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RESEARCH ARTICLE

Comparative evaluation of drought response in Malaysian fragrant rice genotypes from seed germination to grain-filling

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ABSTRACT

Drought has reduced rice (*Oryza sativa* L.) production and impacted worldwide food security. Malaysian Agricultural Research and Development Institute (MARDI) has developed 58 of rice cultivars including fragrant rice. However, little has been studied about drought tolerance of Malaysian fragrant rice. Therefore, the study was conducted to assess drought tolerance level of selected MRQ rice cultivars. Seeds of rice cvs. MRQ50, MRQ74, MRQ76, Wangi88 and MRQ104 were germinated under three different osmotic stress conditions of control (0 MPa), moderate (-0.6 MPa) and severe (-0.9 MPa) induced by polyethylene glycol (PEG) 6000 for 2 wk to evaluate the drought tolerance at early stage. Thereafter, germination percentage (GP), germination index (GI), germination energy (GE), germination rate (GR), seedlings growth traits including seedling height, fresh weight, dry weight, seedlings vigor I (SVI) and seedlings vigor II (SVII) were evaluated. Plant height, number of tillers, weight of 1000 grains, plant biomass was measured for determination of drought tolerance level at vegetative and reproductive stage. The results indicate that increasing drought intensity significantly reduced germination traits and seedling performance, being MRQ104 the most effected. Under severe drought stress (-0.9 MPa), MRQ74 maintained 90% GP and 85% GR, whereas MRQ104 decreased to 50% GP with complete inhibition of GR (0%). Drought condition at vegetative and reproductive stages demonstrated reduction of most parameters. Drought stress reduced 1000 grain weight in all genotypes up to 25%. Cluster analysis shows that MRQ50, MRQ76, Wangi 88 and MRQ74 were classified as drought-tolerant cultivars while MRQ104 was classified as drought-sensitive cultivar.

Key words: Fragrant rice, germination, *Oryza sativa*, seedling.

INTRODUCTION

Rice (*Oryza sativa* L.) is basis of food security in Malaysia as rice was a dietary staple for more than 70% of Malaysian population. Despite rice is very important food in population daily consumption, declining trend in rice output in Malaysia has been recorded from 2018 to 2024. Malaysia’s rice self-sufficiency level dropped to approximately 50%, which is 10% decline from the annual target in 2024, largely due to severe drought and water scarcity that affected over 52 600 ha of paddy fields across main production regions. This shortage required outsource supplies from various countries such as Thailand, Vietnam, and Myanmar.

Malaysia’s imported rice comprises high quality rice to meet the demand for speciality rice as Malaysian lifestyles and socio-economic levels have changed. The imports of specialty rice were categorised into several types including fragrant rice, glutinous rice, Basmati rice, *japonica*, and red rice. Malaysian Agricultural Research and Development Institute (MARDI) has developed fragrant rice cultivars referred to as MRQ50, MRQ74, MRQ76, Wangi88, and MRQ104 under MARDI breeding program (Ramli et al., 2021). These cultivars have aromatic quality, good texture, and competitive yield. However, the successful cultivation of these fragrant rice cultivars is challenging by environmental factors comprises climate change, diseases outbreak and water supply including irrigation, flood, and drought (Shukri et al., 2025).

Drought is the biggest factor limiting rice production and contributing to global food insecurity. Malaysia experiencing in raised of drought significantly impacted rice production. About 5000 ha of paddy fields have been affected in Kelantan, with an estimated loss of nearly 40 000 t in 2024. Drought strives various impact including plant's morphological, physiological, and molecular characteristics which further disturbing plant metabolic activities, crop quality, and yield (Bhardwaj and Kapoor, 2021). Drought decreased rice yield by 21.0% to 50.6% at the vegetative stage, 42.0% to 83.7% at the flowering stage, and 51.0% to 90.6% at the reproductive stage (Zhang et al., 2018). Drought causing morpho-physiological damage and biochemical dysfunction which limit active plant growth and development (Qiao et al., 2024).

Thus, the convergence of fragrant rice development and rising drought vulnerability cause an utmost challenge in Malaysian rice production system. There is an urgent need to improve understanding about drought tolerance profile of Malaysian fragrant rice cultivars and how drought affect growth stages. Besides that, selection of drought resistant genotypes in early growth stage seems to be most crucial and efficient. By knowing all of these, integrated adaptive strategies from physiological, agronomic and biotechnology interventions to improve drought adaption can be executed.

MATERIALS AND METHODS

Drought tolerance profile determination at germination stage and seedlings stage

Five fragrant MRQ rice cultivars were obtained from the Malaysian Agricultural Research and Development Institute (MARDI), Seberang Perai, Penang. All seeds underwent seeds quality determination using floating. Subsequently, surface sterilization was carried out using 20% sodium hypochlorite to minimize microbial contamination. To investigate the effects of water stress on seed germination and seedling vigor, polyethylene glycol (PEG) 6000 was used to simulate osmotic stress at three different water potential levels: 0 MPa (control), -0.6 MPa (moderate stress), and -0.9 MPa (severe stress). The PEG are well-known and established method for evaluating genotypes in laboratory settings to induce osmotic stress and can mimic drought conditions. Seeds were germinated by evenly distributing 10 seeds in a glass jar for each replicate lined with a layer of Whatman filter paper (90 mm size) for 2 wk in a growth room at 25 ± 2 °C, relative humidity 50%-70%, and 12:12 h photoperiod (Evamoni et al., 2023). Data collection focused on several germination and seedling growth parameters. Germination was observed every day according to recommendations by International Seed Testing Association and the number of germinated seeds were recorded for 14 d. The number of germinated seeds were counted and expressed as germination percentage (GP), formula by Scott et al. (1984):

$$\mathrm{GP}\ (\%) = \frac{\text{Number of germinated seed}}{\text{Total number of seeds}} \times\ 100\%$$

The number of germinating seeds each day were counted and expressed as germination index (GI) by using the formula as suggested by the Association of Official Seed Analysis (AOSA, Wichita, Kansas, USA):

$$\mathrm{GI} = \sum \left(\frac{\mathrm{n}}{\mathrm{d}}\right)$$

where n is the number of germinating seeds and d is the respective days of germination.

The number of germinated seeds, number of germinated seeds on respective growth day and number of total germinated seed were recorded and expressed as germination rate (GR) by using the formula by Tang et al. (2019):

$$\mathrm{GR}\ (\%) = \frac{\text{Number of seeds germinated at 4 d}}{\text{Total number of seeds sown}} \times\ 100$$

Germination energy (GE) was computed as percentage of seeds germinated within 3 d by using the formula by Tang et al. (2019):

$$\mathrm{GE} = \frac{\text{Number of seeds germinated within 3 d}}{\text{Total number of seeds sown}}$$

Seedling vigor index (SVI) = Seedling height (SH) × Germination percentage (GP) (Abdul-Baki and Anderson, 1970).

Seedling vigor index II (SVII) = Germination percentage (GP) × Dry weight (DW) (Pant and Bose, 2016).

Fresh seedling weight (FW) was measured using an electric scale while the dry seedling weight (DW) was weighed after drying at 70 °C in an oven until constant weight is obtained (Yan, 2015). Seedling height (SH) was measured with a ruler (Abdul-Baki and Anderson, 1970).

Drought tolerance profile determination at vegetative and reproductive stages

After seed quality determination and sterilization, a pot experiment was conducted under controlled greenhouse conditions in a completely randomized design (CRD) with five replicates. Ten days-old seedlings were transferred to pots. The water regime was precisely managed based on the rice growth stages. During the vegetative phase, control treatment was irrigated with 200 mL water daily until 30 d after sowing, followed by a reduced volume to 60 mL per day for drought treatment for 4 wk. For the determination of drought tolerance at reproductive phase, control treatment was irrigated with 200 mL water until 65 d after sowing, followed by a reduced volume to 60 mL daily for drought treatment for a subsequent 4 wk period. This approach was based on Khan et al. (2019) with slight modification. Plant height and number of tillers were recorded at vegetative stage. At reproductive stage, weight of 1000 grains, and plant biomass were measured.

Statistical analysis

The data were analyzed using two-way ANOVA using SPSS software for Windows version 23 (IBM, Armonk, New York, USA) followed by Duncan's multiple range test (DMRT) at $p \leq 0.05$ for mean comparison.

RESULTS

Germination and seedlings performances of fragrant rice cultivars under drought condition

In this study, the germination traits performance includes germination percentage (GP), germination index (GI), germination energy (GE), and germination rate (GR) of five Malaysian fragrant rice cultivars was assessed under control, moderate, and severe drought levels as presented in Table 1. The ANOVA reveals that as the level of drought increased, germination performances (GP, GI, GE, and GR) decreased significantly ($p \leq 0.05$). The GP indicates the overall proportion of seeds completing germination. All the genotypes presented GP more than 80% and 70% under moderate and severe respectively except MRQ104. MRQ74 showed highest GP for both moderate and severe drought level with 90% and above. The GP was decreased from 95% under control conditions to only 50% in MRQ104 at severe stress, reflecting the substantial inhibitory effect of water deficit on seed viability and emergence.

A similar trend was observed for the GI, which reflects speed and uniformity of germination (Guo et al., 2024). Under control conditions, all genotypes recorded GI values around 18-21; however, severe drought caused drastic reductions, particularly in MRQ104 and MRQ50. By contrast, MRQ74 retained relatively higher GI, suggesting a more synchronized germination even under stress. Drought not only reduces the number of seeds germinating but also delays and desynchronizes the process.

The GE for most cultivars showed sharp decline from moderate drought level to severe drought level. The GE reflects early seed vigour and the ability of seeds to germinate rapidly in the first few days (Guo et al., 2024). Under severe drought, GE dropped dramatically, with some genotypes (e.g., Wangi88 and MRQ104) showing complete inhibition (0%), highlighting that water stress strongly disrupts early metabolic activation and reserve mobilization necessary for rapid seedling establishment. Despite that, most of the genotypes had germination energy (GE) higher than 50 under moderate drought. MRQ74 retained higher GE from 90% under moderate to 45% under severe compared to another cultivar.

Further analysis showed GR of all genotypes decreased as level of drought increased. The GR measures the speed of germination over time (Guo et al., 2024). MRQ50 and MRQ76 showed moderate declines under severe drought (from 80-95 in control to 50-65), suggesting partial sensitivity but with some ability to sustain germination speed. In contrast, the most drastic response was observed in MRQ104, where GR reduced completely to 0 under severe drought, highlighting its extreme vulnerability to water limitation during early germination.

Table 1. Germination performances of five fragrant rice genotypes under different drought conditions. Letters are only comparable within the same drought level. Means ± SE in the same column with the same letter do not differ significantly according to DMRT at ($p \leq 0.05$). GP: Germination percentage; GI: germination index; GE: germination energy; GR: germination rate.

Genotypes	Treatments	GP	GI	GE	GR
MRQ50	Control	90.0 ± 0.00^{a}	18.05 ± 2.21^{a}	80.0 ± 10.00^{a}	80.00 ± 10.00^{a}
	Moderate	85.0 ± 5.00^{ab}	15.89 ± 2.87^{ab}	70.0 ± 20.00^{a}	70.00 ± 20.00^{a}
	Severe	75.0 ± 20.00^{c}	10.19 ± 0.17^{b}	15.00 ± 15.00^{ab}	50.00 ± 10.00^{bc}
MRQ74	Control	95.0 ± 5.00^{a}	20.97 ± 0.71^{a}	90.0 ± 0.00^{a}	95.00 ± 5.00^{a}
	Moderate	95.0 ± 5.00^{a}	20.85 ± 0.58^{a}	90.0 ± 0.00^{a}	90.00 ± 0.00^{a}
	Severe	90.0 ± 0.00^{a}	15.14 ± 1.63^{a}	45.0 ± 15.00^{a}	85.00 ± 5.00^{a}
MRQ76	Control	95.0 ± 5.00^{a}	20.56 ± 1.13^{a}	85.0 ± 5.00^{a}	95.00 ± 5.00^{a}
	Moderate	85.0 ± 5.00^{ab}	18.72 ± 0.71^{ab}	80.0 ± 0.00^{a}	85.00 ± 5.00^{a}
	Severe	75.0 ± 5.00^{b}	11.22 ± 1.13^{b}	25.0 ± 5.0^{ab}	65.00 ± 15.00^{ab}
Wangi88	Control	95.0 ± 5.00^{a}	20.89 ± 0.63^{a}	95.0 ± 5.00^{a}	95.00 ± 5.00^{a}
	Moderate	95.0 ± 5.00^{a}	19.06 ± 0.71^{a}	70.0 ± 20.00^{a}	95.00 ± 5.00^{a}
	Severe	85.0 ± 5.00^{ab}	10.68 ± 0.58^{b}	0 ± 0^{b}	30.00 ± 0.00^{cd}
MRQ104	Control	95.0 ± 5.00^{a}	18.28 ± 0.59^{a}	75.0 ± 5.00^{a}	80.00 ± 10.00^{a}
	Moderate	75.0 ± 5.00^{b}	13.60 ± 0.50^{b}	40.0 ± 10.00^{a}	70.00 ± 0.00^{a}
	Severe	50.0 ± 0.00^{c}	5.02 ± 0.22^{c}	0 ± 0^{b}	0 ± 0^{d}

Seeds germinated in different concentration of PEG6000 solution treatment demonstrated different morphological response after 14 d (Table 2). The seedling performance includes seedling height (SH), fresh weight (FW), dry weight (DW), seedling vigor I (SVI) and seedling vigor II (SVII) was assessed under control, moderate and severe drought level induced by PEG6000. The ANOVA demonstrated that seedlings performances reduces when level of drought increased.

Under moderate drought stress all genotypes showed decline in SH parameter. MRQ50 showed maximum SH in severe drought, while MRQ104 represented minimum SH throughout drought stress. In contrast MRQ74 and Wangi88 demonstrated the largest reduction in SH compared to control treatment indicating low water potential influence the seedlings elongation.

Meanwhile, FW for all genotype treatment showed reductions in all drought levels. MRQ76 showed promising result for both moderate and severe drought level FW of MRQ104 was the lowest in both moderate and severe drought level. Other genotype revealed average FW result throughout different drought level. Similarly, with DW outcomes, MRQ76 showed the highest DW and MRQ104 showed the lowest DW throughout all the drought level. However, MRQ76 and MRQ50 exhibited increase DW under moderate drought level than under well watering condition. In addition, DW between genotypes were less difference under severe drought level.

Seedling vigor index I (SVI) integrates germination percentage with seedling length, thereby reflecting not only the capacity of seeds to germinate but also the early elongation of shoots and roots, which are essential for resource capture and establishment. In this study, SVI was consistently maximal in MRQ50 and minimal in MRQ104 across all drought levels, suggesting that MRQ50 maintains superior germination and seedling elongation even under water-limited conditions. By contrast, the low SVI of MRQ104 highlights its limited growth potential and poor ability to sustain elongation under drought, further cause weak field establishment.

Seedling vigor index II (SVII) combines germination percentage with seedling dry weight, thus serving as an indicator of biomass accumulation and assimilate partitioning during the early growth phase. Interestingly, Wangi88 revealed promising SVII values under moderate and severe drought. It was able to maintain biomass production, probably through efficient water use and reserve mobilization. Similarly with SVI, SVII was observed minimal in MRQ104 for both drought levels.

Table 2. Seedling growth performance of five fragrant rice genotypes under different drought levels. Letters are only comparable within the same drought level. Means ± SE in the same column with the same letter do not differ significantly according to DMRT at ($p \leq 0.05$). SH: Seedling height; FW: fresh weight; DW: dry weight; SVI: seedling vigor I; SVII: seedling vigor II.

Genotypes	Treatments	SH	FW	DW	SVI	SVII
		cm	mg	mg		
MRQ50	Control	8.73 ± 0.40^{a}	58.93 ± 9.90^{a}	17.57 ± 0.57^{b}	786.00 ± 36.00^{a}	1490.33 ± 39.67^{b}
	Moderate	7.40 ± 0.20^{a}	48.42 ± 3.68^{ab}	19.41 ± 1.14^{b}	628.00 ± 20.00^{a}	1449.92 ± 11.42^{c}
	Severe	6.30 ± 0.30^{a}	38.42 ± 2.52^{b}	12.08 ± 0.05^{b}	474.00 ± 54.00^{a}	1087.50 ± 4.50^{b}
MRQ74	Control	9.17 ± 0.37^{a}	45.50 ± 0.33^{a}	18.02 ± 1.25^{b}	872.67 ± 80.67^{a}	1705.33 ± 28.67^{ab}
	Moderate	5.95 ± 0.28^{b}	40.82 ± 1.58^{b}	17.53 ± 1.07^{bc}	563.83 ± 2.83^{b}	1571.84 ± 102.16^{bc}
	Severe	4.53 ± 0.27^{ab}	37.95 ± 0.22^{b}	12.75 ± 0.08^{b}	408.00 ± 24.00^{ab}	1210.83 ± 55.83^{b}
MRQ76	Control	9.00 ± 0.53^{a}	55.15 ± 5.68^{a}	22.25 ± 0.15^{a}	857.67 ± 95.67^{a}	1890.00 ± 98.50^{a}
	Moderate	6.32 ± 0.41^{b}	53.55 ± 2.98^{a}	23.93 ± 0.50^{a}	534.83 ± 3.83^{b}	1792.50 ± 82.17^{ab}
	Severe	3.52 ± 0.85^{b}	50.92 ± 1.02^{a}	15.80 ± 0.20^{a}	259.50 ± 46.17^{bc}	1500.00 ± 60.00^{a}
Wangi88	Control	8.95 ± 0.65^{a}	61.15 ± 2.35^{a}	23.05 ± 0.18^{a}	853.50 ± 106.50^{a}	1958.33 ± 99.67^{a}
	Moderate	5.45 ± 0.15^{b}	49.33 ± 2.57^{ab}	20.28 ± 0.95^{b}	517.00 ± 13.00^{b}	1922.17 ± 11.17^{a}
	Severe	2.73 ± 0.87^{b}	43.08 ± 2.92^{b}	15.75 ± 1.08^{a}	228.00 ± 60.00^{c}	1490.83 ± 24.17^{a}
MRQ104	Control	7.85 ± 0.45^{a}	56.22 ± 4.12^{a}	16.33 ± 0.33^{b}	743.50 ± 3.50^{a}	1553.35 ± 113.35^{b}
	Moderate	5.80 ± 0.00^{b}	43.35 ± 1.92^{b}	15.75 ± 0.05^{c}	435.00 ± 29.00^{c}	1181.00 ± 75.00^{d}
	Severe	2.25 ± 0.48^{b}	30.68 ± 0.78^{c}	12.78 ± 0.52^{b}	112.50 ± 24.17^{c}	639.18 ± 25.83^{c}

Growth and yield performance of five fragrant rice genotypes under drought conditions

To further analyze the effect of drought on the different fragrant rice genotypes, plant growth traits and yield performance were demonstrated in Figures 1, 2, 3 and 4. Plant height, number of tillers, weight of 1000 grains and plant biomass were decreased under drought stress. MRQ76 showed the maximum plant height and weight of 1000 grains under drought stress. Meanwhile, Wangi88 and MRQ50 showed the minimum plant height and weight of 1000 grains respectively under drought condition. With respect to relative reduction of plant height under stress, least reduction was observed in MRQ50 and greatest reduction Wangi88. Drought stress reduced 1000 grain weight in all genotypes up to 25% with least reduction was observed in Wangi88 and greatest reduction was MRQ50. Besides that, least reduction of tillers number was observed in MRQ50 and greatest reduction was Wangi88. Whereas, least reduction of biomass was MRQ74 and greatest reduction of biomass was MRQ104.

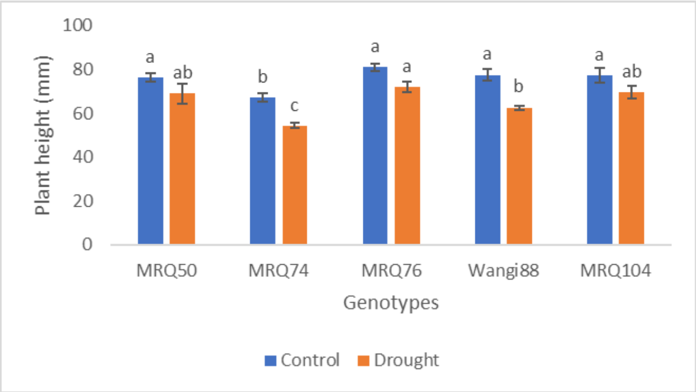

Figure 1. Plant height of five fragrant rice genotypes under control and drought condition. Significantly different mean values are shown in different letters (Duncan's multiple range test at $p \leq 0.05$).

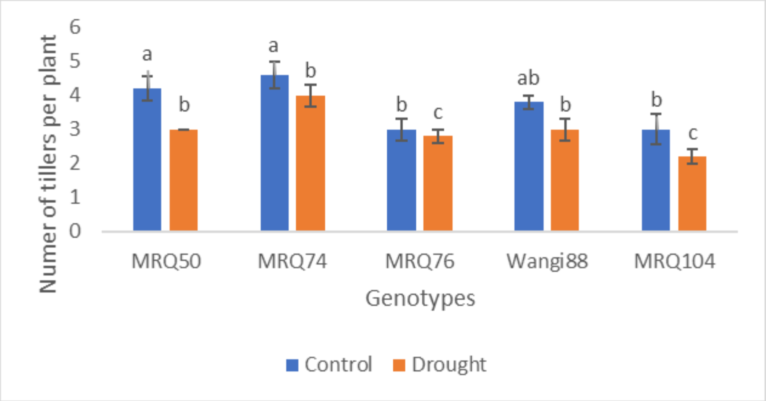

Figure 2. Number of tillers per plant of five fragrant rice genotypes under control and drought condition. Significantly different mean values are shown in different letters (Duncan's multiple range test at *P* ≤ 0.05).

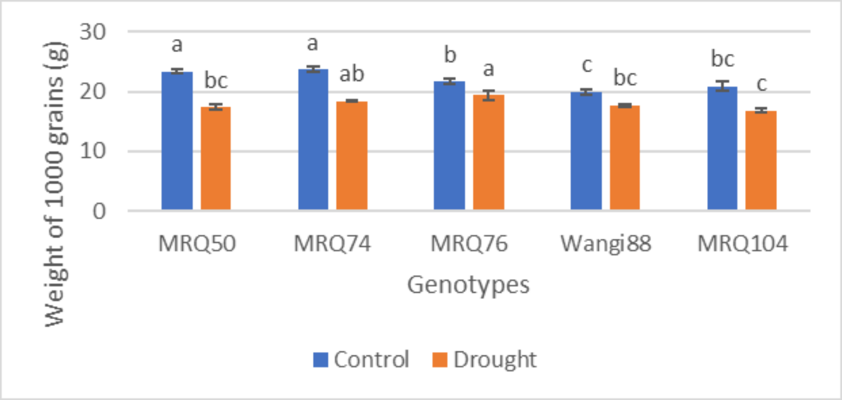

Figure 3. Weight of 1000 grains of five fragrant rice genotypes under control and drought condition. Significantly different mean values are shown in different letters (Duncan's multiple range test at *p* ≤ 0.05).

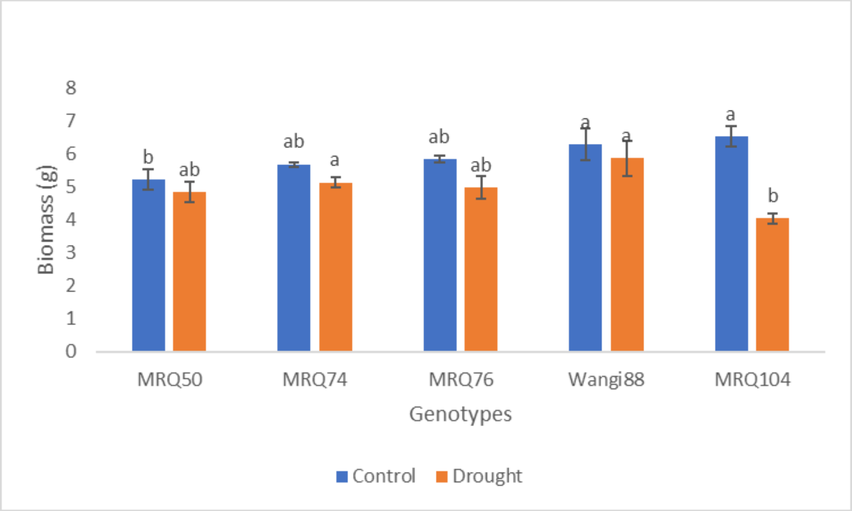

Figure 4. Biomass of five fragrant rice genotypes under control and drought condition. Significantly different mean values are shown in different letters (Duncan's multiple range test at *p* ≤ 0.05).

Drought indices and cluster analysis of five fragrant rice cultivars under drought conditions

Other than using germination trait, growth trait and yield trait, performance of five fragrant rice genotypes under drought stress was assessed using drought indices which are stress susceptibility index (SSI), stress tolerance index (STI), and tolerance index (TOL) as in Table 3. The SSI values less than 1 indicates the genotype was tolerant towards drought stress (Gitore et al., 2021). The SSI values for MRQ104 are greater than one (> 1) indicates these cultivars were sensitive under drought stress treatment. Stress tolerance index (STI) is a method for assessing genotypes potential for high yield under stress and non-stress conditions. Greater value of STI indicates the genotype are more tolerant towards drought stress treatment (Gitore et al., 2021). MRQ104 revealed STI more than another genotype. Small value of TOL indicates a genotype with high tolerant to drought stress (Lamba et al., 2023). MRQ50, MRQ 76, MRQ74 and Wangi88 have small TOL value indicates these genotypes are tolerant to drought while MRQ104 has high TOL values indicates this genotype is sensitive to drought.

Table 3. Drought indices of five fragrant rice genotypes. Means ± SE in the same column with the same letter do not differ significantly according to DMRT at ($p \leq 0.05$). SSI: Stress susceptibility index; STI: stress tolerance index; TOL: tolerance index.

	Drought indices		
Genotype	SSI	STI	TOL
MRQ50	0.45 ± 0.16^{b}	0.01 ± 0.005^{b}	0.38 ± 0.16^{b}
MRQ74	0.61 ± 0.19^{b}	0.02 ± 0.005^{b}	0.55 ± 0.18^{b}
MRQ76	0.91 ± 0.37^{b}	0.02 ± 0.010^{b}	0.85 ± 0.35^{b}
Wangi88	0.44 ± 0.09^{b}	0.01 ± 0.002^{b}	0.42 ± 0.07^{b}
MRQ104	2.38 ± 0.18^{a}	0.07 ± 0.008^{a}	2.50 ± 0.29^{a}

The dendrogram generated from cluster analysis grouping five genotypes into two distinct group based on growth and yield traits and drought indices (Figure 5). The cluster analysis grouped similar data into same clusters thus enabling to determine the relationship between genotypes. Two major clusters were observed at different levels of similarity. The first cluster, shown in blue, grouped MRQ50, MRQ74, MRQ76, and Wangi88 together, indicating that these genotypes share closer similarity in their germination performance and drought response. Within this group, MRQ74 and MRQ76 were more closely related, while MRQ50 formed a relatively distinct sub-branch, reflecting moderate divergence in performance traits. The second cluster, represented in red, consisted solely of MRQ104, which was clearly separated from the other genotypes, highlighting its distinct and inferior performance under drought stress conditions.

This separation indicates that MRQ104 is consistently the most drought-sensitive genotype, showing poor growth performance and drought indices, while the remaining genotypes, particularly MRQ74 and MRQ76, exhibit more vigorous and resilient performance.

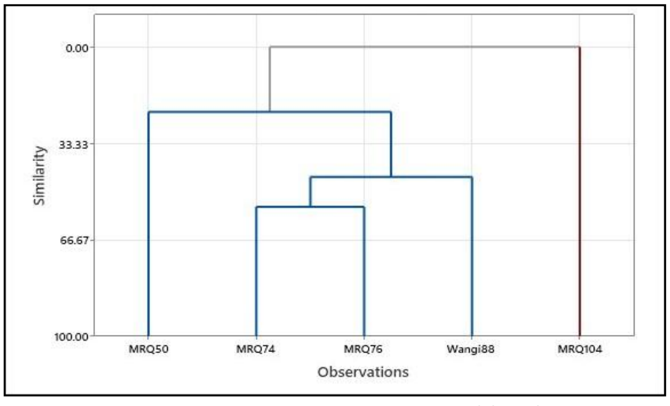

Figure 5. Cluster analysis demonstrated a dendrogram of five fragrant rice genotypes.

DISCUSSION

Different rice genotypes demonstrated different response toward drought stress. Drought has a significant impact on rice performance at all life stage. Previous study also discovered, roots, stems, and leaves all respond differently according to growth stage and drought level (Hassan et al., 2023). Physiological and biochemical responses to drought stress during seed germination and early seedling growth is important to study as this stage is critical for crop establishment, and later plant productivity and yield (Kadam et al., 2017). Rice is extremely sensitive to drought conditions during the germination and early seedling growth stage. Many research has been reported about plant responses to drought stress during seed germination and seedling growth including studies of *Zea mays* L. and *Sorghum bicolor* (L.) Moench (Queiroz et al., 2019). In this study, the germination performances (GP, GI, GE, and GR) decline when polyethylene glycol (PEG) concentration increased. Different genotypes responses differently to three osmotic stresses represent no drought, moderate (-0.6 MPa), and severe stress (-0.9 MPa).

Previous comparative study of germination performance of 15 Malaysian *indica* rice was found as level of drought increased, germination attributes significantly decreased (Evamoni et al., 2023). All genotypes exhibit less reduction in germination percentage (GP), germination index (GI), germination energy (GE), and germination rate (GR) under moderate stress compared to the control treatment. However, all genotypes exhibit the most significant reduction in GP, GI, GE, and GR under severe stress. The poor seed germination performance was mainly due to the low water potential caused by osmosis effects of PEG6000. Drought stress disrupts water balance, and inhibit metabolic process in cell, damage of membrane transport and reduced ATP production and respiration, resulting to poor seed germination (Kadam et al., 2017). Additionally, rising negative osmotic potential disturbs enzyme function, leading in seeds loss ability to germinate (Limbu et al., 2024). Integration of multiple germination parameters (GP, GI, GR, GE), comprehensively characterized the germination characteristics of seeds (Mahpara et al., 2022). Other factors that reduce seed germination was inadequate water imbibition and unfulfilled moisture needs of the seeds (Guo et al., 2024).

Result of this study also showed responses of seedling growth toward different level of drought stress was not much different from seed germination. Seedling height (SH), fresh weight (FW), and dry weight (DW) are major important variables in studying early growth of plants under stress. In this study, seedling performance demonstrated poor growth as drought intensity increase. Percentage of SH and FW decline is different across different genotypes with severe drought level contributed a greatest decline of SH. Both results related to inhibition of cell expansion and reduction of biomass accumulation as physiological response to water deficit (Kapoor et al., 2020). Moisture deficit under high osmotic stress can reduced initially water absorption capability of seed, nutrient transfer to and activity of enzymes involved in hydrolysis of stored material in seed which may result in reduced germination, cell division, cell elongation and subsequently results in poor growth embryo (Fahad et al., 2017).

Three genotypes, MRQ74, Wangi88 and MRQ104, showed reduction trend of DW when drought intensity increased. This is in line with Wang et al. (2024), when the plant experiences drought stress, the most immediate response is the change in the plant DM including decreased stem/root DW and plant DW with the increased level of drought intensity. On the contrary, current study showed MRQ50 and MRQ76 increased their DW under moderate drought. Its unique pattern of increased DW under stress might be related with osmotic adjustment through accumulation of osmolytes (e.g., proline, sugars) (Ozturk et al., 2021). All genotypes showed seedling vigor index I (SVI) and seedling vigor index II (SVII) reduction as level of drought increased. However, least reduction discovered in MRQ50 and greatest reduction discovered in MRQ104. Many physiological growth attributes comprising of percentage of germination, speed of germination, shoot length, seedling growth and seedling vigor of crops are affected by drought (Queiroz et al., 2019).

Drought at seedling stage triggers poor seedling emergence and decreased survival of seedlings. At vegetative phase, it decreases tillering capability, late drought at reproductive phase reduces panicle number per plant stand (Kumar et al., 2020). In this study, plant height, number of tillers, weight of 1000 grain and plant biomass were decreased under drought stress. Wangi88 and MRQ50 showed the lowest of plant height and weight of 1000 grains respectively under drought stress. Furthermore, MRQ104 demonstrated lowest number of tillers and biomass. These findings align with previous research findings on Malaysian rice, which reported that drought stress induce morpho-physiological and yield component changes including plant height, weight of 100 grains and seed quality (Sethuraman et al., 2024). Research on other plant species reported that moderate and severe drought stress significantly decreased the morphological parameters including plant height, stem diameter, and leaf area of cucumber seedlings (Wang et al., 2024). Drought triggers various responses in different crops. Reduction of plant biomass and yield associated with photosynthesis process. Water stress can significantly impact root cell development, impede nutrient uptake subsequently inhibiting photosynthesis process, important for biomass buildup and root elongation (Islam et al., 2018). Besides that, drought causes greatly reduction in rice productivity by influence plant growth, leaf size and number, biomass composition, seed set due to sink capacity reduction as well as DM accumulation (Fei et al., 2020). Lack of soil moisture flowering stage leads to stigma drying and decreases assimilates flow from lower to upper parts, causes ovules abortion, spikelet sterility, and reduces grain yield (Singh et al., 2017; Swain et al., 2017).

The drought susceptibility index (SSI) basically described about how much yield loss due to drought. A higher SSI (> 1) indicates the genotypes is very sensitivity to drought. While a lower SSI (< 1) indicated the genotypes have greater tolerance (Abebe et al., 2020). MRQ104 was the only genotype that recorded SSI more than one. Its SSI value revealed it has greater crop's yield drops under drought conditions compared to normal conditions, which its mean sensitive to drought. The stress tolerance index (STI) measures yield performance of genotypes under stress and non-stress conditions. MRQ50, MRQ76, Wangi88 and MRQ104 showed STI values close to zero, which its mean minimal stress tolerance. MRQ74 showing STI less than zero indicates poor yield performance under drought. Other than SSI and STI, tolerant index (TOL) also used to assess genotype performance under drought stress. The TOL indicates how much the yield drop under drought stress compared to control. Again, TOL value of MRQ104 showed its sensitivity to drought with high TOL value, whereas MRQ74 constantly showed negative value indicates its tolerant to drought. The cluster analysis categorized rice genotypes into distinct clusters, therefore assuring a high to moderate level of variability among the genotypes (Iqbal et al., 2018). The clustering pattern therefore supports the findings from individual parameter analyses and suggests that MRQ74 and MRQ76 can be classified as relatively tolerant genotypes, MRQ50 and Wangi88 as moderately tolerant, and MRQ104 as highly sensitive to drought stress. These results are in line with previous studies where cluster analysis has been effectively applied to classify rice genotypes into tolerant and sensitive groups under abiotic stress (Roy et al., 2021).

CONCLUSIONS

Selected Malaysian fragrant rice genotypes exhibited different response towards different growth stage under drought stress. During germination and the early seedling stage, all genotypes exhibit drought stress tolerance, except for MRQ104, which demonstrates a significant decline in most parameters under severe drought conditions. While at vegetative phase, drought decrease in the plant height, number of tillers, weight of 1000 grains, and biomass all showed prominent inhibition under drought stress. Different rice genotypes react differently to drought stress, which may indicate that certain rice genotypes have better tolerance. The study discriminated four genotypes as drought tolerant, MRQ50, Wangi88, MRQ74, and MRQ76, whereas MRQ104 was the most drought sensitive. The stability and adaptability of genotypes across variable drought intensities and growth stages are crucial for identifying drought-tolerant lines suitable for breeding.

Author contribution

Conceptualization: N.M.R., R.N. Methodology: N.M.R., R.N. Software: N.M.R., R.N. Validation: N.M.R., R.N. Formal analysis: N.M.R., R.N. Investigation: N.M.R., R.N. Resources: N.M.R., R.N. Data curation: N.M.R., R.N. Writing-original draft: N.M.R. Writing-review & editing: N.M.R., R.N. Visualization: N.M.R. Supervision: R.N. Project administration: R.N. Funding acquisition: R.N. All co-authors reviewed the final version and approved the manuscript before submission.

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