Journal of Smart Farming and Food Security
Universiti Malaysia Sabah Press
e-ISSN: 3122-7090
Volume 2, Issue 2, Pages 180–189 (31 December 2026)
DOI: https://doi.org/10.51200/jsffs.v2i2.8127

Research Article
OPEN ACCESS

Growth performance and yield evaluation of upland rice (*Oryza sativa* L.) varieties collected from Lahad Datu, Sabah, Malaysia

Nikmael Nikson[1,*], Lum Mok Sam[2], Muhammad Azizul Hasnain[1], Mohd Miqdam Jubidin[1]

[1] Politeknik Sandakan Sabah, 90000 Sandakan, Sabah, Malaysia.
[2] Faculty of Sustainable Agriculture, Universiti Malaysia Sabah, 90000 Sandakan, Sabah, Malaysia.

* Corresponding author: nikmael@pss.edu.my

Manuscript received: 2 July 2026 | Accepted: 16 November 2026 | Published online: 18 November 2026

Abstract: Malaysia's domestic rice production remains insufficient to meet national demand, and upland rice is a potentially valuable but underutilized resource, particularly in Sabah. This study aimed to evaluate the growth performance and yield characteristics of eight upland rice (*Oryza sativa L.*) varieties collected from Lahad Datu, Sabah, and to identify the most promising variety for cultivation. A field experiment was conducted under net-house conditions at the Faculty of Sustainable Agriculture, Universiti Malaysia Sabah, Sandakan. The study employed a single-factor completely randomized design (CRD), with eight rice varieties and five replications. Growth parameters assessed included days to flowering, grain-filling period, days to maturity, plant height, leaf area, flag leaf area, tiller number, and percentage of productive tillers. Yield-related traits included panicle length, number of panicles per plant, number of grains per panicle, percentages of filled and unfilled grains, grain weight per panicle, 1000-grain weight, seed dimensions, and extrapolated seasonal yield. Data were analysed using one-way analysis of variance, and treatment means were compared using the Least Significant Difference test at the 5% significance level. Significant differences among varieties were observed for nearly all growth and yield parameters. Among the evaluated varieties, Tadong consistently exhibited superior performance, recording the largest leaf area (77.63 cm²), flag leaf area (50.46 cm²), longest panicle length (28.5 cm), and highest 1000-grain weight (40.28 g). The findings indicate substantial variability among upland rice varieties and identify Tadong as the most promising genotype for upland rice production in Sabah. Further field evaluation under diverse environmental conditions is recommended to validate its performance and support its wider adoption by farmers.

Keywords: *Oryza sativa*, Sabah, upland rice, yield evaluation

1. Introduction

Rice (*Oryza sativa* L.) is one of the most important staple crops globally and plays a major role in food security, particularly in Asia. Rice is also a major staple food in Malaysia, with average per capita consumption reaching approximately 76.7 kg per person per year in 2023. However, domestic rice production remains insufficient to meet national demand, resulting in continued dependence on imported rice. In 2023, Malaysia produced approximately 1.44 million metric tonnes of rice while importing around 1.28 million metric tonnes to fulfil domestic consumption

Copyright: © 2026 Nikson et al. This is an open access article distributed under the Creative Commons Attribution (CC BY 4.0) License, which permits use, sharing, adaptation, distribution, and reproduction in any medium, provided the original author(s) and the source are properly credited. Author(s) retain copyright and grant Journal of Smart Farming and Food Security the right of first publication.
Citation: Nikson, N., Lum, M. S., Hasnain, M. A., & Jubidin, M. M. (2025). Growth performance and yield evaluation of upland rice (*Oryza sativa* L.) varieties collected from Lahad Datu, Sabah, Malaysia. Journal of Smart Farming and Food Security, 2(2), 180–189. https://doi.org/10.51200/jsffs.v2i2.8127

DOI: 10.51200/jsffs.v2i2.8127

requirements (Malaysia Competition Commission, 2024). In Sabah, paddy cultivation remains relatively limited compared with the state's agricultural potential. The 2024 Agriculture Census reported approximately 12,900 ha of paddy-planted area in Sabah, representing a relatively small proportion of the state's agricultural land.

Upland rice is cultivated mainly under rainfed conditions and on non-flooded land, making it an important rice production system in areas where lowland irrigation is limited. In Sabah and Sarawak, upland rice is traditionally cultivated by rural communities and is closely associated with local food systems and cultural practices. However, productivity is generally lower than that of irrigated lowland rice, and production is often affected by rainfall variability and other environmental constraints. Therefore, the identification and evaluation of upland rice varieties with good agronomic performance is important for improving the productivity and resilience of rainfed rice production.

Upland rice also represents an important source of genetic diversity for rice improvement. Recent studies have demonstrated substantial variation among upland rice germplasm in growth, yield components and grain yield, indicating the potential of local germplasm for selection and breeding (Marwan *et al.*, 2022; Pavankumar *et al.*, 2022). In Malaysian Borneo, genetic and morphological studies have also confirmed considerable diversity among traditional upland rice varieties. Chong *et al.* (2021) reported genetic variation among traditional upland rice germplasm collected from different divisions of Sabah, while a recent characterization of rice landraces from Sarawak demonstrated variation in important agronomic and morphological traits (Clifton *et al.*, 2024). Such variation provides an important basis for the conservation, selection and future utilization of local rice genetic resources.

Yield performance is influenced by several agronomic characteristics, including plant height, tiller production, panicle development, grain number and grain weight. Differences among genotypes in these traits can contribute to variation in grain yield and may provide useful selection criteria for identifying promising germplasm. Recent evaluations of upland rice cultivars have shown significant variation in yield-related traits and demonstrated the potential of selected local cultivars for further breeding and evaluation (Marwan *et al.*, 2022). In addition, the evaluation of local germplasm under standardized growing conditions provides an initial assessment of varietal performance before more extensive field testing.

Despite the availability of traditional upland rice varieties in Sabah, information on the agronomic performance and yield potential of upland rice germplasm specifically collected from the Lahad Datu area remains limited. Comparative information on the growth performance, yield components and grain yield of these local varieties under standardized growing conditions is lacking. This information is important for determining which germplasm shows sufficient potential to justify further field evaluation and conservation. Therefore, evaluating locally collected varieties can provide baseline information for subsequent agronomic studies, breeding activities and the sustainable utilization of Sabah's rice genetic resources.

This study was therefore conducted to evaluate the growth performance and yield components of eight upland rice varieties collected from Lahad Datu, Sabah, and to identify promising varieties for subsequent field evaluation and future rice improvement programmes.

2. Materials and Methods

2.1 Site, soil, and experimental period

The experiment was conducted in Net House 3 at the Faculty of Sustainable Agriculture, Universiti Malaysia Sabah, Sandakan (5°49′59.99″N, 118°07′00.00″E), from April to October 2019. Prior to transplanting, the experimental site and growing medium were prepared. The collected soil was air-dried for approximately three weeks, mechanically ground, and sieved to remove stones and other debris. The plastic pots were cleaned and sun-dried before use. The

growing medium consisted of Silabukan soil (Ultisol) and well-decomposed goat dung obtained from Universiti Malaysia Sabah, Sandakan Campus. The soil and goat dung were thoroughly mixed at a ratio of 3:1 (soil:goat dung, w/w) to ensure a homogeneous growing medium. The prepared mixture was distributed into 40 plastic pots, each measuring 30 cm in diameter and containing 8 kg of growing medium. The pots were subsequently arranged and randomized according to the experimental design. The initial physicochemical properties of the Silabukan soil and goat dung were not determined before the experiment. Consequently, the study focused on evaluating varietal differences in plant growth and yield performance under the established growing conditions, without assessing the influence of initial soil and organic amendment characteristics on plant responses.

2.2 Plant material and seed preparation

Eight upland rice varieties, namely Lombug, Kelopak, Mahsuri, Worik, Tadong, TN-1, 3 Bulan, and Purak, were used in this study. The seed materials were obtained from Lahad Datu, Sabah. Detailed provenance records, including specific collection locations, farmer/source, accession numbers, and seed generation, were not available. Therefore, the materials are referred to as upland rice varieties rather than confirmed traditional landraces. Seeds were pre-soaked in distilled water to remove unfilled grains, then germinated on moistened tissue paper at room temperature for 4–5 days. Germinated seedlings were transplanted at the three-leaf stage (one seedling per pot) in June 2019.

2.3 Fertilizer application

Fertilizer was applied by top-dressing in three splits. At 30 and 60 days after transplanting (DAT), each pot received 0.50 g YaraMila NPK Green (15:15:15) and 0.384 g urea (46% N). At the booting stage, each pot received 0.518 g YaraMila NPK Blue (12:12:17). In total, each pot received 1.00 g NPK Green, 0.768 g urea and 0.518 g NPK Blue, supplying 0.565 g N, 0.212 g P_2O_5 and 0.238 g K_2O per pot (equivalent to 80 kg N, 30 kg P_2O_5 and 33.7 kg K_2O ha^{-1}, based on a pot surface area of 0.0707 m^2). The K_2O supplied was slightly above the recommended 30 kg ha^{-1} (Oikeh *et al.*, 2008) because of the K-rich composition of NPK Blue. Fertilizers for each application were weighed for all 40 pots (e.g. 20.0 g NPK Green and 15.35 g urea at each of 30 and 60 DAT, and 20.7 g NPK Blue at booting), thoroughly mixed, and divided equally among the pots. Nutrients contributed by goat dung were not deducted from the fertilizer calculation.

2.4 Experimental site and environmental conditions

The experimental pots were irrigated twice daily using tap water to maintain non-flooded conditions, simulating an upland rice production system. Each pot was provided with drainage holes to prevent waterlogging. The experiment was conducted in Net House 3, which was covered with UV greenhouse plastic only, allowing the plants to receive natural sunlight throughout the experimental period. No pesticides or fungicides were applied during the study. Weeds were removed manually at 7-day intervals to minimize competition with the rice plants. Air temperature and relative humidity were not monitored during the experimental period. Therefore, the effects of environmental conditions on plant growth and yield could not be evaluated and are acknowledged as a limitation of this study.

2.5 Experimental design and data collection

A single-factor completely randomized design (CRD) with eight treatments (varieties) and five replications per treatment was used, for a total of 40 experimental units. Phenological development recorded included days to flowering, grain-filling period, and days to maturity. Vegetative growth recorded were plant height, leaf area ($A = L \times W \times 0.75$; Kemp, 1960), flag

DOI: 10.51200/jsffs.v2i2.8127

leaf area, and number of tillers per plant. Yield components measured at physiological maturity included percentage of productive tillers, panicle length, number of panicles per plant, number of grains per panicle, percentage of filled grains, grain weight per panicle, 1000-grain weight, seed length and width, yield per pot, and extrapolated grain yield (t ha^{-1}). Grain yield was extrapolated to t ha^{-1} based on an estimated plant population of 111,111 hills ha^{-1} at 30 cm × 30 cm spacing to facilitate comparison among varieties under standardized conditions. All data were analyzed by one-way ANOVA using SAS 9.4, with means separated using the Least Significant Difference (LSD) test at $p < 0.05$. Pearson correlation analysis was also performed to determine the relationships among the measured growth, yield components, and grain yield variables.

3. Results and Discussion

3.1 Phenological development

Phenological characteristics of the upland rice varieties is summarized in Table 1. Days to flowering among the evaluated upland rice varieties ranged from 74 days (Kelopak) to 110 days (Mahsuri), indicating considerable variation in flowering behaviour among genotypes. The observed differences suggest variation in genetic background and developmental responses among upland rice varieties. Similar variability in flowering duration and maturity period has been reported among upland rice genotypes grown under different environmental conditions. Shrestha (2012) demonstrated significant differences in phenological traits among upland rice genotypes along an altitudinal gradient, highlighting the influence of genotype-specific responses on flowering and maturity duration. Furthermore, Shrestha *et al.* (2013) reported that upland rice phenology is influenced by genotype × environment interactions, where differences in temperature, altitude, and growing conditions contribute to variation in crop duration.

The maturity duration recorded in the present study ranged from 101 days (Kelopak and TN-1) to 115 days for most varieties. The variation observed indicates differences in crop development patterns among the tested genotypes. Early maturing varieties such as Kelopak and TN-1 could potentially provide an agronomic advantage by shortening the crop cycle and reducing the duration of exposure to late-season environmental constraints. However, the contribution of early maturity as a stress adaptation mechanism requires further evaluation under specific stress conditions. Bernier *et al.* (2008) reported that early flowering and maturity are important drought adaptation mechanisms in upland rice because they allow plants to complete reproductive development before severe moisture depletion occurs.

Similar phenotypic variation among Malaysian upland rice varieties was reported by Sinton *et al.* (2019), who observed differences in growth and yield-related traits among Bario, Tadong, and Kondoduvon varieties under open field conditions in Sabah. These differences were associated with genetic variation among varieties and their responses to local growing environments. Such variation highlights the importance of evaluating diverse upland rice genotypes to identify varieties with suitable agronomic characteristics for specific production environments.

The grain-filling duration in the present study varied from 5 days (Mahsuri) to 25 days (TN-1), indicating differences in reproductive development among varieties. Grain filling is an important developmental phase that influences final grain weight through carbohydrate translocation and accumulation in developing grains. Boonjung and Fukai (1996) reported that water deficit during reproductive and grain-filling stages can negatively affect biomass accumulation and yield formation in upland rice. Therefore, differences in grain-filling duration among varieties may contribute to variation in grain development and yield potential, although further evaluation of grain weight and yield components is required to confirm this relationship.

Recent studies have emphasized the importance of selecting upland rice varieties with suitable phenological characteristics for environments where water availability is limited. Pope

et al. (2023) demonstrated that water stress duration affects growth and yield components in upland rice, highlighting the importance of appropriate crop duration and stress tolerance in maintaining productivity under rainfed conditions. Therefore, the phenological variation observed in the present study provides useful information for identifying upland rice varieties with contrasting developmental characteristics. Varieties combining appropriate maturity duration with sufficient grain-filling periods may have potential for improved productivity and adaptation, but this requires further validation under diverse environmental conditions.

Table 1. Phenological characteristics of eight upland rice varieties.

Variety	Days to flowering	Grain filling period (days)	Days to maturity
Lombug	90	22	115
Kelopak	74	19	101
Mahsuri	110	5	115
Worik	105	10	115
Tadong	104	11	115
TN-1	76	25	101
3 Bulan	96	19	115
Purak	87	16	115

3.2 Vegetative growth

Plant height differed significantly among upland rice varieties ($p < 0.05$). TN-1 recorded the shortest plant height (approximately 100 cm) and was significantly lower than the other varieties. In contrast, most varieties exhibited moderate plant height ranging from 120–150 cm, with Lombug, Worik, and Tadong showing the highest values. Variation in plant height among varieties indicates differences in genetic characteristics and adaptation responses under upland conditions. Leaf area differed significantly among upland rice varieties ($p < 0.05$). Lombug recorded the highest leaf area and was significantly different from other varieties, while TN-1 and Mahsuri showed the lowest leaf area. No significant difference was observed between Worik and Tadong. Variation in leaf area among varieties may be attributed to genetic differences affecting leaf expansion and development. Larger leaf area enhances light interception and photosynthetic capacity, contributing to greater assimilate production during grain filling (Fu & Lee, 2008; Thakur *et al.*, 2011). However, canopy photosynthetic efficiency also depends on light distribution and leaf function within the canopy (Weiss *et al.*, 2004).

Table 2. Vegetative growth of eight upland rice varieties.

Variety	Plant height (cm)	Leaf area (cm^2)	Flag leaf area (cm^2)	Number of tillers per plant
Lombug	145^{a}	93^{a}	52.5^{a}	14^{e}
Kelopak	130^{b}	58^{c}	46.0^{ab}	21^{c}
Mahsuri	139^{ab}	41^{de}	36.5^{c}	50^{a}
Worik	148^{a}	75^{b}	45.5^{ab}	17^{cd}
Tadong	145^{a}	78^{b}	50.0^{a}	12^{e}
TN-1	97^{c}	31^{e}	32.0^{cd}	44^{b}
3 Bulan	139^{ab}	59^{c}	39.0^{bc}	17^{cd}
Purak	138^{ab}	51^{cd}	26.0^{d}	16^{cde}

Note: Values followed by different letters within the same column indicate significant differences according to LSD test at $p < 0.05$.

DOI: 10.51200/jsffs.v2i2.8127

3.3 Yield components

Panicle length differed significantly among varieties ($p < 0.05$). Tadong had the longest panicle (28.5 cm), while TN-1 had the shortest (22.1 cm). Panicle length was strongly correlated with seed length ($r = 0.640$), 1000-grain weight ($r = 0.594$), grain weight per panicle ($r = 0.336$), and extrapolated yield ($r = 0.593$), supporting earlier reports linking panicle architecture to yield potential (Ganesan & Subramanian, 1990). Similarly, Sinton *et al.* (2019) reported that Tadong produced the longest panicle length (28.47 cm) and the highest extrapolated yield among three upland rice varieties evaluated under field conditions, further highlighting the importance of panicle length as a key yield-contributing trait in upland rice.

Tadong recorded the highest values for seed length (0.97 cm), seed width (0.38 cm), and 1000-grain weight (40.28 g). Mahsuri had the lowest values for all three grain morphology parameters, including the lowest 1000-grain weight (12.54 g). Seed length was highly correlated with 1000-grain weight ($r = 0.772$) and extrapolated yield ($r = 0.772$), aligning with the findings of Li *et al.* (2019), who demonstrated that larger grain dimensions positively influence 1000-grain weight in indica rice. The superior grain weight of Tadong is also consistent with the findings of Sinton *et al.* (2019), who identified grain weight as an important factor contributing to the higher yield performance of this variety. A summary of key yield components is presented in Table 3.

Table 3. Yield components of eight upland rice varieties.

Variety	Productive tillers (%)	Panicle length (cm)	No. of panicles per plant	No. of grains per panicle	Filled grains (%)	Grain weight per panicle (g)	1000-grain weight (g)	Seed length (mm)	Seed width (mm)	Yield per pot (g)	Extrapolated grain yield (t ha^{-1})
Lombug	80	24.6^{b}	11^{b}	121^{de}	38.5^{c}	2.34^{ab}	20.80^{bc}	8.1^{ab}	3.3^{ab}	25.60^{c}	2.31^{bc}
Kelopak	79	25.1^{b}	16^{b}	141^{bcd}	79.5^{b}	3.42^{a}	22.14^{bc}	8.2^{ab}	2.8^{c}	51.90^{ab}	2.46^{bc}
Mahsuri	81	23.8^{cd}	40^{a}	178^{a}	80.0^{b}	1.48^{b}	12.54^{d}	6.7^{c}	2.5^{c}	48.49^{ab}	1.39^{c}
Worik	74	27.1^{a}	12^{b}	167^{ab}	82.5^{b}	2.61^{ab}	24.61^{bc}	8.5^{b}	3.5^{ab}	41.04^{bc}	2.74^{bc}
Tadong	87	28.5^{a}	10^{b}	154^{abc}	81.0^{b}	3.41^{a}	40.28^{a}	9.7^{a}	3.8^{a}	34.22^{bc}	4.47^{a}
TN-1	76	22.1^{d}	33^{a}	131^{cd}	80.0^{b}	2.33^{ab}	23.76^{c}	7.4^{c}	3.4^{ab}	78.23^{a}	2.64^{bc}
3 Bulan	91	24.3^{bc}	16^{b}	113^{de}	90.5^{a}	1.87^{b}	26.17^{b}	8.2^{ab}	2.7^{c}	40.49^{bc}	2.91^{b}
Purak	95	24.7^{bc}	15^{b}	92^{e}	79.5^{b}	2.44^{ab}	28.48^{a}	9.0^{a}	3.1^{b}	44.48^{bc}	3.17^{b}

Note: Values followed by different letters within the same column indicate significant differences according to LSD test at $p < 0.05$.

3.4 Yield per Pot and Extrapolated Yield

Yield per pot differed significantly among upland rice varieties ($p < 0.05$). TN-1 recorded the highest yield per pot (78.23 g), followed by Kelopak (51.90 g) and Mahsuri (48.49 g), whereas Lombug produced the lowest yield per pot (25.60 g). The superior yield performance of TN-1 was associated with its higher productive tiller number and panicle production, which contributed to greater grain accumulation per plant.After recalculation using the corrected extrapolation approach based on yield per plant and estimated plant population at 30 × 30 cm spacing, TN-1 also recorded the highest estimated yield per hectare. This result indicates that yield performance was primarily influenced by total grain production per plant rather than individual grain characteristics alone.

Although Tadong exhibited superior grain morphological characteristics, including the highest 1000-grain weight (40.28 g), seed length (0.97 cm), and seed width (0.38 cm), these characteristics did not directly translate into the highest overall yield. This suggests that grain size is only one component contributing to yield formation, while productive tillering, panicle number, and grain production per plant also play important roles in determining final yield. The importance of yield components was further supported by Pearson correlation analysis. Yield per plant showed significant positive relationships with productive tiller number, grain weight per panicle, and other yield-associated traits. These results indicate that efficient source–sink

balance, where sufficient assimilates produced by vegetative structures are effectively partitioned into developing grains, is essential for achieving high yield performance.

Panicle length differed significantly among varieties ($p < 0.05$). Tadong produced the longest panicle (28.5 cm), followed by Worik (27.1 cm), whereas TN-1 recorded the shortest panicle length (22.1 cm). Longer panicles may provide greater potential for spikelet development and grain formation; however, panicle length alone does not determine yield performance, as yield is also dependent on productive tiller number, grain filling efficiency, and grain weight.

The positive correlation between panicle length and yield-related traits suggests that panicle architecture contributes to yield formation. However, the present study indicates that varieties with favourable grain morphology do not necessarily achieve the highest yield when other yield components are limited. Therefore, selection of upland rice varieties should consider multiple traits, including productive tillering ability, panicle development, grain filling characteristics, and grain weight. Tadong showed the highest grain morphological values, including 1000-grain weight, seed length, and seed width. Similar relationships between grain size characteristics and grain weight have been reported in rice, where larger grain dimensions contribute to increased individual grain weight (Table 3). However, the present findings demonstrate that higher individual grain weight alone is insufficient to maximize yield, as overall productivity depends on the interaction between sink capacity and assimilate partitioning.

Previous studies, including Sinton *et al.* (2019), reported favourable yield-related characteristics of Tadong under Malaysian upland rice conditions. However, differences between studies may occur due to environmental conditions, cultivation systems, and the specific yield components contributing to productivity. Therefore, while Tadong showed desirable grain quality characteristics, TN-1 demonstrated superior yield potential under the present experimental conditions due to its higher grain production per plant.

Table 4. Pearson correlation analysis between extrapolated yield per season and selected yield components

	PL	**GWP**	**SL**	**SW**	**TGW**	**EYS**
PL	1					
GWP	0.336*	1				
SL	0.640**	0.240	1			
SW	0.367**	0.252	0.280	1		
TGW	0.594**	0.457**	0.772**	0.527**	1	
EYS	0.593**	0.457**	0.772**	0.527**	1**	1

Note: PL = panicle length; GWP = grain weight per panicle; SL = seed length; SW = seed width; TGW = 1000-grain weight; EYS = extrapolated yield per season. Correlation analysis was performed based on the mean values of eight upland rice varieties (n = 8). *Significant at $p < 0.05$; ** Significant at $p < 0.01$.

The present study demonstrated significant variation among upland rice varieties in vegetative growth, yield components, and yield performance, indicating considerable genetic diversity among the evaluated genotypes. Differences in plant height, tillering capacity, leaf development, panicle characteristics, and grain traits suggest that varieties possess distinct growth architectures that influence biomass production and reproductive performance. Such variation is important for identifying suitable genetic materials for upland rice improvement, particularly in environments where productivity is constrained by variable environmental conditions.

DOI: 10.51200/jsffs.v2i2.8127

Yield performance among varieties was associated with the interaction of multiple yield components rather than a single trait. TN-1 recorded the highest yield performance, which was mainly associated with greater productive tillering ability and grain production per plant. In contrast, Tadong exhibited superior grain characteristics, including larger seed size and higher 1000-grain weight, indicating differences in grain development potential. These findings highlight that yield formation in upland rice depends on the balance between source capacity, including leaf development and photosynthetic potential, and sink capacity, including productive tillers, panicle number, grain number, and grain filling efficiency.

Panicle traits also contributed to varietal differences in yield performance. Tadong produced the longest panicle among the evaluated varieties, while other varieties showed advantages in tillering and grain production. A longer panicle may increase spikelet-bearing capacity; however, panicle length alone does not determine final yield because grain filling and productive panicle number also influence overall productivity. Therefore, selection of high-yielding upland rice varieties should consider multiple interacting traits rather than individual characteristics.

The variation observed in the present study is consistent with previous reports showing substantial genetic diversity among upland rice varieties. Sinton *et al.* (2019) reported differences in productive tillers, panicle characteristics, grain traits, and yield among Malaysian upland rice varieties, including Tadong, under Sabah conditions. However, differences between studies may arise from genotype × environment interactions, including variation in soil conditions, climatic factors, cultivation systems, and management practices. Therefore, superior performance of a variety under one environment may not always translate directly to other production systems.

The controlled net-house conditions used in this study provided a relatively uniform growing environment for evaluating varietal differences. However, the higher estimated yield observed under these conditions should not be interpreted as direct evidence of increased genetic yield potential because no field comparison was included. Instead, the results represent the relative performance of varieties under the experimental conditions. Field validation under diverse upland environments is required to confirm yield stability and identify varieties with consistent performance under farmer production conditions.

For Sabah upland rice improvement, the observed variation among varieties provides useful information for future selection strategies. Varieties combining efficient tillering, favourable panicle development, effective grain filling, and suitable grain characteristics may contribute to improved productivity. Therefore, integrating multiple agronomic traits rather than selecting based on a single yield component will be important for developing upland rice varieties adapted to local environmental challenges.

4. Conclusion

Eight upland rice varieties collected from Lahad Datu, Sabah, exhibited significant variation in growth characteristics, yield components, and grain traits under net-house conditions. The observed differences among varieties demonstrated the influence of genetic variation on plant architecture, panicle development, grain characteristics, and yield performance. TN-1 recorded the highest yield per pot and corrected estimated yield performance, which was associated with its greater productive tillering ability and grain production per plant. Meanwhile, Tadong exhibited superior grain characteristics, including higher 1000-grain weight, larger seed dimensions, and longer panicles, indicating desirable traits for future breeding and selection programs. However, the present findings were obtained from a single-season pot experiment under net-house conditions. Therefore, the observed varietal differences should be further validated through multi-location and multi-season field trials under diverse environmental conditions before recommendations for farmer adoption are made. Future research should

evaluate the stability of yield performance, grain quality characteristics, and adaptability of promising upland rice varieties under actual cultivation conditions in Sabah.

Data Availability

The original replicate-level data generated during this study are no longer available due to the loss of the research records. The experiment was conducted between 2019 and 2020 as part of an undergraduate thesis at Universiti Malaysia Sabah. Consequently, the underlying raw data cannot be made available for independent verification or reanalysis. Further information regarding the experimental methodology may be requested from the corresponding author.

Author Contributions

Nikmael Nikson: Methodology, Investigation, Writing - Original Draft. **Lum Mok Sam:** Conceptualization, Supervision. **Muhammad Azizul Hasnain:** Writing - Review & Editing. **Mohd Miqdam Jubidin:** Writing - Review & Editing.

Acknowledgement

The authors gratefully acknowledge the Faculty of Sustainable Agriculture, Universiti Malaysia Sabah, Sandakan Campus, for providing the experimental facilities and technical support. We thank the Department of Agriculture Sabah for information on upland rice varieties. Seed materials were collected from farmers in Lahad Datu, Sabah, and we appreciate their contribution.

Conflicts of Interest

The authors declare that they have no conflicts of interest. No commercial, financial, or personal relationships exist that could influence the interpretation or presentation of the results.

Ethics Statement

This study did not involve human participants, animal subjects, or identifiable personal data. Therefore, ethical approval was not required.

References

Bernier, J., Atlin, G. N., Serraj, R., Kumar, A., & Spaner, D. (2008). Breeding upland rice for drought resistance. Journal of the Science of Food and Agriculture, 88(6), 927–939. https://doi.org/10.1002/jsfa.3153

Boonjung, H., & Fukai, S. (1996). Effects of soil water deficit at different growth stages on rice growth and yield under upland conditions. 2. Phenology, biomass production and yield. Field Crops Research, 48(1), 47–55. https://doi.org/10.1016/0378-4290(96)00039-1

Chong, E. T. J., Goh, L. P. W., Latip, M. A., Aziz, Z. A., Surugau, N., & Lee, P.-C. (2021). Genetic diversity of upland traditional rice varieties in Malaysian Borneo based on mitochondrial cytochrome c oxidase 3 gene analysis. AIMS Agriculture and Food, 6(1), 235–246. https://doi.org/10.3934/agrfood.2021015

Clifton, Z. F., Yeo, F. K. S., Sylvester Embuas, R. P. T., Kalu, M., Shabdin, Z., & Lai, L. S. (2024). Preliminary characterisation of lowland and upland rice from Sarawak, Malaysian Borneo. Borneo Journal of Resource Science and Technology, 14(1), 123–138. https://doi.org/10.33736/bjrst.5653.2024

Fu, J.-D., & Lee, B. W. (2008). Changes in photosynthetic characteristics during grain filling of a functional stay-green rice SNUSG1 and its F_1 hybrids. Journal of Crop Science and Biotechnology, 11(1), 75–82.

Ganesan, K., & Subramanian, M. (1990). Genetic study of the F_2 and F_3 tall × semi-dwarf rice varieties. International Rice Research Newsletter, 15, 4.

Kemp, C. D. (1960). Methods of estimating the leaf area of grasses from linear measurements. Annals of Botany, 24(4), 491–499. https://doi.org/10.1093/oxfordjournals.aob.a083723

Li, R., Li, M., Ashraf, U., Liu, S., & Zhang, J. (2019). Exploring the relationships between yield and yield-related traits for rice varieties released in China from 1978 to 2017. Frontiers in Plant Science, 10, Article 543. https://doi.org/10.3389/fpls.2019.00543

Malaysia Competition Commission. (2024). *The paddy and rice industry in Malaysia: Public summary 2024*. https://www.mycc.gov.my/sites/default/files/pdf/newsroom/MyCC_Paddy%20and%20Rice%20Industry%20in%20Malaysia%20%28Public%20Report%29_%28ENG%29.pdf

Marwan, A. P., Munandar, A., Anwar, A., Syarif, A., & Hayati, P. K. D. (2022). Variability, heritability, and performance of 28 West Sumatran upland rice cultivars, Indonesia. Biodiversitas Journal of Biological Diversity, 23(2), 1058–1064. https://doi.org/10.13057/biodiv/d230249

Oikeh, S. O., Nwilene, F. E., Agunbiade, T. A., Oladimeji, O., Ajayi, O., Semon, M., Tsunematsu, H., & Samejima, H. (2008). *Growing upland rice: A production handbook*. Africa Rice Center (WARDA). https://www.fao.org/fileadmin/user_upload/ivc/docs/uplandrice.pdf

Pavankumar, R., Lavanaya, G. R., Taranum, S. A., Bishnoi, R., & Krishna, B. J. S. (2022). Genetic diversity analysis for economic traits in advance breeding lines of upland rice (*Oryza sativa* L.) germplasm. Journal of Cereal Research, 14(3), 258–267. https://doi.org/10.25174/2582-2675/2022/131250

Pope, E. M., Opile, W., Ngode, L., & Chepkoech, E. (2023). Effect of water stress duration on the growth characteristics and yield components of upland rice varieties in Kenya. Asian Journal of Research in Crop Science, 8(4), 273–286. https://doi.org/10.9734/ajrcs/2023/v8i4208

Shrestha, S. P. (2012). *Genotypic responses of upland rice to an altitudinal gradient* [Doctoral dissertation, University of Hohenheim]. https://hdl.handle.net/10568/42079

Shrestha, S., Asch, F., Brueck, H., Giese, M., Dusserre, J., & Ramanantsoanirina, A. (2013). Phenological responses of upland rice grown along an altitudinal gradient. Environmental and Experimental Botany, 89, 1–10. https://doi.org/10.1016/j.envexpbot.2012.12.007

Sinton, F. V., Lum, M. S., Benedick, S., & Jalloh, M. B. (2019). Evaluation of the yield of upland rice varieties under open field trial. Transactions on Science and Technology, 6(2–2), 253–258. https://tost.unise.org/pdfs/vol6/no2-2/6x2-2x253-258.pdf

Thakur, A. K., Rath, S., Patil, D. U., & Kumar, A. (2011). Effects on rice plant morphology and physiology of water and associated management practices of the system of rice intensification and their implications for crop performance. Paddy and Water Environment, 9(1), 13–24. https://doi.org/10.1007/s10333-010-0236-0

Weiss, M., Baret, F., Smith, G. J., Jonckheere, I., & Coppin, P. (2004). Review of methods for in situ leaf area index (LAI) determination: Part II. Estimation of LAI, errors and sampling. Agricultural and Forest Meteorology, 121(1–2), 37–53. https://doi.org/10.1016/j.agrformet.2003.08.001