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MULTI-TRAIT GENOTYPE-IDEOTYPE DISTANCE INDEX-BASED SELECTION OF DROUGHT-TOLERANT RICE (*ORYZA SATIVA* L.) GENOTYPES IN INDONESIA

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SUMMARY

Drought is a major problem that threatens rice production worldwide. The development of drought-tolerant rice (*Oryza sativa* L.) genotypes is vital in overcoming such challenges. The study's objective sought to investigate the diversity of drought responses of 33 elite rice cultivars of Indonesia. Two sets of experiments proceeded, covering germination and seedling stages. Imposing drought stress treatment in the germination stage used 25% polyethylene glycol (PEG) 6000, while in the seedling stage, treating rice germplasms with water stress took place in a soil-filled concrete tank. The selection of the best germplasm ensued using the multi-trait genotype-ideotype distance index (MGIDI). Based on the MGIDI selection, six drought-tolerant rice cultivars succeeded in their identification, including Inpari 13, Inpari 35, Inpari 28, Inpari 37, Inpari 23, and Inpari 43. The rice variety Inpari 13 showed close similarity to the ideotype in response to drought stress at the germination stage, whereas Inpari 35 and Inpari 43 exhibited close similarity to the ideotype in response to drought stress during the seedling stage. The selected drought-tolerant rice from an elite germplasm collection is a valuable genetic source for rice improvement and, in the short term, for direct deployment of the genotype in drought-prone environments.

Keywords: Rice (*O. sativa* L.), germplasm, drought tolerance, MGIDI, Inpari 13

Key findings: This study identified drought-tolerant rice (*O. sativa* L.) genotypes based on a multi-trait index selection, which will be a valuable genetic resource for rice improvement.

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INTRODUCTION

Rice (*Oryza sativa* L.) plays a critical role in ensuring food security, with over 50% of the global population relying on it as a primary food (Muthayya *et al*., 2014). Rice cultivation is mainly in irrigated areas, which cover about 75% of global rice production, while the remaining harvest results in rainfed areas (GRiSP, 2013). Intensive water supply is the key to sustainably producing rice in irrigated areas. However, drought events may restrict water supply to rice fields, with increasing intensity because of climate change. Moreover, climate change-induced drought exacerbates conditions for rice cultivation in rainfed regions, where drought stress is a limiting factor. One potential solution for addressing drought-related issues is by developing drought-tolerant varieties (Panda *et al*., 2021; Bhattacharjee *et al*., 2023).

However, breeding rice varieties with enhanced drought tolerance has experienced hindrances from the complexity of genetic mechanisms involved (Jiang *et al*., 2023). Field selection poses challenges due to low heritability, time constraints, and the influence of environmental factors on genotypes (Bhattacharjee *et al*., 2023). Screening for drought-tolerant rice in controlled environments can be an effective method for enhancing the efficiency and accuracy of genotype selection, ensuring that assessing drought tolerance is without the influence of environmental factors (Kakar *et al*., 2022; Bhattacharjee *et al*., 2023).

Different simulation tools had successful uses to evaluate drought tolerance in rice, providing a comprehensive understanding of how different genotypes respond to water stress. Polyethylene glycol (PEG) is a common means of replicating osmotic stress in laboratory settings, whereas soil-based drought simulation offers a more accurate representation of how plants react under field conditions. Several studies have demonstrated that using PEG 6000 or PEG 8000 can differentiate rice varieties tolerant and susceptible to drought (Mahreen *et al*., 2022; Fatima *et al*., 2024).

The complex genetic control of drought tolerance shows an association with multiple physiological and morphological characteristics (Bhandari *et al*. 2023). Incorporating different traits into genotype selection is challenging and requires the use of appropriate statistical methods. The Multi-trait Genotype-Ideotype Distance Index (MGIDI) analysis, as proposed by Olivoto and Lúcio (2020), was a novel approach to genotype selection based on multiple traits, effectively avoiding the multicollinearity issues that arise when using classical linear multi-trait selection indices. The MGIDI has become increasingly applied in genotype selection for varietal improvement across different crops, including rice (Chaity *et al*., 2026), maize (Azrai *et al*., 2023), wheat (Zahedi *et al*., 2026), and mung bean (Basavaraj *et al*., 2026).

Identification of potential sources of drought-tolerant traits from Indonesian germplasm has released reports in previous studies, mainly from traditional varieties (Salsinha *et al*., 2019; Sebastian *et al*., 2022; Megasari *et al*., 2025). While traditional rice varieties are important resources for abiotic stress tolerance, utilization of these exotic germplasm in the breeding program often affects the agronomic characteristics of elite germplasm (Breseghello and Coelho, 2013). Alternatively, elite varieties and breeding lines serve as valuable sources for discovering new drought-tolerant donors and can provide a short-term strategy for mitigating the effects of drought.

Even though many rice varieties have had successful releases in Indonesia for different rice ecosystems, information on their tolerance to drought remains limited. This study’s objective sought to investigate the diversity of responses of elite rice genotypes from Indonesia against drought stress both at the germination and seedling stages. The multi-trait genotype-ideotype distance index (MGIDI) (Olivoto and Lúcio, 2020) helped identify tolerant genotypes based on different drought-related traits.

MATERIALS AND METHODS

Genetic material

The selection of 33 rice (*O. sativa* L.) genotypes started for the drought screening experiment, which represents elite rice cultivars in Indonesia (Sastro *et al*., 2022). Most rice varieties have an Inpari designation, which refers to inbred rice varieties for irrigated areas (Table 1). The study also included the most popular rice variety in Indonesia, Ciherang, along with a drought-susceptible check, IR20, and a drought-tolerant check, Salumpikit, as controls.

Drought stress evaluation in the germination stage

Evaluation of drought tolerance of rice genotypes continued at the germination stage using polyethylene glycol (PEG) to induce osmotic stress (Widyastuti *et al*., 2017). Rice genotypes' subjection to two treatments comprised 25% PEG 6000 and without PEG (control). The experiment had a completely randomized design with two replications. For each treatment, a total of 20 uniform rice seeds selected from each rice genotype underwent germination in a petri dish using 10 mL distilled water. Imposing PEG treatment on two-day-old seedlings included adding 10 mL of 25% PEG 6000 to the petri dish. Observation progressed at seven days after treatment. Data recording took place for germination rate (GR), root length (RL), fresh root weight (FRW), shoot length (SL), and fresh shoot weight (FSW). Drought tolerance determination of rice varieties used the stress tolerance index (STI) (Fernandez, 1992) with a formula:

$$STI = \frac{(Y_i)_{NS} * (Y_i)_S}{(\bar{Y}_i^2)_{NS}}$$

Where, $(Y_i)_{NS}$ refers to rice response under non-stress conditions, and $(Y_i)_S$ is rice response under drought stress. A higher value of STI indicated a higher level of drought resistance.

Drought stress evaluation in the greenhouse

Screening for drought tolerance began at the seedling stage in a concrete tank (length 5.5 m × width 1.3 m × height 0.6 m) placed in a greenhouse. The concrete tank was soil-filled, taken from a rice field in Bogor, Indonesia. Rice establishment proceeded by sowing the rice seeds in the concrete tank. Rice seeds of each accession reached direct sowing in the soil. The plants sustained a spacing adjustment of 20 cm between lines, with the experiment set in a randomized block design with two replications. Soil moisture maintenance was normal until the seedlings were two weeks old. The greenhouse temperature during the day ranged from 28 °C to 45 °C; the relative humidity ranged from 60% to 95%. Drought levels in the soil incurred monitoring using the soil water tension Irrometer. Drought stress, when imposed, had the water supply stopped until the susceptible check variety died, which occurred when the average soil water tension reached 63 kPa. Then, resuming water application sought to determine plant recovery after drought stress. Scoring performance helped to evaluate rice response against drought stress, including leaf rolling (LR), leaf drying (LD), and plant recovery (PR), following the scaling method described in the Standard Evaluation System for Rice (IRRI, 2013).

Multi-trait genotype-ideotype distance index (MGIDI)

The use of the multi-trait genotype-ideotype distance index (MGIDI) served to identify drought-tolerant rice genotypes based on drought response at germination (GR, RL, FRW, SL, and FSW) and seedling stages (LR, LD, and PR). The MGIDI analysis, as performed, used the R package "metan" (Olivoto and Lúcio, 2020). Higher STI in the germination stage evaluation is desirable, while a lower score of drought response is preferable in the seedling stage evaluation. A 20% selection proportion on the lowest MGIDI enabled the identification of the best-performing germplasm based on drought tolerance.

Table 1. Characteristics of elite Indonesian rice genotypes. (Source: Sastro *et al*., 2022).

No.	Varieties	Parentage	Year released	Maturity (days)	Average yield (t ha^{-1})	Amylose content (%)
1	Inpari 1	IR64/IRBB-7//IR64	2008	108	7.3	22.0
2	Inpari 3	Digul/BPT164C-68-7-2	2008	110	6.5	20.6
3	Inpari 4	S4384F-14-1/Way Apo Buru/S4384F-14-1	2008	115	6.0	21.1
4	Inpari 6 Jete	Dakava line 85/ Membramo	2008	118	6.8	18.0
5	Inpari 7 Lanrang	S3054-2D-12-2/Utri Merah-2	2009	112	6.2	20.8
6	Inpari 9 Elo	IR65469-161-2-2-2-3-2-2/ IR61979-138-1-3-2-2	2009	125	6.4	20.5
7	Inpari 10 Laeya	S487b-5/2*IR19661// 2*IR64	2009	112	4.8	22.0
8	Inpari 13	OM606/IR18348-36-3-3	2010	99	6.6	22.4
9	Inpari 16 Pasundan	Ciherang/ Cisadane// Ciherang	2011	118	6.3	22.7
10	Inpari 17	Bio9-MR-V3-11-PN-5// IR64*3/IRBB21	2011	111	6.2	26.0
11	Inpari 18	BP364B-33-3-PN-5-1/ Bio530B-45-9-3-1	2011	102	6.7	18.0
12	Inpari 19	BP342B-MR-1-3/ BP226E-MR-76	2011	104	6.7	18.0
13	Inpari 20	S2823E-KN-33/ IR64// S282E-KN-33	2011	104	6.4	21.1
14	Inpari 23 Bantul	B11738RS(Gilirang/ BP342F-MR-1-3//Gilirang)	2012	113	6.9	17.0
15	Inpari 24 Gabusan	Bio 12 – MR-1-4-PN-6/ Beras	2012	111	6.7	18.0
16	Inpari 25 Opak Jaya	BIO 530C-MR-1/ IRBB 21	2012	115	7.0	5.7
17	Inpari 27	BALDO/7904-TR4-4-2-1-1	2012	125	5.7	21.8
18	Inpari 28 Kerinci	IR 63872-14-2-2-1/ CEA-1	2012	120	6.6	23.7
19	Inpari 29 Rendaman	IR69502-6-SKN-UBN-1-B-1-3/KAL9418F// Pokhali/ Angke	2012	110	6.5	21.1
20	Inpari 30 Ciherang Sub1	Ciherang/IR64Sub1//Ciherang	2012	111	7.2	22.4
21	Inpari 31	Pepe/BP342B-MR-1-3-KN-1-2-3-6-MR-3-BT-1	2013	119	6.0	21.1
22	Inpari 32 HDB	Ciherang/IRBB64	2013	120	6.3	23.5
23	Inpari 33	BP360E-MR-79-PN-2/IR71218-38-4-3//BP360EMR-79-PN-2	2013	107	6.6	23.4
24	Inpari 34 Salin Agritan	BR41/IR61920-3B-22-2	2014	102	5.1	24.9
25	Inpari 35 Salin Agritan	IR10206-29-21/SUAKOKO (SEL.)	2014	106	5.3	24.0
26	Inpari 36 Lanrang	IR58773-35-3-1-2/IR65475-62-3-1-3-1-3-1	2014	114	6.7	20.7
27	Inpari 37 Lanrang	CT9162-12/Seratus Hari T36//Memberamo/ Cibodas///Cibodas///IR66160-121-4-5-3/Membramo	2015	114	6.3	21.4
28	Inpari 38 Tadah Hujan Agritan	IR68886B/BP68*10/Selegreng/Guarani/ Asahan	2015	115	5.7	20.9
29	Inpari 39 Tadah Hujan Agritan	BP342B-MR-1-3/Dendang//IR69502-6SKM-UBN-1-B1	2015	115	5.9	20.2
30	Inpari 41 tadah Hujan Agritan	Limboto/Towuti//Ciherang	2015	114	5.6	20.1
31	Inpari 42 Agritan GSR	Huangxinzhan/Fenghuazhan	2016	112	7.1	18.8
32	Inpari 43 Agritan GSR	WuFengZhan/IRBB5/WuFengZhan	2016	111	6.9	19.0
33	Ciherang	IR18349-53-1-3-1-3/3*IR19661-131-3-1-3//4*IR64	2000	120	6.0	23.0

RESULTS

Drought tolerance variation at the germination stage

The stress tolerance index (STI) used to determine drought-tolerant rice (*O. sativa* L.) genotypes at the germination stage using PEG is available in Table 2. The higher index indicates the genotype is more tolerant. The STI of rice genotype's germination rate varied from 0 (Ciherang) to 0.99 (Inpari 27). The drought-tolerant check variety Salumpikit showed a 0.63 STI, while the susceptible check IR20 showed a 0.32 STI. A total of 12 genotypes have higher STIs than the drought-tolerant variety Salumpikit.

The STI of root length ranged from 0 (Ciherang) to 0.58 (Salumpikit), and none of the improved rice varieties had a higher STI

Table 2. Stress-tolerant index of rice characters at germination stage under drought stress using 25% PEG 6000.

Varieties	Germination rate	Root length	Fresh root weight	Shoot length	Fresh shoot weight
Inpari 1	0.66	0.13	0.19	0.07	0.01
Inpari 3	0.35	0.14	0.09	0.08	0.04
Inpari 4	0.42	0.17	0.22	0.08	0.02
Inpari 6	0.65	0.17	0.15	0.06	0.02
Inpari 7	0.32	0.30	0.45	0.22	0.17
Inpari 9	0.22	0.30	0.10	0.09	0.08
Inpari 10	0.77	0.15	0.08	0.19	0.05
Inpari 13	0.50	0.38	0.47	0.33	0.73
Inpari 16	0.29	0.26	0.52	0.16	0.10
Inpari 17	0.49	0.18	0.17	0.31	0.06
Inpari 18	0.87	0.19	0.42	0.15	0.08
Inpari 19	0.75	0.31	0.10	0.15	0.12
Inpari 20	0.35	0.14	0.15	0.10	0.04
Inpari 23	0.69	0.24	0.27	0.15	0.09
Inpari 24	0.93	0.21	0.25	0.12	0.03
Inpari 25	0.51	0.19	0.15	0.11	0.07
Inpari 27	0.99	0.25	0.51	0.17	0.07
Inpari 28	0.82	0.28	0.66	0.25	0.24
Inpari 29	0.62	0.18	0.15	0.11	0.05
Inpari 30	0.81	0.14	0.14	0.04	0.01
Inpari 31	0.74	0.09	0.07	0.05	0.02
Inpari 32	0.62	0.12	0.07	0.05	0.04
Inpari 33	0.08	0.07	0.37	0.03	0.03
Inpari 34	0.14	0.15	0.25	0.12	0.09
Inpari 35	0.65	0.36	1.02	0.15	0.14
Inpari 36	0.15	0.26	0.13	0.06	0.01
Inpari 37	0.49	0.49	0.44	0.14	0.16
Inpari 38	0.06	0.28	0.47	0.09	0.03
Inpari 39	0.76	0.29	0.22	0.15	0.07
Inpari 41	0.58	0.21	0.14	0.11	0.02
Inpari 42	0.03	0.19	0.12	0.13	0.00
Inpari 43	0.53	0.29	0.30	0.12	0.06
Ciherang	0.00	0.00	0.00	0.00	0.00
IR 20 (Drought susceptible check)	0.32	0.17	0.36	0.09	0.05
Salumpikit (Drought tolerant check)	0.63	0.58	0.39	0.19	0.12

than the tolerant check. Among improved varieties, the best varieties for the root length trait are Inpari 37 (STI 0.49), Inpari 13 (STI 0.38), and Inpari 35 (STI 0.36). Different from the root length, the STI for fresh root weight of some improved rice varieties is higher than Salumpikit (STI 0.39) as the tolerant check. Varieties with high STI for fresh root weight are Inpari 35, Inpari 28, Inpari 16, Inpari 27, Inpari 13, Inpari 38, and Inpari 7 (Table 2). Among improved rice varieties, four genotypes showed higher STI for the shoot length, viz., Inpari 13 (0.33), Inpari 17 (0.31), Inpari 28 (0.25), and Inpari 7 (0.22). The varieties Inpari 13, Inpari 28, and Inpari 35 also exhibited higher STI than Salumpikit for the fresh shoot weight character.

Drought tolerance variation at the seedling stage

Drought tolerance of Indonesian elite rice genotypes at the seedling stage succeeded in its determination based on three criteria, i.e., leaf rolling, leaf drying, and plant recovery. The tolerant variety, Salumpikit, exhibited a tolerant response in all criteria, while the susceptible check, IR20, showed high susceptibility for leaf rolling, leaf drying, and plant recovery. Almost all rice genotypes suffered leaf rolling when subjected to drought stress, reaching classification as susceptible to highly susceptible genotypes (Table 3). Using these criteria, only Inpari 35 showed a moderate response.

Based on leaf drying observation, several rice genotypes have shown moderate susceptibility symptoms, including Inpari 13, Inpari 23, Inpari 34, Inpari 35, Inpari 36, Inpari 37, Inpari 42, and Inpari 43. The genotypes displaying moderate susceptibility response for leaf drying criteria mostly demonstrated moderate susceptibility for the plant recovery criteria, except for Inpari 34 and Inpari 35, which showed moderate tolerance responses (Table 3).

Table 3. Drought tolerance response of elite Indonesian rice genotypes at the seedling stage and the MGIDI value based on eight drought tolerance traits at the germination and seedling stages.

Varieties	Leaf rolling		Leaf drying		Plant recovery		MGIDI value	MGIDI_rank
	Scale	Response	Scale	Response	Scale	Response		
Inpari 1	9	HS	7	S	6	MS	5.61	25
Inpari 3	9	HS	8	S	8	S	5.90	32
Inpari 4	9	HS	9	HS	9	HS	5.84	31
Inpari 6	9	HS	8	HS	6	S	5.62	27
Inpari 7	9	HS	9	HS	8	S	4.68	8
Inpari 9	9	HS	9	HS	9	HS	5.61	26
Inpari 10	9	HS	9	HS	7	S	5.35	20
Inpari 13	6	S	4	MS	5	MS	2.20	1
Inpari 16	9	HS	9	HS	7	S	4.87	11
Inpari 17	8	HS	8	HS	8	HS	4.80	10
Inpari 18	9	HS	9	HS	7	S	5.02	13
Inpari 19	9	HS	9	HS	7	S	5.05	14
Inpari 20	9	HS	9	HS	7	S	5.78	29
Inpari 23	7	S	5	MS	5	MS	4.49	6
Inpari 24	9	HS	9	HS	8	S	5.35	19
Inpari 25	9	HS	9	HS	7	S	5.51	23
Inpari 27	9	HS	9	HS	9	HS	5.01	12
Inpari 28	8	HS	7	S	5	MS	3.64	4
Inpari 29	8	HS	7	S	6	S	5.22	17
Inpari 30	9	HS	8	S	7	S	5.80	30
Inpari 31	9	HS	8	S	7	S	5.92	33
Inpari 32	9	HS	7	S	5	MS	5.75	28
Inpari 33	9	HS	7	S	6	S	5.96	34
Inpari 34	6	S	4	MS	3	MT	5.17	16
Inpari 35	4	MS	4	MS	3	MT	3.09	2
Inpari 36	7	S	5	MS	6	MS	5.50	22
Inpari 37	7	S	5	MS	6	MS	3.81	5
Inpari 38	9	HS	6	S	5	MS	5.13	15
Inpari 39	9	HS	7	S	5	MS	4.72	9
Inpari 41	9	HS	7	S	5	MS	5.30	18
Inpari 42	6	MS	6	MS	5	MS	5.43	21
Inpari 43	6	MS	6	MS	5	MS	4.57	7
Ciherang	8	S	8	S	6	MS	6.75	35
IR 20	9	HS	9	HS	7	S	5.53	24
Salumpikit	2	T	1	T	1	T	3.44	3

T = Tolerant, MT = Moderately tolerant, MS = Moderately susceptible, S = Susceptible, HS = Highly susceptible. Drought tolerance scores underwent averaging from two replications.

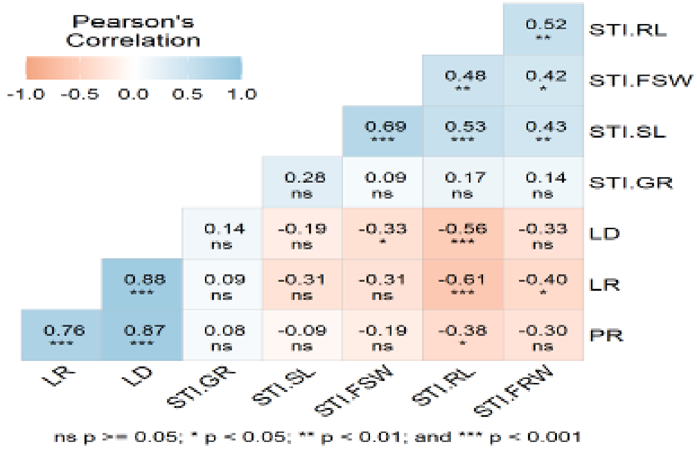

Figure 1. Pearson's correlation coefficient matrix for eight drought tolerance traits in rice genotypes. STI.GR = STI for germination rate, STI.RL = STI for root length, STI.FRW = STI for fresh root weight, STI.SL = STI for shoot length, STI.FSW = STI for fresh shoot weight, LR = leaf rolling, LD = leaf drying, and PR = plant recovery.

Correlation of drought tolerance traits

Positive correlations appeared among traits of drought tolerance at the germination stage (STI.SL, STI.FSW, STI.RL, and STI.FRW), except for the STI.GR (Figure 1). Positive correlations were also evident among drought-tolerant traits at the seedling stage (LR, LD, and PR). Among qualities of drought tolerance at the germination stage, only the STI for root length (STI RL) consistently showed a significant correlation with characteristics of drought tolerance at the seedling stage. Correlation analysis revealed that STI for root length had a significant correlation with all the seedling stage drought tolerance traits (LD, LR, and PR). A negative correlation between STI for RL and seedling drought tolerance traits indicates that the higher the STI for RL, the greater the tolerance level of rice seedlings (based on the scoring system).

Drought tolerance evaluation based on MGIDI

The MGIDI application sought to identify drought-tolerant ideotypes based on drought response traits both at the germination and seedling stages. The MGIDI index ranked rice germplasm by trait performance (Table 3, Figure 2). Using 20% selection intensity, six rice germplasms were options, including Inpari 13, Inpari 35, Inpari 28, Inpari 37, Inpari 23, and Inpari 43. The tolerant check Salumpikit was also among the selected genotypes.

The factorial loadings and communalities obtained from the factor analysis using varimax rotation indicated two distinct groups. FA1 revealed an association with drought response traits from soil screening (LR, LD, and PR), while FA2 indicated an association with the response in PEG evaluation (STI.GR, STI.RL, STI.FRW, STI.SL, and STI.FSW) (Table 4). The five traits, which are related to drought tolerance in the germination stage (STI.GR, STI.RL, STI.FRW, STI.SL, and STI.FSW), incurred subjection for positive selection, with the traits related to drought tolerance in the seedling stage (LR, LD, and PR) subjected to negative selection. The selection differentials (SDs), which measure the mean trait value changes between the original population and selected lines, ranged from -28.8% for PR to 163% for STI.FSW.

The radar plot visualization explained the strengths and weaknesses of the rice germplasm in response to drought stress by categorizing the contributing factors toward MGIDI (Figure 3). The most influential factors

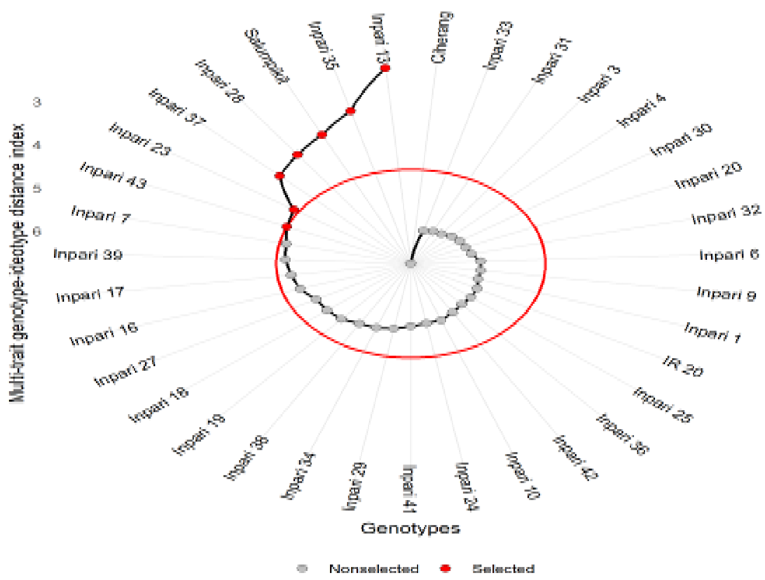

Figure 2. Genotype ranking based on multi-trait genotype-ideotype distance index (MGIDI) using 20% selection proportion. The selected genotypes are shown in red.

Table 4. Factorial loadings, communalities, uniqueness, sense and selection differential obtained from the factor analysis.

Traits	FA1	FA2	Communality	Uniqueness	Sense	Xo	Xs	SD (%)	Goal
STI.GR	0.30	-0.51	0.35	0.65	increase	0.51	0.62	21.5	100
STI.RL	-0.51	-0.65	0.68	0.32	increase	0.22	0.37	66.4	100
STI.FRW	-0.33	-0.63	0.50	0.50	increase	0.27	0.51	85.7	100
STI.SL	-0.07	-0.88	0.77	0.23	increase	0.13	0.19	50.5	100
STI.FSW	-0.21	-0.76	0.62	0.38	increase	0.08	0.22	163.0	100
LR	-0.90	-0.24	0.87	0.13	decrease	8.03	5.71	-28.8	100
LD	-0.95	-0.15	0.93	0.07	decrease	7.17	4.57	-36.3	100
PR	-0.91	-0.03	0.82	0.18	decrease	6.17	4.29	-28.8	100

STI.GR = STI for germination rate, STI.RL = STI for root length, STI.FRW = STI for fresh root weight, STI.SL = STI for shoot length, STI.FSW = STI for fresh shoot weight, LR = leaf rolling, LD = leaf drying, and PR = plant recovery.

reached plotting closer to the center, while factors with less contribution gained a plotting farther from the center. FA1 had the lowest effect on Salumpikit, Inpari 35, and Inpari 43, which indicated these genotypes had close similarity to the ideotype in response to drought stress during the seedling stage. These genotypes maintain good performance on LR, LD, and PR. FA2 showed lower impact on Inpari 13, suggesting this genotype was the best performer in response to drought stress at the germination stage, approaching an ideotype for these traits. Inpari 13 had a good response on STI.GR, STI.RL, STI.FRW, STI.SL, and STI.FSW.

DISCUSSION

In this study, drought tolerances of 33 Indonesian rice (*O. sativa* L.) genotypes succeeded in their evaluation using the PEG-based method in the germination stage and a soil-based method in the seedling stage. The germplasms used in this study were elite rice genotypes for irrigated lowland areas of

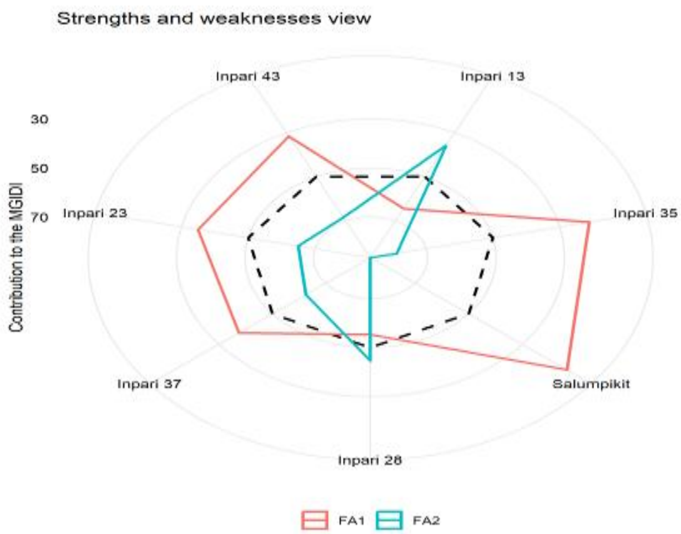

Figure 3. The strengths and weaknesses of selected genotypes as the proportion of each factor based on MGIDI.

Indonesia, which have high yield and were resistant to different pests and diseases. Screening in the germination stage continued using PEG to induce the osmotic stress. In this study, drought stress induction used 25% PEG-6000, a concentration exceeding those applied in previous studies (Han *et al*., 2018; Mas-ud *et al*., 2022; Fatima *et al*., 2024), which ranged from 15% to 20%. The drought-tolerant rice germplasm identified in this study will have higher levels of tolerance relative to previously characterized materials.

This study demonstrated variation in drought stress response among Indonesian elite rice genotypes, as indicated by the variation in the STI for drought-related traits, i.e., germination rate (GR), root length (RL), fresh root weight (FRW), shoot length (SL), and fresh shoot weight (FSW). In the germination phase, drought stress inhibits water absorption, thereby reducing seed vigor (Bhandari *et al*., 2023). Reports of a reduction in germination rate and early vigor development of rice under drought stress have also appeared in previous studies (Evamoni *et al*., 2023; Nyasulu *et al*., 2024; Joseph and Makwinja, 2026).

The response of the drought-tolerant check, Salumpikit, and drought-susceptible check, IR20, can be clearly discriminated using this tolerance index. Raman *et al*. (2012) demonstrated that the STI is an effective parameter for identifying drought-tolerant rice genotypes that also performed well under non-stress conditions. Therefore, the study suggests rice germplasm exhibiting a high STI in this study, including Inpari 13, Inpari 28, and Inpari 35, possesses high adaptability under both stress and non-stress environments.

Rice is sensitive to drought at the seedling and reproductive stages. As drought stress in the reproductive stage is critical and can cause severe yield loss, the screening of drought tolerance in the reproductive stage is difficult. This is because of the complex mechanism underlying tolerance in this stage, having high effects from the environment (Verulkar and Verma 2014). Drought tolerance screening in the seedling stage is more efficient and has been effective in routinely identifying drought-tolerant rice germplasm for decades (O’Toole *et al*., 1978; de Datta *et al*., 1988; Kakar *et al*., 2022; Wei *et al*., 2022). Evaluation of drought tolerance of Indonesian germplasms in the presented study indicated most rice accessions are susceptible to drought at the seedling stage. Two genotypes, Inpari 34 and Inpari 35, showed moderate tolerance in response to drought. These two genotypes are typical as salinity-tolerant rice genotypes, which are adapted to coastal regions in Indonesia (Rumanti *et al*., 2018; Sembiring *et al*., 2019). Drought tolerance response shown by salinity-tolerant germplasms is possibly due to common regulatory elements governing salinity and drought-stress responses in plants (Mishra *et al*., 2018).

The utilization of the multi-trait genotype-ideotype distance index (MGIDI) served to select drought-tolerant genotypes using eight traits. This included STI for germination rate (STI.GR), STI for root length (STI.RL), STI for fresh root weight (STI.FRW), STI for shoot length (STI.SL), STI for fresh shoot weight (STI.FSW), leaf rolling (RL), leaf drying (LD), and plant recovery (PR). Using MGIDI, the selection focused more on increasing or decreasing specific traits to find genotypes that are close to an ideotype (Olivoto and Nardino, 2021). This method avoids multicollinearity issues when using the classical linear multi-trait selection index. Correlation analysis of drought tolerance traits indicated some traits have significant correlation; therefore, the MGIDI method can help prevent distorted results and biased coefficients during multi-trait selection. Using 20% selection intensity, this study has identified the top six genotypes for drought tolerance. Drought-tolerant germplasms identified from this study comprised Inpari 13, Inpari 35, Inpari 28, Inpari 37, Inpari 23, and Inpari 43. Their tolerance level is comparable to the tolerant check Salumpikit. Several drought-tolerant rice genotypes from Indonesian germplasms have previously occurred in reports, primarily consisting of traditional varieties (Salsinha *et al*., 2019; Sebastian *et al*., 2022; Megasari *et al*., 2025). In contrast, the drought-tolerant rice germplasm identified in this study originates from elite germplasm collections, which hold potential for direct deployment in drought-prone environments.

Each genotype has strengths and weaknesses in response to drought, as revealed by the MGIDI. For instance, the best genotype, Inpari 13, has strength related to drought tolerance in the germination stage (STI.GR, STI.RL, STI.FRW, STI.SL, and STI.FSW); therefore, it will be suitable for drought-prone areas where limited water is available during the early season. Interestingly, Inpari 13 is a short-duration and high-yielding rice variety. Early maturing variety has the potential to minimize crop damage due to end-of-season drought (Bernier *et al*., 2008). Combining drought resistance in the vegetative stage and short-duration traits will be an important strategy to reduce the effect of drought on rice production.

CONCLUSIONS

Identification of new genetic sources to improve drought tolerance in rice (*O. sativa* L.) is crucial to minimize the impact of climate change in the future on food production. This study has identified six drought-tolerant rice genotypes in the early vegetative stages based on the MGIDI analysis, including Inpari 13, Inpari 35, Inpari 28, Inpari 37, Inpari 23, and Inpari 43. Selected drought-tolerant rice from an elite germplasm collection in this study is a valuable genetic source for rice improvement and, in the short term, to directly deploy the genotype in drought-prone environments. Further study is essential to clarify the tolerance of these genotypes in the reproductive stage, which is crucial in rice production.

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