standard evaluation system (SES) recommended by IRRI., 2013). Vigour index I and vigour index II were calculated to assess seedling vigour as suggested by Abdul-Baki and Anderson (1973) [13].

Vigour index I = Germination (%) × Total seedling length (cm)

Vigour index II = Germination (%) × Seedling dry weight (g)

Chlorophyll 'a', chlorophyll 'b' and total chlorophyll were extracted using DMSO from 30 days old seedlings [14,15] and calculations were made based on Arnon's equation.

$$\text{Chlorophyll 'a' (mg/g fresh weight)} = ((12.7 * A_{663}) - (2.69 * A_{645})) * (V/1000 * W)$$

$$\text{Chlorophyll 'b' (mg/g fresh weight)} = ((22.9 * A_{645}) - (4.68 * A_{663})) * (V/1000 * W)$$

$$\text{Total chlorophylls (mg/g fresh weight)} = ((20.08 * A_{645}) + (8.02 * A_{663})) * (V/1000 * W)$$

Alpha amylase activity was estimated from pre-germinated seeds [16]. Analysis of variance was carried out using R software (R version 4.3.1) and variability parameters such PCV, GCV [17], broad sense heritability [18] and genetic advance as percentage of mean [19] were calculated. Simple correlation among the different parameters contributing to the seedling vigour was performed. Principal Component Analysis (PCA) was done to comprehend how each trait contributes to the variation and how the genotypes are distributed along the axes of principal components using GRAPES software (version 1.1.0) [20].

### 3. RESULTS AND DISCUSSION

Analysis of variance showed significant differences among the genotypes for all the characters studied, illustrating the presence of high variability among the germplasm lines for seedling vigour related traits in turn signifying ample scope for selection. Seedlings were scored for ESV on 30 DAS. Out of the 100 genotypes studied, nearly half (52 genotypes) of them recorded ESV score of 1 which is classified as highly vigorous. Twenty four genotypes were normal with four leaves and no tillers. Genotypes 86 (*Krishna Neela bhatta*) and 93 (*Omachi*) were very weak with stunted growth and yellowing. All the check varieties were normal with a score of 5. Genotype 11 (*Gharib*) showed the highest value for number of tillers, leaves, nodal roots and root network area at 30 DAS. At the same day, longest shoot length and root length were recorded by genotype 12 (*Honduras*) (16.09 cm and 39.08 cm respectively) and shortest (4.52 cm) shoot length by 93 (*Omachi*) and root length (5.11 cm) by 86 (*Krishna Neela bhatta*). Highest (0.71 g) and lowest (0.03 g) shoot dry weights at 30 DAS were recorded by genotype 18 (*Agami M1*) and 36 (*Jamaica 3*) respectively. The parameters vigour index I and II at 30 DAS were highest (5148.9 and 74.41 respectively) in genotype 12 (*Honduras*), whereas VI-I was lowest (652.4) in genotype 93 (*Omachi*) and VI-II (4.73) in genotype 36 (*Jamaica 3*).

The mean and variability parameters are given in Table 2. Traits viz., mesocotyl and coleoptile lengths, chlorophyll 'b', total chlorophyll, alpha amylase, speed of emergence, shoot length, root length, total seedling length, number of nodal roots, fresh and dry weights of both shoot and root, root network area and volume, and vigour indices, irrespective of their days of observation, and number of leaves, tillers and ESV at 30 DAS exhibited considerable amount of variation as suggested by their high PCV and GCV values. Furthermore, these traits were predominantly

controlled by additive gene effects as they had a high heritability coupled with high genetic advance as percentage of mean. These results were consistent with the findings of [1] and [21]. Seedling length had high heritability and GAM as per the observations of [22]. All the traits studied had higher PCV than GCV indicating the influence of environment. Number of leaves at 15 DAS and emergence (%) showed low GCV and moderate PCV which implied less variation and high influence of environment on these traits.

**Table 2. Mean, range and genetic parameters for seedling vigour related traits among rice germplasm**

S.No.	Character	Mean	Min.	Max.	PCV (%)	GCV (%)	H(%)	GAM
1.	Mesocotyl length (cm)	0.22	0	2.63	124.98	121.66	94.75	243.96
2.	Coleoptile length (cm)	1.29	0.44	2.39	29.86	25.33	71.92	44.25
3.	Chlorophyll 'a' (mg/g fresh wt.)	2.43	0.68	3.69	21.02	19.82	88.92	38.5
4.	Chlorophyll 'b' (mg/g fresh wt.)	0.85	0.32	1.42	29.33	25.57	76	45.92
5.	Total chlorophyll (mg/g fresh wt.)	3.28	0.99	5.18	21.01	20.56	95.75	41.44
6.	Alpha amylase (mg maltose min <sup>-1</sup> )	5.49	0.2	11.07	31.21	30.86	97.75	62.85
7.	Emergence %	83.46	60	96.67	12.22	7.81	40.83	10.28
8.	Speed of emergence	1.65	0.65	3.2	23.17	22.09	90.88	43.38
<b>15 DAS</b>								
9.	No. of leaves	2.7	2.2	3.67	13.27	8.92	45.21	12.36
10.	Shoot length (cm)	5.66	3.26	9.28	22.07	21.18	92.11	41.87
11.	Root length (cm)	7.18	3.06	12.22	26.48	25.18	90.4	49.31
12.	Total seedling length (cm)	12.85	6.68	19.21	20.07	19.34	92.9	38.4
13.	No. of nodal roots	4.46	1.47	8	33.76	31.32	86.07	59.85
14.	Fresh shoot wt. (g)	0.104	0.042	0.616	67.53	66.46	96.85	134.72
15.	Dry shoot wt. (g)	0.019	0.01	0.088	56.1	55.17	96.69	111.75
16.	Fresh root wt. (g)	0.033	0.012	0.275	83.59	82.79	98.08	168.89
17.	Dry root wt. (g)	0.007	0.002	0.04	71.52	65.4	83.61	123.19
18.	Root network area (cm <sup>2</sup> )	2.57	0.76	8.30	51.12	50.77	98.62	103.86
19.	Root network volume (cm <sup>3</sup> )	0.14	0.02	0.94	112.53	111.88	98.85	229.15
20.	Vigour index-I	1070.1	580.5	1664.	21.82	21.16	94.03	42.27
		2	5	87				
21.	Vigour index-II	2.16	0.815	7.25	52.94	52.31	97.6	106.45
<b>30 DAS</b>								
22.	No. of leaves	6.62	2.6	16.27	41.17	40.8	98.2	83.29
23.	No. of tillers	1.68	0	7.6	84.58	82.79	95.81	166.93
24.	ESV (SES score)	8.24	9	1	25.4	22.44	78.03	40.83
25.	Shoot length (cm)	9.13	4.52	16.09	24.82	24.61	98.35	50.28
26.	Root length (cm)	14.64	5.11	39.08	39.89	39.7	99.09	81.41
27.	Total seedling length (cm)	23.77	9.93	55.17	31.45	31.33	99.27	64.31
28.	No. of nodal roots	7.26	2	15.33	36.29	35.57	96.07	71.81
29.	Fresh shoot wt. (g)	0.781	0.11	2.48	64.26	64.21	99.85	132.17
30.	Dry shoot wt. (g)	0.225	0.03	0.71	64.25	64.15	99.68	131.94
31.	Fresh root wt. (g)	0.236	0.03	1.32	87.27	87.19	99.81	179.44

S.No.	Character	Mean	Min.	Max.	PCV (%)	GCV (%)	H(%)	GAM
32.	Dry root wt. (g)	0.041	0	0.22	86.3	86.16	99.66	177.18
33.	Root network area (cm <sup>2</sup> )	13.49	4.75	70.48	71.02	70.67	99.02	144.86
34.	Root network volume (cm <sup>3</sup> )	1.25	0.2	3.52	63.68	63.42	99.16	130.09
35.	Vigour index-I	1998.4	652.4	5148.89	35.73	35.63	99.42	73.18
36.	Vigour index-II	22.65	4.73	74.41	66.96	66.88	99.77	137.6

Fig. 1. depicts the correlation among the ESV and related traits. There was significant positive correlation between ESV and all the traits, except mesocotyl and coleoptile lengths. In the study by [23] also, coleoptile length was not significantly correlated with emergence (%) which is indeed a contributing factor to ESV. Vigour index- I showed significant positive correlation with all traits except mesocotyl length while vigour index-II was correlated with all other traits except mesocotyl length, coleoptile length and chlorophyll 'b' content. As observed in the present study, [24] reported significant and positive correlation of Vigor Index -I and Vigor Index -II with germination percentage, seedling shoot length, root length, fresh weight, dry weight, number of leaves and total seedling length. Mesocotyl length exhibited no correlation with any of the traits. Emergence percentage, speed of emergence, alpha amylase activity and total chlorophyll content were found to be significantly correlated with ESV, Vigour index-I and Vigour index-II in positive direction. As per the report of [25], amylase activity was a reliable indicator of rice seed's germination and seedling vigour. Germination rate, amylase activity, and chlorophyll content were significantly correlated with ESV in rice according to [26,27,28]. The absence of significant correlation of coleoptile length with ESV, emergence (%) or speed of emergence agreed with the findings of [29].

Traits such as number of leaves and tillers, ESV, shoot, root and total seedling lengths, number of nodal roots, fresh and dry shoot weights, dry root weight, root network area, network volume, VI-I and VI-II, were inter correlated in a significantly positive manner which conforms with the findings of [30]. None of the traits under study exhibited significant negative correlation. Hence, traits viz., number of leaves and tillers, shoot, root and seedling lengths, number of nodal roots, fresh shoot and root weights, dry shoot and root weights, root network area and volume, chlorophyll 'a', chlorophyll 'b', total chlorophyll contents, alpha amylase activity, emergence (%) and speed of emergence can be used as

selection indices for the improvement of early seedling vigour in rice as per correlation analysis.

In order to understand the trends among low and high early seedling vigour genotypes and the traits that are contributing to the observed variability, principal component analysis was performed for all 104 genotypes (Fig. 2). On the cultivar-by-trait biplot based on first two principal components, rice genotypes were scattered as groups, with seedling vigour related traits shown as vectors.

The first six principal components with >1.0 Eigen value together accounted for the 80.13% of the total variation, of which PC1 had the most significant contribution of 44.6%. The other components in order viz., PC2 to PC6 contributed for 11.09%, 7.93%, 6.48%, 5.37%, and 4.66% of the variation individually. Variation in PC1 was mainly attributed to Vigour index-I, II and total seedling length which was in accordance with [1] for which the Eigen values were 7.96, 7.72 and 7.56 respectively. PC2 was highly related to total chlorophyll (22.07%), chlorophyll 'a' (19.74%) and chlorophyll 'b' (19.55%). Moreover, they were considered as the major discriminators due to long vector lengths. Similar to our findings, shoot length was identified as one of the major discriminators in the study of [30], and seedling vigour index-I and II were major contributors to the total variation as per [31]. Phenotypic diversity among the genotypes was illustrated by their distribution along the axes, where the genotypes that clustered together on the biplot exhibited a similar diversity composition. Highest estimates were recorded in the genotypes 7,8,15 (*British Honduras crede, Carolina gold, Sufaid*) representing high ESV values. Minimum values of ESV were recorded by 93 (*Omachi*) and 86 (*Krishna neela bhata*). Genotype 11 (*Gharib*) had high values for the traits represented by PC1 and PC2 and it stands out, in terms of these traits and has a unique combination of trait values. Genotype 12 (*Honduras*) had greater values

for Vigour index-I and II, shoot length and root length as the respective vectors point toward it and also farther from the origin. Genotype 93 and 86 (*Omachi* and

*Krishna neela bhatta*) can be concluded as poor in terms of ESV as they were plotted farther in opposite direction of the ESV vector.

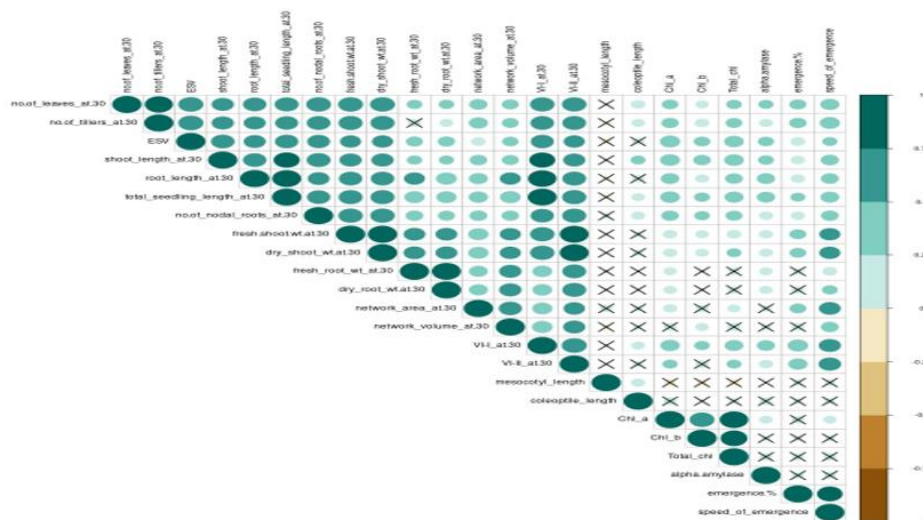


Fig. 1. Correlogram showing the correlation among the ESV traits studied. (Non-significant correlations are indicated by cross marks)

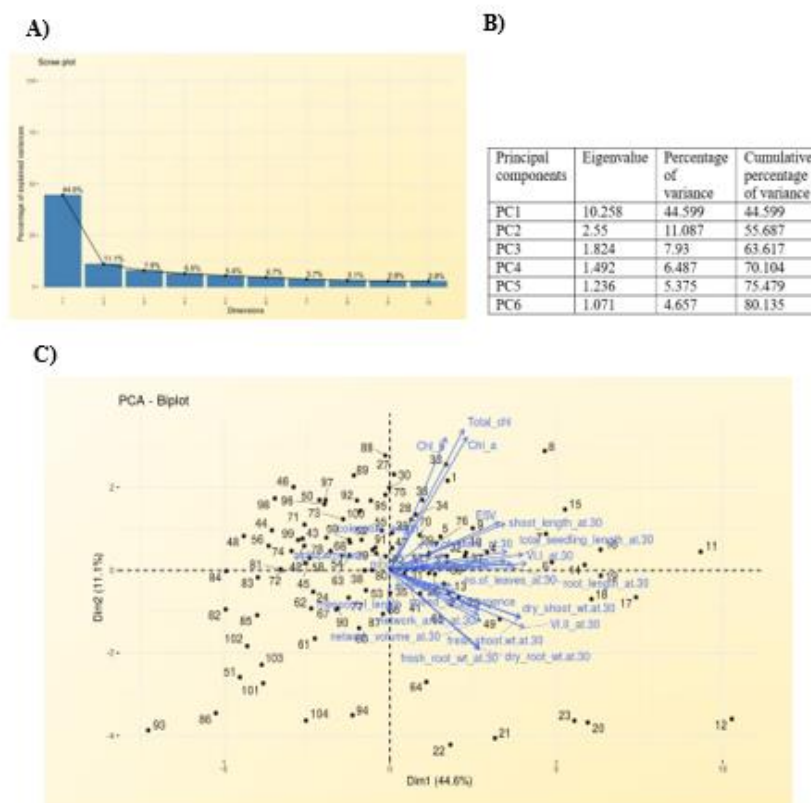


Fig. 2. Principal component analysis (PCA) based on seedling vigour-related traits of rice germplasm. A) Scree plot representing the percentage contribution of PCs. B) Percentage and cumulative percentage contribution of principal components to the total variation. C) Projection of variables. (Genotypes are illustrated as numbers (black))

#### 4. CONCLUSION

The study found significant variability among the germplasm for the evaluated traits viz., mesocotyl and coleoptile lengths, chlorophyll 'b', total chlorophyll, alpha-amylase, speed of emergence, shoot length, root length, total seedling length, number of nodal roots, fresh and dry weights of both shoot and root, root network area and volume, and vigour indices indicating potential for selection to develop rice genotypes suitable for DSR condition. As these traits were predominantly controlled by additive gene effects, the germplasm with desired traits can be exploited in hybridization programs to fix the new recombinants with desirable traits. Positive correlations were observed between seedling vigour and various traits like emergence, speed of emergence, chlorophyll content and alpha-amylase activity. Based on PCA, certain traits like vigour index-I, II, total seedling length, and chlorophyll contents were identified as major discriminators in direct seeded rice germplasm. The research suggests that superior genotypes for seedling vigor could be used as donors in rice breeding programs to develop genotypes specifically suited to direct seeding in rice.

#### COMPETING INTERESTS

Authors have declared that no competing interests exist.

#### REFERENCES

1. Uzair M, Patil SB, Zhang H, Kumar A, Mkumbwa H, Zafar SA, Li X. Screening direct seeding-related traits by using an improved mesocotyl elongation assay and association between seedling and maturity traits in rice. *Agronomy*. 2022;12(4):975.
2. Mahender A, Anandan A, Pradhan SK. Early seedling vigour, an imperative trait for direct-seeded rice: an overview on physio-morphological parameters and molecular markers. *Planta*. 2015;241:1027-1050.
3. Mahajan G, Saradana V, Brar AS, Gill MS. Grain yield comparison among rice (*Oryza sativa* L.) varieties under direct seeding and transplanting. *Haryana J Agron*. 2004;20(1):68-70.
4. Tuong TP, Bouman BA. Rice production in water-scarce environments. In: J W Kijne, R Barker and D Molden (Eds.), *Water Productivity in Agriculture: Limits and Opportunities for Improvement* CABI publishing. 2003;13-42.
5. Chauhan BS, Mahajan G, Sardana V, Timsina J, Jat ML. Productivity and sustainability of the rice-wheat cropping system in the Indo-Gangetic Plains of the Indian subcontinent: Problems, opportunities, and strategies. *Advances in Agronomy*. 2012;117:315-369.
6. Gathala MK, Ladha JK, Kumar V, Saharawat YS, Kumar V, Sharma PK, Pathak H. Tillage and crop establishment affects sustainability of South Asian rice-wheat system. *Agronomy Journal*. 2011;103(4):961-971.
7. Adkins SW. Some present problems and future approaches to weed management in the Asian-Pacific region: Supporting food and environment security by 2020. In *The role of weed science in supporting food security by 2020. Proceedings of the 24th Asian-Pacific Weed Science Society Conference, Bandung, Indonesia. Weed Science Society of Indonesia*. 2013;1-12.
8. Pathak H, Tewari AN, Sankhyani S, Dubey DS, Mina U, Singh VK, Jain N. Direct-seeded rice: Potential, performance and problems-A review. *Current Advances in Agricultural Sciences (An International Journal)*. 2011;3(2), 77-88.
9. Sandhu N, Yadav S, Kumar Singh V, Kumar A. Effective crop management and modern breeding strategies to ensure higher crop productivity under direct seeded rice cultivation system: A review. *Agronomy*. 2021;11(7):1264.
10. Maguire JD. Speed of germination-aid in selection and evaluation for seedling emergence and vigor. *Crop Sci*. 1962;2:176-177.
11. GiA Roots: Software for the high throughput analysis of plant root system architecture (manuscript). Taras Galkovskyi, Yuriy Mileyko, Alexander Bucksch, Brad Moore, Olga Symonova, Charles A Price, Christopher N Topp, Anjali S Iyer-Pascuzzi, Paul Zurek, Suqin Fang, John Harer, Philip N Benfey and Joshua S Weitz.
12. SES I. Standard evaluation system for rice. International Rice Research Institute, Philippines; 2013.
13. Abdul-Baki AA, Anderson JD. Vigor determination in soybean seed by multiple criteria 1. *Crop science*. 1973;13(6):630-633.



14. Hiscox JD, Israelstam GF. A method for the extraction of chlorophyll from leaf tissue without maceration. Canadian Journal of Botany. 1979;57(12):1332-1334.
15. Richardson AD, Duigan SP, Berlyn GP. An evaluation of noninvasive methods to estimate foliar chlorophyll content. New phytologist. 2002;153(1):185-194.
16. Paul AK, Mukherji S, Sircar SM. Metabolic changes in rice seeds during storage. Indian Journal of Agricultural Science. 1970;40(12):1031-1036.
17. Gw B. Quantitative inheritance in grasses. Pro VI Int Grassl Cong. 1952;277-283.
18. Lush JL. Intra-sire correlations or regressions of offspring on dam as a method of estimating heritability of characteristics. Journal of Animal Science. 1940;(1):293-301.
19. Johnson HW, Robinson HF, Comstock RE. Estimates of genetic and environmental variability in soybeans 1. Agronomy Journal. 1955;47(7):314-318.
20. Gopinath PP, Parsad R, Joseph B, Adarsh VS. GRAPES: General Rshiny based analysis platform empowered by statistics; 2020. Available:<https://www.kaugrapes.com/home>. version 1.0.0  
DOI: 10.5281/zenodo.4923220
21. Akshitha B, Senguttuvel P, Latha VH, Yamini KN, Rani KJ, Beulah P. Variability and correlation analysis for seedling vigour traits in rice (*Oryza sativa* L.) genotypes. Int. J. Curr. Microbiol. App. Sci. 2020;9(7):2877-2887.
22. Akshaya M, Thirumurugan T, Chitra S, Nithila S, Jeyaprakash P. Genetic variability in rice (*Oryza sativa* L.) landraces for seedling vigour traits. Electronic Journal of Plant Breeding. 2020;11(01):91-96.
23. Lee HS, Sasaki K, Kang JW, Sato T, Song WY, Ahn SN. Mesocotyl elongation is essential for seedling emergence under deep-seeding condition in rice. Rice. 2017;10(1):1-11.
24. Mithraa T. Characterization of rice (*Oryza sativa*) germplasm accessions for seedling vigor and its related traits. Electronic Journal of Plant Breeding. 2018;9(3):1024-1030.
25. Nandi S, Das G, Sen-Mandi S.  $\beta$ -amylase activity as an index for germination potential in rice. Annals of Botany. 1995;75(5):463-467.
26. Cui K, Peng S, Xing Y, Xu C, Yu S, Zhang Q. Molecular dissection of seedling-vigor and associated physiological traits in rice. Theoretical and Applied Genetics. 2002;105:745-753.
27. Wang ZF, Wang JF, Bao YM, Wang FH, Zhang HS. Quantitative trait loci analysis for rice seed vigor during the germination stage. Journal of Zhejiang University Science B. 2010;11:958-964.
28. Diwan J, Channbyregowda M, Shenoy V, Salimath P, Bhat R. Molecular mapping of early vigour related QTLs in rice. Res J Biol. 2013;1:24-30.
29. Ogiwara H, Terashima K.  $\alpha$ -Amylase activity and soluble sugar supply from endosperm in relation to varietal differences in seedling establishment under low-temperature conditions in rice (*Oryza sativa* L.). Plant Production Science. 2010; 13(4):321-330.
30. Anandan A, Anumalla M, Pradhan SK, Ali J. Population structure, diversity and trait association analysis in rice (*Oryza sativa* L.) germplasm for early seedling vigor (ESV) using trait linked SSR markers. PloS One. 2016;11(3):0152406.
31. Adebisi MA, Okelola FS, Ajala MO, Kehinde TO, Daniel IO, Ajani OO. Evaluation of variations in seed vigour characters of West African rice (*Oryza sativa* L.) genotypes using multivariate technique; 2013.

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