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Comparative impact of drought stress on growth and yield traits of riceberry and KDML105 rice varieties

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Abstract The impact of drought stress on the growth and yield components of two Thai rice varieties, Riceberry and KDML 105, was investigated under four irrigation levels (1,000, 3,000, 5,000, and 7,000 mL per 10 days). Significant differences were observed between the two varieties across multiple traits. KDML 105 exhibited superior stem height, dry matter accumulation, and grain production, particularly under high water availability. In contrast, Riceberry produced a greater number of tillers per hill and retained higher soil moisture under limited irrigation, indicating improved water use efficiency (WUE). While KDML 105 achieved optimal grain production and seed weight at 7,000 mL, Riceberry demonstrated superior adaptability to water-limited conditions, due to its compact morphology and effective water retention. These findings suggested that KDML 105 is better suited for water-abundant environments, whereas Riceberry is a promising variety for drought-prone areas requiring water-saving cultivation practices.

Keywords: Riceberry, KDML 105, Drought stress, Water use efficiency, Rice yield

Introduction

Rice (*Oryza sativa* L.) is widely regarded as one of the most important staple crops in the world, serving as the primary source of nutrition for more than half of the global population (FAO, 2019). In Thailand, rice is not only a dietary staple but also a key economic commodity that sustains rural livelihoods and contributes significantly to the national economy (OAE, 2020). However, rice production faces mounting challenges due to climate change, particularly the increased frequency and severity of droughts. According to Wassmann *et al.* (2009) and Kamoshita *et al.* (2009), drought stress negatively affects rice development at critical growth stages, including the seedling, grain filling, and

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maturity stages. Farooq *et al*. (2009) and Lafitte and Courtois (2002) demonstrated that drought-stressed rice plants exhibit reduced plant height, fewer tillers, lower biomass, and decreased grain yield.

Among Thai rice cultivars, KDML 105 (Khao Dawk Mali 105) and Riceberry are widely cultivated due to their desirable traits. KDML 105 is renowned for its aromatic quality and high market value, particularly in export markets, while Riceberry, a pigmented variety, is noted for its high antioxidant content and associated health benefits (Pinkaew *et al*., 2020). Despite their popularity, the comparative agronomic and physiological responses of these two cultivars to drought stress have not been thoroughly investigated under controlled conditions.

A comprehensive understanding of varietal responses to drought is essential for improving water use efficiency and maintaining rice production in regions with limited water availability. Therefore, this study aimed to evaluate and compare the effects of drought stress which imposed through varying water supply levels on the growth, yield components, and water use efficiency (WUE) of Riceberry and KDML 105 under controlled conditions.

Materials and methods

Each container was placed on a plastic tray to prevent water seepage, and irrigation treatments were manually applied every ten days to simulate field conditions. Water volumes were measured and distributed consistently using graduated cylinders. Environmental conditions in the simulated field plot, including temperature and humidity, were monitored daily to ensure uniformity across all replicates. Daytime temperatures ranged from 30–35°C, while nighttime temperatures ranged from 25–28°C. Relative humidity remained between 60% and 75% throughout the experimental period.

Baseline soil fertility and pH were determined by analyzing samples collected before the experiment. The loamy soil used had a pH of 6.2, an organic matter content of 2.3%, and sufficient levels of macronutrients. No additional fertilizers were applied during the experiment to isolate the effects of water stress on plant growth and development.

During the flowering stage, a SPAD-502 chlorophyll meter was used to measure chlorophyll content in the uppermost, fully expanded leaves. Three readings per plant were averaged for analysis. At physiological maturity, plant biomass was harvested, and fresh and dry weights were measured using a precision balance. Dry weight was determined after oven-drying the samples at 70°C for 72 hours.

Water use efficiency (WUE) was calculated using the following formula:

$$WUE = \frac{\text{Grain yield (g per pot)}}{\text{Total water applied (mL per pot)}}$$

Grain yield was adjusted to a standard moisture content of 14% for consistency. To evaluate grain characteristics, panicles were randomly selected from each pot. The number of filled and unfilled grains per panicle was counted manually, and the weight of 100 filled grains was measured using an analytical balance. Plant morphology, leaf rolling, and leaf color were also recorded as indicators of drought stress response.

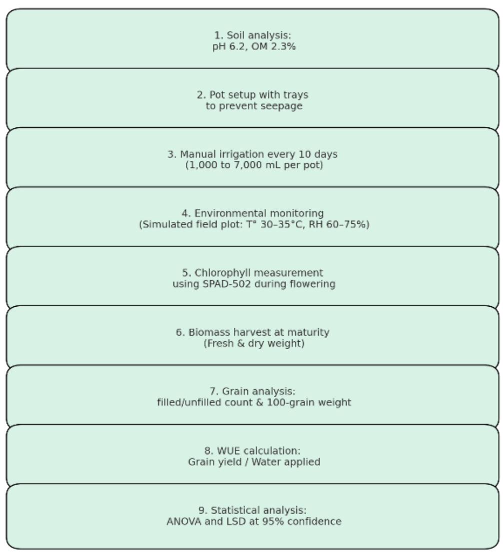

Figure 1. Schematic representation of the experimental workflow for evaluating drought stress response in KDML 105 and Riceberry rice varieties

All data were statistically analyzed using analysis of variance (ANOVA), and treatment means were compared using Fisher's Least Significant Difference (LSD) test at a 95% confidence level (Figure 1).

Results

Stem height comparison between varieties under different water levels

The results demonstrated significant differences in growth and yield components between the two rice varieties under varying drought stress levels.

For stem height, KDML 105 exhibited the tallest growth at the highest irrigation level (7,000 mL), reaching 89.33 cm. This height gradually decreased with lower water availability, indicating sensitivity to drought. Riceberry, while generally shorter than KDML 105, maintained more stable plant height across all treatments, showing less drastic reduction under severe drought (40.27 cm at 1,000 mL), suggesting a more conservative water use strategy (Table 1).

Tillering ability and number of tillers per hill across water treatments

The number of tillers per hill showed distinct varietal differences. Riceberry consistently produced more tillers than KDML 105 at every water level, peaking at 34.79 tillers under 5,000 mL. In contrast, KDML 105 reached its maximum at 23.10 tillers under the same treatment. This suggests Riceberry's greater ability to maintain vegetative propagation under moderate drought stress, which can contribute to stable yield (Table 1).

Variation in hill width as an indicator of canopy spread

Hill width, which reflects overall canopy spread, was also greater in Riceberry across all treatments, especially under higher irrigation levels (18.33 cm at 7,000 mL), compared to KDML 105 (16.20 cm). A wider hill may contribute to better light interception and photosynthesis.

Grain production and fertility: grains and filled grains per panicle

In terms of reproductive traits, Riceberry significantly outperformed KDML 105 in the number of total grains and filled grains per panicle under 3,000 and 5,000 mL irrigation levels. For example, at 5,000 mL, Riceberry produced 106.6 filled grains compared to 94.0 in KDML 105. This indicates better grain retention and fertilization under moderate water availability. Notably, KDML 105 failed to produce grains under severe drought (1,000 mL), whereas Riceberry still achieved 5.00 filled grains per panicle, reflecting superior resilience.

Comparison of 100-seed weight under varying drought stress levels

Grain weight was not significantly different between the two varieties under optimal irrigation (7,000 mL), with both achieving approximately 28.3 g per 100 seeds. However, under limited water supply (1,000 and 3,000 mL), seed development was severely inhibited, resulting in negligible grain weight, particularly for KDML 105 (Table 1).

Total biomass accumulation under different water supply conditions

Biomass accumulation followed a similar trend, with KDML 105 producing significantly higher stem and leaf weights (969 g fresh, 283 g dry) under 7,000 mL. Riceberry showed lower total biomass but demonstrated more efficient resource use, maintaining relatively stable biomass under reduced water conditions—indicative of enhanced drought tolerance mechanisms. The scatter plot illustrates a positive correlation between stem height and dry biomass in both varieties across irrigation levels. KDML 105 exhibited a steeper trend, with taller plants strongly associated with greater dry biomass, especially at 7,000 mL, indicating its reliance on ample water for vegetative growth. Conversely, Riceberry showed more moderate increases, consistent with a conservative growth strategy under drought stress. These findings support the conclusion that KDML 105 performs best in water-abundant environments, whereas Riceberry maintains stable biomass with higher efficiency in water use, making it more suitable for drought-prone conditions (Figure 2).

Soil moisture retention and its role in drought adaptation

Soil moisture measurements supported the observed trends. Riceberry plots retained higher volumetric water content at every irrigation level, particularly under moderate stress (e.g., 163 volts at 5,000 mL) compared to KDML 105 (114.33 volts). This may be attributed to Riceberry's more compact and upright canopy structure, which reduces evapotranspiration.

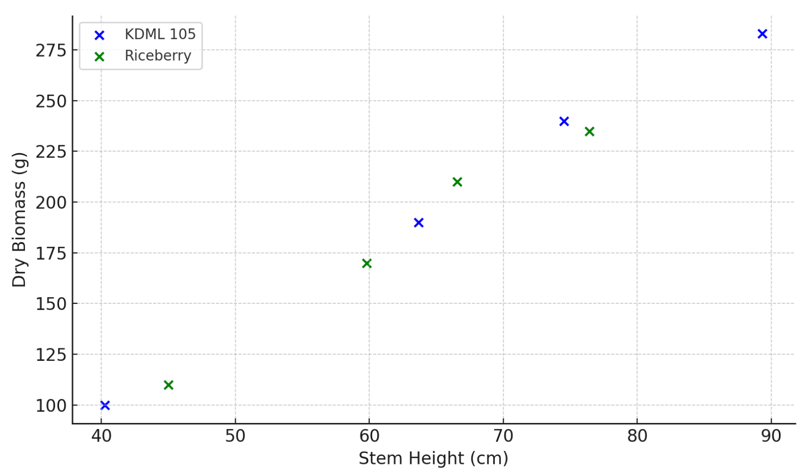

Figure 2. Scatter plot showing the relationship between stem height and dry biomass of KDML 105 and Riceberry under different water levels

Chlorophyll retention and leaf physiology during drought stress

Chlorophyll content, measured using SPAD units, declined with increasing drought stress. However, Riceberry retained slightly higher chlorophyll levels under moderate drought conditions (42.01–42.36 SPAD) than KDML 105, indicating better maintenance of photosynthetic capacity under stress.

Overall, the findings highlight contrasting drought response strategies of the two cultivars. KDML 105 thrives in water-abundant environments, showing high productivity when water is readily available but exhibiting low resilience under drought conditions. In contrast, Riceberry demonstrates strong adaptive traits under drought stress, particularly in tillering capacity, grain setting, and soil moisture retention, making it a promising variety for drought-prone areas and sustainable cultivation systems.

Table 1. Effects of irrigation levels on growth traits and yield components of KDML 105 and Riceberry rice varieties

Water Level (ml.)	**Variety**	**1,000**	**3,000**	**5,000**	**7,000**	**Avg.**	**F-test Water**	**F-test Var**	**CV (%)**
Stem Height (cm)	KDML 105	[2]/D 44 a[1]/	C 48.00 a	B 73.00 a	A 89.33 a	**63.8**	**	**	1.53
	Rice berry	C 40.27 b	B 46.00 b	A 70.00 b	A 69.67 b	**56.5**			
	Avg.	**42.62**	**47.00**	**71.50**	**79.50**	**60.2**			
Number of Tillers per Hill	KDML 105	C 15.10 b	B 19.87 b	A 23.1 b	A 22.96b	**20.28**	**	**	2.00
	Rice berry	C 22.03 a	D 20.73 a	A 34.79 a	B 29.78 a	**26.83**			
	Avg.	**18.56**	**20.30**	**28.98**	**26.37**	**23.55**			
Hill Width	KDML 105	C 9.65 b	C 10.20 b	B 13.50 b	A 16.2b	**12.39**	**	**	3.81
	Rice berry	C 10.62 a	B 12.40 a	A 17.67 a	A 18.33 a	**14.76**			
	Avg.	**10.13**	**11.30**	**15.58**	**17.27**	**13.57**			
Number of Filled Grains per Panicle	KDML 105	C 0.00 b	B 3.67 b	A 94.0 b	A 93.33b	**47.75**	**	**	1.65
	Rice berry	C 5.00 a	B 11.67 a	A 106.6 a	A 107.0 a	**57.59**			
	Avg.	**2.50**	**7.67**	**100.33**	**100.17**	**52.67**			

Table 1. (Con.)

Number of Grains per Panicle	KDML 105	C 0.00 b	B 17.00 b	A 117.33 a	A 117.6 a	**63.00**	**	**	2.65
	Rice berry	C 9.00 a	B 43.67 a	A 116.6 a	A 116.6a	**71.50**			
	Avg.	**4.50**	**30.33**	**117.00**	**117.17**	**67.25**			
Weight of 100 good seeds (g.)	KDML 105	0.00	0.07	28.32	28.36	**14.19**	**	ns	1.10
	Rice berry	0.06	0.15	28.23	28.17	**14.15**			
	Avg.	**B 0.03**	**B 0.11**	**A 28.28**	**A 28.26**	**14.17**			
Stem and Leaf Weight (g.)	KDML 105	[2/]D 336 a[1/]	C 388 a	B 744 a	A 969 a	**609.67**	**	**	0.77
	Rice berry	D 322 b	C 359b	B 452 b	A 534 b	**340.67**			
	Avg.	**329.50**	**373.67**	**598.17**	**752.00**	**513.34**			
Dry Weight (g.)	KDML 105	C 105.00 a	C 104.67 a	B 265.67 a	A 283.00 a	**189.59**	**	**	2.67
	Rice berry	B 92.67 b	B 87.33 b	A 135.00 b	A 135.67 b	**112.67**			
	Avg.	**98.83**	**96.00**	**200.33**	**209.33**	**151.12**			
Soil Moisture (Volts)	KDML 105	D 63.00 b	C 85.00 b	B 114.33 b	A 1,000 a	**315.58**	**	**	0.97
	Rice berry	D 77.67 a	C 129.0 a	B 163.0 a	A 1,000 a	**342.42**			
	Avg.	**70.33**	**107.00**	**138.67**	**1,000**	**329.00**			
Chlorophyll Content (SPADunit)	KDML 105	A 46.14 a	C 42.00 a	B 44.40 a	B 44.50 a	**44.26**	**	**	0.95
	Rice berry	A 46.03 a	B 42.01 a	B 41.95 b	B 42.36 b	**43.09**			
	Avg.	**46.08**	**42.01**	**43.18**	**43.43**	**43.68**			

Note: ** Significant difference at the $p<0.01$ level, ns = No significant difference, 1/ Horizontal means followed by different lowercase letters are significantly different at the 95% confidence level, as determined by Fisher's LSD., 2/ Vertical means followed by different uppercase letters are significantly different at the 95% confidence level, as determined by Fisher's LSD.

Figure 3. Visual comparison of canopy architecture in KDML 105 (left) and Riceberry (right) under identical irrigation conditions. KDML 105 displays a more horizontal and outward leaf orientation, while Riceberry exhibits a compact and upright canopy, potentially contributing to its greater water retention and drought tolerance

Figure 4. Morphological response of KDML 105 (left) and Riceberry (right) under 3,000 mL irrigation at 30 days. KDML 105 displays symptoms of water stress, including leaf rolling and reduced leaf turgor, whereas Riceberry maintains upright leaves and healthy green coloration, reflecting greater drought tolerance under moderate water deficit

Influence of leaf morphology on water use

Differences in leaf morphology between the two rice varieties played a significant role in water use dynamics under varying irrigation treatments. KDML 105, characterized by its long, broad, and outward-spreading leaves, exhibited higher transpiration rates, as evidenced by consistently lower soil moisture levels across all water treatments. At the highest irrigation level (7,000 mL), soil moisture in KDML 105 pots was measured at 200 volts, indicating rapid water depletion likely due to the increased surface area for transpiration. This observation aligns with existing literature suggesting that varieties with larger and more horizontally oriented leaves tend to experience greater evapotranspiration, driven by increased light interception and higher leaf temperatures, which stimulate stomatal opening and water loss (Figure 3).

In contrast, Riceberry exhibited shorter, more upright leaves and a reduced leaf area, contributing to improved soil moisture retention at all water levels. Although both varieties showed similar soil moisture readings (200 volts) at full irrigation (7,000 mL), notable differences emerged at lower water levels. For instance, at 5,000 mL, Riceberry recorded a significantly higher soil moisture value (163.00 volts) compared to KDML 105 (114.33 volts), reflecting its more conservative water use strategy. The compact and vertical canopy of Riceberry likely reduced direct solar radiation on the leaf surface and minimized stomatal conductance, thereby decreasing transpiration (Figure 3).

Water use efficiency (WUE)

The variation in water uses efficiency (WUE) observed between KDML 105 and Riceberry is primarily attributed to their contrasting leaf morphologies. KDML 105’s broader, more horizontal leaves facilitate higher photosynthetic capacity, but also result in increased water loss through transpiration. Conversely, Riceberry's erect and compact canopy reduces leaf surface exposure, conserving soil moisture and promoting more efficient water use, particularly under moderate irrigation levels (3,000–5,000 mL). These physiological traits suggest that while KDML 105 performs well under ample water conditions, Riceberry is better suited for water-limited environments and water-saving systems such as alternate wetting and drying (AWD).

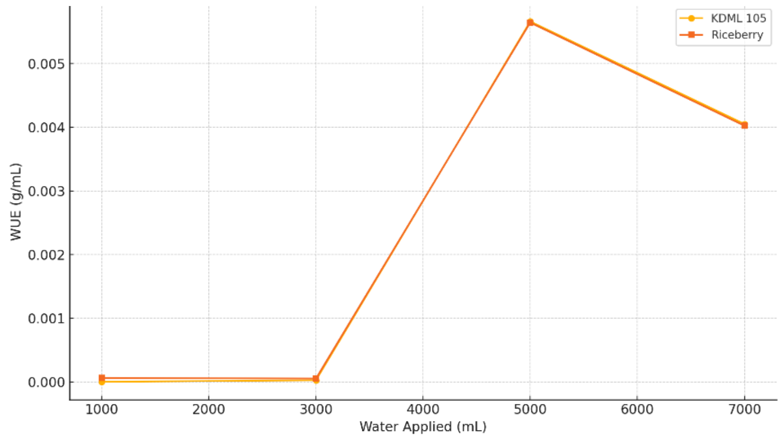

Figure 5. Water use efficiency (WUE) of KDML 105 and Riceberry rice varieties under different irrigation levels

Both varieties achieved maximum WUE at 5,000 mL, indicating optimal water utilization at this level. Under 7,000 mL, WUE declined despite high grain yield, reflecting reduced efficiency due to water surplus. At lower water levels (1,000 and 3,000 mL), WUE was minimal in both varieties. Riceberry showed slightly higher WUE under water-limited conditions, supporting its suitability for resource-efficient cultivation (Figure 5).

Discussion

This study focuses on the contrasting physiological responses and water use efficiencies (WUE) of KDML 105 and Riceberry rice varieties under different irrigation regimes. The results demonstrate that leaf morphology significantly influences water use and drought adaptation. KDML 105, with its expansive, horizontally oriented leaves, exhibited greater biomass accumulation under well-watered conditions, consistent with findings from Lu *et al*. (2021), which associate larger leaf surface area with enhanced photosynthesis and yield potential. However, this came at the expense of increased transpiration and reduced soil moisture retention, a pattern similarly reported by Liu *et al*. (2020) and Sharma *et al.* (2017).

In contrast, Riceberry displayed a more compact and erect leaf architecture, which effectively minimized water loss and preserved soil moisture under limited irrigation. Such traits align with reports by Xie *et al*. (2018) and Kato *et al.* (2018), who emphasized the benefits of vertical canopy structure in improving WUE. Notably, Riceberry maintained higher WUE than KDML 105 under moderate drought (3,000–5,000 mL), indicating its greater adaptability to waterscarce conditions and confirming previous findings on conservative water use strategies in pigmented and traditional varieties (Farooq *et al*., 2009).The observed peak in WUE at the 5,000 mL level for both varieties suggests that this irrigation threshold may represent an optimal balance between water input and grain yield output. Beyond this level, such as at 7,000 mL, WUE declined despite increased biomass, supporting the concept of diminishing returns in water productivity as noted by Bouman and Tuong (2001) and Bouman *et al*. (2007). Under severe drought (1,000–3,000 mL), both cultivars showed minimal WUE, consistent with stress-induced limitations in stomatal conductance and grain development described by Chaves *et al.* (2011) and Concenço *et al.* (2018). In terms of agronomic implications, Riceberry appears more suited to environments with fluctuating or limited water supply, including rainfed systems or alternate wetting and drying (AWD) regimes (Inukai, 2024). Its superior soil moisture retention and resilience in moderate drought suggest potential for sustainable cultivation in drought-prone regions (Kamoshita *et al.,* 2004; Lafitte and Courtois, 2002). KDML 105, on the other hand, may be more appropriate for high-input systems with reliable irrigation, where its high photosynthetic capacity can be fully exploited (Dingkuhn *et al*., 1999; Liu *et al*., 2020).

Collectively, these findings are contributed to a deeper understanding of genotype-specific responses to drought stress, reinforcing the importance of leaf morphological traits in improving water productivity. Future breeding and management strategies should integrate such physiological characteristics to enhance rice resilience under climate variability.

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