Borneo Journal of Resource Science and Technology (2024), 14(1): 123-138
DOI: https:doi.org/10.33736/bjrst.5653.2024

Preliminary Characterisation of Lowland and Upland Rice from Sarawak, Malaysian Borneo

ZAZEVIA FRANK CLIFTON[1], FREDDY KUOK SAN YEO[1]*, RENEE PRISCILLA TRAWAS SYLVESTER EMBUAS[1], MEEKIONG KALU[1], ZINNIRAH SHABDIN[1] & LEE SAN LAI[2]

[1]Faculty of Resource Science and Technology, Universiti Malaysia Sarawak, Jalan Datuk Mohammad Musa, 94300, Kota Samarahan, Sarawak, Malaysia; [2]Agriculture Research Centre Semongok, KM20, Jalan Puncak Borneo, 93250, Kuching, Sarawak
*Corresponding author: yksfreddy@unimas.my
Received: 21 April 2023 Accepted: 08 May 2024 Published: 30 June 2024

ABSTRACT

Oryza sativa L. or commonly known as rice belongs to the family of Poaceae. In Malaysia, rice is normally cultivated either as lowland or upland rice. Sarawak is a state with diverse types of rice. All Sarawak rice are landraces. Despite the fact that Sarawak is rich in rice biodiversity, the assessment of the morphological traits which may provide basic information that is useful for the future breeding programs is still unavailable. The nomenclature of the landraces is based on the name given by the farmers. Problems arise when landraces having the same morphological characteristics were given different names and vice versa. In addition, the purity of seeds is unreliable. Common practices by the local farmers such as planting different rice landraces in the same field either in one plot or in different plots but very near to each other has contributed to the impurity of the seeds. The present study was undertaken with the objective to characterise the morphological traits of 22 lowland and 22 upland rice accessions from the North-Western region of Sarawak. The morphological traits observed on the 44 rice accessions *viz*., blade colour, ligule shape, ligule colour, auricle colour, heading days, flowering days, panicle type, culm length, panicle number, number of filled grain, seed length and grain colour exhibited variations. There are variations which may be considered in future Sarawak rice breeding programs.

Keywords: Lowland rice, *Oryza sativa*, rice breeding, Sarawak, upland rice

INTRODUCTION

Rice being the staple food of Malaysian is the country's most important crop. Food and Agriculture Organization reported that rice production in Malaysia for the year 2019 was 2.8 million tonnes, 3.6% more than the average rice production from the year 2014 to 2018 (Food and Agriculture Organization of the United Nations, 2019). Although the production shows an increasing trend, with the growing number of residents in Malaysia annually, the production of rice in the country is still considered insufficient to meet domestic demands. Malaysia still relies on the neighbouring countries such as Vietnam, Thailand, and Pakistan for importing rice (Khazanah Research Institute, 2019).

Sarawak is the country's fifth largest rice producing state, after Kedah, Perak, Kelantan and Perlis with 134, 260 ha of land planted with lowland and upland rice (Masni & Wasli, 2019). Rice is economically, socially and culturally important in Sarawak. There are two types of rice planted in Sarawak; lowland rice, which is grown in field that is either rain-fed or irrigated; and upland rice, which is grown in an area naturally well-drained without surface water accumulation (International Rice Research Institute [IRRI], n.d.). The state is very rich in the diversity of rice (Yeo *et al*., 2018). For example, Sarawak rice has different resistance towards *Pyricularia oryzae* (Lai *et al*., 2019; Yeo *et al*., 2024) and may have different defence mechanisms against *Scirpophaga incertulas* (Cheok *et al*., 2019;

Hamsein *et al*., 2020; Ling *et al*., 2020), and different toxicity response to antifungal nanoparticles (Tang *et al*., 2023), which are potential genetic resources for rice breeding.

Department of Agriculture, Sarawak has declared a total of 2011 rice accessions are currently deposited in the gene bank of Agriculture Research Centre (including imported accessions) (Department of Agriculture Sarawak, 2020). Sarawak rice accessions should be considered as landraces. The nomenclature of the landraces is based on the name given by the farmers. There is problem with identification when landraces having the same morphological characteristics were given different names or vice versa. The purity of farmer's seed is also unreliable because of the common practice of planting different rice landraces in the same field either in one plot or in different plots but very near to each other (Yeo *et al*., 2018).

Despite the fact that Sarawak is rich in rice biodiversity, the morphological characteristics of each Sarawak rice landrace are unclear. Thus far, no report is available describing the morphological characteristics of the Sarawak rice landraces. The information on morphological trait is useful for rice breeders in selecting parents of specific traits for breeding programs. Therefore, the objective of this study was to characterise the morphological traits of Sarawak rice landraces collected from the northwest region of Sarawak.

In order to allow unique individuals from each rice landrace collection (heterogenous population) to be assessed, Simple Sequence Repeats (SSR) marker was used in this study for genotyping and plant selection. SSR are commonly used for fingerprinting and effectively used for assessing the genetic diversity among closely related rice cultivar (Bhattarai *et al*., 2021) due to its ability to reveal polymorphism even in closely related varieties (Spada *et al*., 2004). Four SSR markers (RM1, RM279, RM489 and RM335) has been tested on 220 accessions. Out from 220 accessions, 44 accessions showed polymorphism.

MATERIALS AND METHODS

Collection and Pre-Selection of Rice Landrace

A total of 22 rice landraces (11 lowland and 11 upland landraces) were collected from different localities across different divisions in northwest region of Sarawak (Supplementary Table 1). A total of 10 seeds per landrace were germinated in different batches (Supplementary Table 2) in distilled water. Germinated seeds, were transplanted into trays containing planting medium of topsoil, compost and sand (3:2:1 ratio). Each seedling was considered as different accession (Total = 220 accessions). The seedlings were then genotyped using Simple Sequence Repeat (SSR) markers.

Young leaf samples, about 4-5 cm, were collected from the 220 accessions. Deoxyribonucleic acid (DNA) was extracted using Cetyltrimethylammonium Bromide protocol by Doyle and Doyle (1987). A total of 12 SSR markers were randomly chosen from RiceGenes database (www.gramene.org) representing the 12 chromosomes of rice. The 12 SSR markers were tested on two randomly selected accessions from different rice landrace. Four SSR markers (Supplementary Table 3) which showed polymorphisms were chosen for genotyping the 220 accessions. Polymerase Chain Reaction (PCR) amplification was performed by following Zhu *et al.* (2012). After electrophoresis, the agarose gel was stained with ethidium bromide and visualized.

From the 10 seedlings of each landrace, individuals with polymorphic genotype based on the four SSR markers were chosen for morphological characterisation without replication. For a landrace, with ten seedlings having monomorphic genotype, one individual was selected randomly. In total, there were 44 accessions selected for morphological characterisation (22 accessions for lowland and upland rice, respectively).

The selected lowland rice accessions were transplanted into pots (13 inches, 5 gallons). Each pot was filled three-quarters full of soil mixture of topsoil, compost and sand (3:2:1 ratio). For pots used for planting lowland rice accessions, drainage holes were drilled on two sides of a pot, about 8 cm above the soil surface in the pot, to create a constant water level. Pots for upland rice accessions, had three drainage holes at the bottom to drain excess water. Watering was done once a day using tap water. The nitrogen, phosphorus and potassium (NPK) fertilizer (17.5:15.5:10) was used for fertilization. Ten grams of fertilizer was applied per pot per application. The first fertiliser application took place at roughly the same time with transplanting. The second application took place about 30-40 days after the first application. The third application took place during the flowering stage. The experiment was performed from October 2018 to June 2019, following the main rice planting season in Sarawak.

Morphological Characterisation

A total of 14 traits were selected from the International Rice Research Institute guidelines (International Board for Plant Genetic Resources & International Rice Research Institute Rice Advisory Committee, 1980) and 8 additional traits were added based on the observation of this study (Total = 22 morphological traits). Apart from observing morphological traits, developmental traits such as heading days (HD) and flowering days (FD) were studied throughout the experiment. All recorded characters, methods and criteria are shown in Supplementary Table 4. Thirteen quantitative morphological traits were compared between lowland and upland rice accessions. Student's t-test was used to analyse the data.

Cluster analysis was done based on nine qualitative traits. Data matrices were analysed using Paleontological Statistic (PAST) software version 4.03 to construct a dendrogram made up using Jaccard's coefficient, showing the relatedness between the 44 rice accessions.

RESULTS

Pre-Screening of Rice Accessions

A total of 44 accessions out of 220 accessions were selected based on their SSR marker genotype (Supplementary Table 5). From the 44 accessions, there were 22 accessions of lowland rice designated as UNIMAS-23 – UNIMAS-44 and 22 accessions of upland rice designated as UNIMAS-01 – UNIMAS-22.

Morphological Characterisation of Rice Accessions

A total of 22 traits were recorded for both lowland and upland accessions. There were nine qualitative and 13 quantitative traits along with two observed developmental traits (Supplementary Table 4).

Qualitative Traits.

Polymorphism was observed in seven of the nine qualitative traits in the present study (Table 1). The leaf blade colour (BC) showed polymorphisms among the 44 accessions. BC had three classes recorded *viz*. pale green, green and dark green in both types of rice accessions (Supplementary Figure 1). From the observed 22 lowland rice accessions, 12 accessions had pale green BC, eight recorded dark green and only two accessions (UNIMAS-32 and UNIMAS-41) recorded green BC. For upland rice accessions, four accessions were pale green, 12 accessions were green and the remaining accessions were dark green.

The ligule shape (LS) was polymorphic for lowland rice accessions but was monomorphic for upland rice accessions where all the accession had acute to acuminate LS. For lowland rice accessions, there were two groups of LS recorded: acute to acuminate and 2-cleft. Seventeen (78%) of lowland rice accessions were recorded as having acute to acuminate LS while five accessions had 2-cleft LS (Supplementary Figure 2).

The colour of ligule (LC) and auricles (AC) of lowland rice accessions were monomorphic. All of them had white coloured ligule and auricle. The LC and AC were polymorphic for upland rice accessions. All the upland rice accessions had white LC and AC, except for one accession (UNIMAS-07) having purple ligule and auricle (Supplementary Figure 2).

As for the panicle, the type of panicle (PT) separated the lowland and upland rice accessions into three different groups, *viz*., compact, intermediate and open PT (Supplementary Figure 3). For lowland rice accessions, a total of 12 accessions had intermediate PT, three accessions (UNIMAS-31, UNIMAS-39 and UNIMAS-42) showed an open PT and two accessions (UNIMAS-37 and UNIMAS-38) with compact PT. Five other accessions did not produce any panicles during the period of observation. A majority, 14 out from 22 (64%) accessions were having intermediate PT and six accessions exhibited open PT. Only one accession (UNIMAS-15) was having compact PT. There was one upland accession (UNIMAS-22) that did not produce any panicles during the period of observation.

Secondary branches (SB) in a panicle were grouped into three types: absent, light and heavy (Supplementary Figure 4) in both lowland and upland accessions. Among the 17 lowland rice accessions that flowered, SB was absent in three accessions (UNIMAS-23, UNIMAS-24 and UNIMAS-28), 12 accessions recorded light SB and the remaining two accessions had heavy SB (UNIMAS-27 and UNIMAS-37) (Table 1). For the 21 upland rice accessions that flowered, SB was found absent in eight accessions. Another eight accessions were having light SB and the remaining five accessions (UNIMAS-07, UNIMAS-08, UNIMAS-15, UNIMAS-17, and UNIMAS-18) were having heavy SB (Table 1).

The seed shape (SS) varied, where three classes were recorded among the rice accessions that flowered: oblong, elliptic and linear (Supplementary Figure 5 & 6). Oblong and linear SS were recorded for the 17 flowered lowland rice accessions (Table 1), where 10 lowland rice accessions produced seeds with linear SS and the remaining seven lowland rice accessions had oblong SS. For the 21 flowered upland rice accessions, 20 had linear SS and one accession had elliptic SS (Table 1).

Variation was also observed among the flowered rice accessions in seed colour (SC). The lowland rice accessions were grouped into four categories of SC; (1) yellow, (2) pale yellow, (3) blackish yellow and (4) golden-brown husk colour (Supplementary Figure 5 & 6). Ten out of 17 flowered lowland rice accessions exhibited pale yellow SC; four accessions with yellow SC, two accessions had blackish yellow SC and one accession with golden brown SC (Table 1). On the other hand, the flowered upland rice accessions exhibited yellow, blackish yellow and golden-brown husk SC. A majority, 13 (62%) accessions were having yellow SC. Five other accessions (24%) were having blackish yellow SC and the remaining three accessions (UNIMAS-12, UNIMAS- 19 and UNIMAS-21) were having golden brown SC (14%) (Table 1).

Table 1. The characters of nine qualitative traits for the 44 rice accessions

Type	Accession	BC	LS	LC	AC	PT	SB	SS	SC	GC
LOWLAND	UNIMAS-23	1	1	1	1	2	0	2	4	1
	UNIMAS-24	3	1	1	1	2	0	2	2	4
	UNIMAS-25	1	1	1	1	2	1	2	2	3
	UNIMAS-26	1	1	1	1	2	1	2	2	4
	UNIMAS-27	1	1	1	1	2	2	2	3	1
	UNIMAS-28	1	1	1	1	2	0	4	2	3
	UNIMAS-29	3	2	1	1	2	1	2	3	4
	UNIMAS-30	1	2	1	1	2	1	4	1	1
	UNIMAS-31	1	1	1	1	3	1	4	2	2
	UNIMAS-32	2	2	1	1	2	1	4	1	2
	UNIMAS-33	1	2	1	1	N/A	N/A	N/A	N/A	N/A
	UNIMAS-34	1	1	1	1	N/A	N/A	N/A	N/A	N/A
	UNIMAS-35	3	1	1	1	2	1	4	2	2
	UNIMAS-36	3	1	1	1	2	1	4	2	2
	UNIMAS-37	3	1	1	1	1	2	2	2	2
	UNIMAS-38	3	1	1	1	1	1	4	2	6
	UNIMAS-39	3	1	1	1	3	1	4	2	2
	UNIMAS-40	3	1	1	1	N/A	N/A	N/A	N/A	N/A
	UNIMAS-41	2	1	1	1	N/A	N/A	N/A	N/A	N/A
	UNIMAS-42	1	1	1	1	3	1	4	1	1
	UNIMAS-43	1	2	1	1	2	1	4	1	1
	UNIMAS-44	1	1	1	1	N/A	N/A	N/A	N/A	N/A
UPLAND	UNIMAS-01	3	1	1	1	2	0	4	1	1
	UNIMAS-02	1	1	1	1	3	0	4	1	1
	UNIMAS-03	2	1	1	1	2	0	4	1	1
	UNIMAS-04	2	1	1	1	2	0	4	1	1
	UNIMAS-05	2	1	1	1	2	0	4	1	1
	UNIMAS-06	2	1	1	1	2	1	4	1	1
	UNIMAS-07	2	1	3	2	2	2	4	1	3
	UNIMAS-08	2	1	1	1	2	2	4	1	2
	UNIMAS-09	2	1	1	1	2	1	4	1	1
	UNIMAS-10	2	1	1	1	2	1	4	1	1
	UNIMAS-11	3	1	1	1	2	1	4	1	2
	UNIMAS-12	2	1	1	1	2	0	4	1	1
	UNIMAS-13	2	1	1	1	2	1	4	1	2
	UNIMAS-14	2	1	1	1	3	1	4	1	2
	UNIMAS-15	1	1	1	1	1	2	4	1	1
	UNIMAS-16	3	1	1	1	3	1	3	1	4
	UNIMAS-17	1	1	1	1	3	2	4	1	1
	UNIMAS-18	3	1	1	1	3	2	4	1	1
	UNIMAS-19	1	1	1	1	3	1	4	4	1
	UNIMAS-20	2	1	1	1	2	0	4	3	1
	UNIMAS-21	3	1	1	1	2	0	4	4	1
	UNIMAS-22	3	1	1	1	N/A	N/A	N/A	N/A	N/A

Note. N/A: Data Not Available. BC: Blade Colour (Scale: 1; Pale Green, 2; Green, 3; Dark Green, 4; Purple Tips, 5; Purple Margins, 6; Purple Blotch), LS: Ligule Shape (Scale: 1;Acute To Acuminate, 2; 2-Cleft, 3; Truncate), LC: Ligule Colour (Scale: 1; White, 2; Purple Lines, 3; Purple), AC: Auricle Colour (Scale:1; White, Or 2; Purple, 3; Pale Green), PT: Panicle Type (Scale: 1; Compact, 2; Intermediate, And 3; Open), SB: Secondary Branching (Scale: 0; Absent, 1; Light, 2; Heavy), SS: Seed Shape (Scale: 1; Round, 2; Oblong, 3; Elliptic, 4; Linear), SC: Seed Colour (Scale: 1; Yellow, 2; Pale Yellow, 3; Blackish Yellow, 4; Golden Brown), GC: Grain Colour (Scale: 1; Milky White, 2; Reddish Brown, 3; Dark Brown, 4; Black, 5; Greenish White, 6; Light Reddish Brown)

Grain colour (GC) also showed high polymorphism among the flowered rice accessions. The 17 flowered lowland rice accessions were grouped into five GC groups: milky white, light reddish-brown, reddish brown, dark brown, and black (Supplementary Figure 5). Meanwhile, the 21 flowered upland rice accessions were grouped into four different groups: milky white, reddish-brown, dark brown and black (Supplementary Figure 6).

Cluster analysis grouped the 44 rice accessions into two main clusters based on the similarity index (Figure 1). The first cluster consisted of 27 rice accessions and the second cluster consisted of 17 rice accessions (Table 2). Among the nine qualitative traits used for PAST analysis, SB seemed to be the main character which separated the 44 rice accessions into two clusters. The cluster with 27 accessions was mainly consists of accessions with light (scale: 1) and heavy (scale: 2) SB. The other cluster consists of mostly accessions having absent (scale: 0) of SB.

Table 2. Clustering of 44 rice accessions based on nine qualitative traits using Jaccard's coefficient

Cluster	Number of Accessions	Accession
I	27	UNIMAS-42-SRI/L, UNIMAS-39-SAMA/L, UNIMAS-38-SAMA/L, UNIMAS-37-SAMA/L, UNIMAS-36-SAMA/L, UNIMAS-35-SAMA/L, UNIMAS-32-SAMA/L, UNIMAS-31-SAMA/L, UNIMAS-30-SAMA/L, UNIMAS-29-SRI/L, UNIMAS-27-KCH/L, UNIMAS-25-KCH/L, UNIMAS-19-SRI/U, UNIMAS-18-SRI/U, UNIMAS-17-SRI/U, UNIMAS-16-SRI/U, UNIMAS-15-SRI/U, UNIMAS-13-KCH/U, UNIMAS-06-KCH/U, UNIMAS-07-KCH/U, UNIMAS-08-KCH/U, UNIMAS-09-KCH/U, UNIMAS-10-KCH/U, UNIMAS-11-KCH/U, UNIMAS-14-KCH/U, UNIMAS-26-KCH/U, UNIMAS-42-SRI/L
II	17	UNIMAS-40-KCH/L, UNIMAS-21-SRI/U, UNIMAS-12-KCH/U, UNIMAS-05-KCH/U, UNIMAS-04-KCH/U, UNIMAS-03-SER/U, UNIMAS-02-SER/U, UNIMAS-01-SER/U, UNIMAS-20-SRI/U, UNIMAS-22-KCH/U, UNIMAS-08-KCH/U, UNIMAS-23-SER/L, UNIMAS-24-KCH/U , UNIMAS-28-SR1/L, UNIMAS-33-SR1/L, UNIMAS-34-SR1/L, UNIMAS-41-KCH/L, UNIMAS-44-SR1/L,

Note. The accession number followed by an abbreviation indicating the division where seeds were collected and either it is lowland or upland rice accession. SRI: Sri Aman, SAMA: Kota Samarahan, KCH: Kuching, SER: Serian, /L: lowland rice accession, /U: upland rice accession

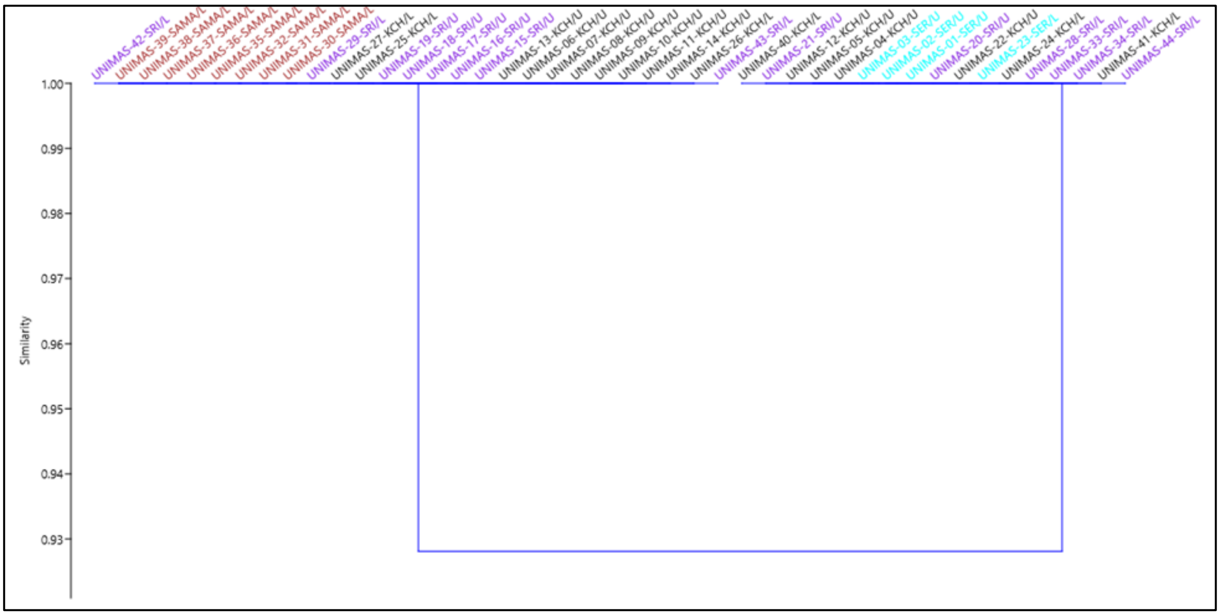

Figure 1. Dendrogram made up using Jaccard's coefficient of 44 rice accessions of lowland and upland rice from different divisions of the North-Western Region of Sarawak. *Note.* Purple: Sri Aman, Maroon: Kota Samarahan, Black: Kuching, Light Blue: Serian. Accession number followed by "/L" indicates lowland rice accession, "/U" indicates upland rice accession.

Quantitative Traits.

A total of 15 quantitative morphological traits of the 44 rice accessions are furnished in Table 3 and Table 4.

Plant height at five leaves stage or seedling height (SH) of lowland rice accessions (Table 3) ranged from 38.8 cm (UNIMAS-33) to 54.5 cm (UNIMAS-29). While among upland rice accessions, the SH ranged from 41.1 cm (UNIMAS-16) to 54.5 cm (UNIMAS-08) (Table 4). There was no significant difference in SH between lowland and upland rice accessions (Table 5).

At the mature stage, the plant height (PH) of lowland rice accessions (Table 3) ranged from 153.4 cm (UNIMAS-26) to 225.3 cm (UNIMAS-34). For upland rice accessions, PH ranged from 90.9 cm (UNIMAS-09) to 201.2 cm (UNIMAS-07) (Table 4). In average, the lowland rice accessions were significantly taller than those upland rice accessions (Table 5).

Culm length (CL) for lowland rice accessions (Table 3) was ranging from 81.5 cm (UNIMAS-26) to 143.4 cm (UNIMAS-34). For upland rice accessions, the CL ranged from 40.7 cm (UNIMAS-02) to 115.7 cm (UNIMAS-22) (Table 4). The CL of lowland rice accessions was statistically longer than those of upland rice accessions (Table 5).

Culm diameter (CD) for lowland rice accessions (Table 3) ranged from 3.0 cm (UNIMAS-27, UNIMAS-37, UNIMAS-39, and UNIMAS-43) to 3.6 cm (UNIMAS-41). Among upland rice accessions, the mean of CD was 3.21 cm, ranging from 2.7 cm (UNIMAS-17) to 4.1 cm (UNIMAS-19) (Table 4). No significant difference was observed for CD between lowland and upland rice accessions (Table 5).

The leaf length (LL) observed among the lowland rice accessions ranged from 51.0 cm (UNIMAS-32) to 80.50 cm (UNIMAS-35) (Table 3), while 42.3 cm (UNIMAS-02) to 72.0 cm (UNIMAS-19) for upland rice accessions (Table 4). The LL was similar between the lowland and upland rice accessions (Table 5).

The leaf width (LW) for lowland rice accessions ranged from 1.1 cm (UNIMAS-25 and UNIMAS-44) to 2.2 cm (UNIMAS-31) (Table 3). With an average LW of 1.64 cm, lowland rice accessions had narrower LW as compared to those upland rice accessions (Table 5). The upland rice accessions had LW ranging from 1.4 cm (UNIMAS-04) to 2.1 cm (UNIMAS-03), with a mean of 1.79 cm (Table 4).

The number of panicles (NP) among the lowland rice accessions ranged from one (UNIMAS-25, UNIMAS-26, UNIMAS-28 and UNIMAS-41) to ten panicles per plant (Table 3), while NP among the upland accessions ranged from one (UNIMAS-20) to seven (UNIMAS-04 and UNIMAS-06) panicles per plant (Table 4). There was no significant difference in NP between the lowland and upland rice accessions (Table 5).

The mean length of panicle (LP) of lowland rice accessions (Table 3) was 29.23 cm, ranged from 24.5 cm (UNIMAS-25) to 35.6 cm (UNIMAS-23), similar to the LP of upland rice accessions averaged at 28.82 cm, ranging from 23.9 cm (UNIMAS-20) to 39.8 cm (UNIMAS-14) (Table 4 & 5).

The number of filled grains (NFG) per accession in lowland rice accessions, ranged from 84 grains (UNIMAS-42) to 1091 grains (UNIMAS-32) (Table 3). At an average of 443 grains per accession, the NFG of lowland rice accessions was similar to the NFG of upland rice accessions (Table 5), which ranged from 63 (UNIMAS-05) to 990 (UNIMAS-15) grains (Table 4).

The seed length (SL) ranged from 0.7 cm to 1.1 cm and 0.7 cm to 1.0 cm among lowland (Table 3) and upland rice accessions (Table 4 respectively. Seed width (SW) among the lowland rice accessions ranged from 0.2 cm to 0.4 cm (Table 3) and 0.2 cm to 0.3 cm for upland rice accessions (Table 4). The SL and SW did not show a significant difference between the lowland and upland rice accessions (Table 5).

The grain length (GL) among the lowland rice accessions had an average of 0.6 cm, ranging from 0.5 cm to 0.8 cm (Table 3). Among the upland rice accessions, the GL ranged from 0.6 cm to 0.9 cm (Table 4). For grain width (GW), the lowland rice accessions had an average of 0.19 cm, ranging from 0.2 cm to 0.3 cm (Table 3). The GW of upland rice accessions ranged from 0.15 cm to 0.2 cm (Table 4). The lowland rice accessions had shorter GL but wider GW than those of upland rice accessions (Table 5).

Table 3. The 13 quantitative traits and two development traits observed on 22 lowland rice accessions

Acc.	SH (cm)	PH (cm)	LL (cm)	LW (cm)	CL (cm)	CD (cm)	NP	LP (cm)	NFG	SL (cm)	SW (cm)	GL (cm)	GW (cm)	HD (days)	FD (days)
UNIMAS-23	51.4	168.2	53.2	1.5	113.5	3.5	3	35.6	320	1.0	0.3	0.5	0.2	125	154
UNIMAS-24	44.6	172.3	57.5	1.3	116.6	3.5	2	25.2	300	0.9	0.2	0.7	0.2	134	158
UNIMAS-25	40.3	172.6	62.8	1.1	108.3	3.2	1	24.5	250	0.7	0.3	0.6	0.2	134	158
UNIMAS-26	47.0	153.4	71.4	1.2	81.5	3.5	1	26.4	200	0.8	0.3	0.6	0.2	134	158
UNIMAS-27	46.8	174.0	70.9	1.6	101.5	3.0	2	30.1	159	0.8	0.3	0.5	0.2	119	145
UNIMAS-28	44.3	199.2	68.5	2.1	130.9	3.1	1	32.7	120	0.9	0.2	0.6	0.2	114	147
UNIMAS-29	54.5	187.5	74.8	1.9	114.6	3.4	6	28.3	660	1.0	0.4	0.6	0.2	130	159
UNIMAS-30	50.1	165.1	75.2	2.1	89.4	3.2	5	29.9	391	1.0	0.3	0.7	0.2	119	143
UNIMAS-31	48.9	173.6	54.1	2.2	121.6	3.4	8	24.6	690	1.1	0.2	0.7	0.2	112	140
UNIMAS-32	45.7	174.4	51.0	1.8	120.5	3.2	10	27.5	1091	1.0	0.2	0.7	0.2	113	138
UNIMAS-33	38.8	210.0	78.1	1.7	132.8	3.2	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
UNIMAS-34	42.4	225.3	80.3	1.6	143.4	3.3	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
UNIMAS-35	47.2	176.0	80.5	1.8	94.50	3.1	2	32.6	118	1.0	0.3	0.7	0.2	103	138
UNIMAS-36	40.8	189.4	71.4	1.7	118.0	3.2	2	34.5	274	1.0	0.3	0.8	0.2	89	117
UNIMAS-37	46.5	180.1	59.3	1.5	119.2	3.0	5	31.4	1055	0.8	0.3	0.6	0.3	86	115
UNIMAS-38	43.3	175.2	60.7	2.1	116.7	3.2	3	30.3	493	0.8	0.3	0.6	0.3	83	116
UNIMAS-39	39.5	170.8	65.8	1.9	103.2	3.0	2	28.2	696	0.9	0.3	0.6	0.2	89	118
UNIMAS-40	40.2	164.3	55.5	1.5	111.0	3.4	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
UNIMAS-41	43.4	159.5	57.0	1.7	105.2	3.6	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
UNIMAS-42	46.0	170.1	72.1	1.3	99.40	3.1	2	25.5	84	0.8	0.2	0.6	0.2	120	151
UNIMAS-43	48.2	173.0	70.7	1.3	106.1	3.0	7	29.6	630	0.9	0.2	0.6	0.2	111	138
UNIMAS-44	49.8	179.0	69.4	1.1	107.5	3.3	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Note. Acc. indicates accession, N/A indicates data not available. SH: Seedling Height in centimetre, PH: Plant Height in centimetre, LL: Leaf Length in centimetre, LW: Leaf Width in centimetre, CL: Culm Length in centimetre, CD: Culm Diameter in centimetre, HD: Heading Days, FD: Flowering Days, NP: Number of Panicles, LP: Length of Panicle in Centimetre, NFG: Number of Filled Grains, SL: Seed Length, SW: Seed Width, GL: Grain Length, GW: Grain Width

Table 4. The 13 quantitative traits and two development traits observed on 22 upland rice accessions

Acc.	SH (cm)	PH (cm)	LL (cm)	LW (cm)	CL (cm)	CD (cm)	NP	LP (cm)	NFG	SL (cm)	SW (cm)	GL (cm)	GW (cm)	HD (days)	FD (days)
UNIMAS-01	46.3	127.3	54.1	1.8	65.7	3.2	5	33.5	276	1.0	0.2	0.7	0.2	124	151
UNIMAS-02	50.1	154.7	42.3	1.9	109.8	3.3	4	30.3	477	0.9	0.2	0.7	0.2	126	153
UNIMAS-03	47.1	139.4	67.8	2.1	88.9	3.1	5	24.5	407	0.8	0.2	0.6	0.2	112	140
UNIMAS-04	45.1	171.0	69.1	1.4	95.2	3.0	7	25.7	520	1.0	0.2	0.7	0.2	106	128
UNIMAS-05	44.9	172.1	70.1	1.8	90.1	2.9	3	26.7	63	1.0	0.2	0.7	0.2	103	132
UNIMAS-06	43.2	169.1	65.1	1.9	99.1	2.8	7	25.8	788	0.9	0.2	0.7	0.2	107	141

Continue ***Table 4:***

Acc.	SH (cm)	PH (cm)	LL (cm)	LW (cm)	CL (cm)	CD (cm)	NP	LP (cm)	NFG	SL (cm)	SW (cm)	GL (cm)	GW (cm)	HD (days)	FD (days)
UNIMAS-07	44.9	201.2	69.1	2.0	89.1	2.9	5	29.8	785	0.8	0.3	0.6	0.2	112	145
UNIMAS-08	54.5	185.6	58.2	1.8	100.7	3.3	6	27.9	627	0.9	0.2	0.8	0.2	112	142
UNIMAS-09	46.1	90.9	56.7	1.9	88.9	3.2	3	33.3	518	0.7	0.2	0.6	0.2	114	143
UNIMAS-10	49.1	149.9	57.4	1.7	85	3.4	4	32.1	413	0.9	0.2	0.8	0.2	102	127
UNIMAS-11	47.2	159.4	58.1	1.7	92.1	3.4	5	34.6	673	0.8	0.2	0.7	0.2	103	128
UNIMAS-12	48.1	159.9	58.7	1.5	87.1	3.1	2	24.7	158	0.8	0.2	0.6	0.2	126	146
UNIMAS-13	46.1	159.1	60.5	1.8	99.1	3.2	3	30.2	620	0.9	0.2	0.6	0.2	104	130
UNIMAS-14	49.1	163.5	63.4	1.8	102.1	3.3	3	39.8	710	0.8	0.2	0.6	0.2	99	129
UNIMAS-15	43.1	169.3	65.9	1.7	95.0	3.2	3	28.8	990	0.9	0.2	0.7	0.15	104	127
UNIMAS-16	41.1	167.3	70.0	1.9	80.8	2.9	3	26.3	687	0.9	0.2	0.7	0.2	101	131
UNIMAS-17	44.6	147.8	61.0	1.8	76.4	2.7	3	27.9	865	1.0	0.2	0.6	0.2	107	137
UNIMAS-18	46.1	139.9	70.2	1.9	40.7	3.1	5	25.4	723	0.9	0.2	0.9	0.2	94	128
UNIMAS-19	45.3	120.9	72.0	1.7	64.5	4.1	2	29.9	466	0.9	0.2	0.7	0.2	107	132
UNIMAS-20	45.7	196.7	65.3	1.7	91.0	2.9	1	23.9	120	0.9	0.3	0.7	0.2	103	140
UNIMAS-21	49.2	138.5	60.5	1.7	56.9	3.7	3	24.2	256	0.8	0.3	0.6	0.2	111	147
UNIMAS-22	49.4	175.2	64.0	1.8	115.7	3.8	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Note. Acc. indicates accession, N/A indicates data not available. SH: Seedling Height in centimetre, PH: Plant Height in centimetre, LL: Leaf Length in centimetre, LW: Leaf Width in centimetre, CL: Culm Length in centimetre, CD: Culm Diameter in centimetre, HD: Heading Days, FD: Flowering Days, NP: Number of Panicles, LP: Length of Panicle in Centimetre, NFG: Number of Filled Grains, SL: Seed Length, SW: Seed Width, GL: Grain Length, GW: Grain Width

Table 5. Comparison of 13 quantitative morphological traits between lowland and upland rice accessions. The values indicate the mean ± standard error

Traits	Lowland	Upland
SH (cm)	45.44 ± 0.885	46.65 ± 0.614
*PH (cm)	177.86 ± 3.480	150.35 ± 6.160
LL (cm)	66.37 ± 1.950	65.61 ± 1.958
*LW (cm)	1.64 ± 0.071	1.79 ± 0.032
*CL (cm)	111.61 ± 3.046	87.00 ± 3.725
CD (cm)	3.25 ± 0.039	3.21 ± 0.072
NP	3.71 ±0.652	3.81± 0.321
LP (cm)	29.2294 ± 0.82657	28.8238 ± 0.89602
NFG	443.00 ±76.376	530.57 ±55.373
SL (cm)	0.90 ± 0.026	0.87 ± 0.017
SW (cm)	0.26 ± 0.010	0.21 ± 0.007
*GL (cm)	0.62 ± 0.019	0.72 ± 0.004
*GW (cm)	0.22 ± 0.005	0.19 ± 0.002

Note. Asterisk (*) indicates significant difference at $p<0.05$ (t-test). SH: Seedling Height, PH: Plant Height, LL: Leaf Length, LW: Leaf Width, CL: Culm Length, CD: Culm Diameter, NP: Number of Panicles, LP: Length of Panicles, NFG: Number of Filled Grains, SL: Seed Length, SW: Seed Width, GL: Grain Length, GW: Grain Width

For the developmental traits, the heading days (HD) of the lowland rice accessions ranged from 83 (UNIMAS-38) to 134 days (UNIMAS-24, UNIMAS-25 and UNIMAS-26) (Table 3), while the HD of upland rice accessions ranged from 94 days (UNIMAS-18) to 126 days (UNIMAS-02 and UNIMAS-12) (Table 4). The flowering days

(FD) of lowland rice accessions took around 115 days (UNIMAS-37) to 159 days (UNIMAS-29) (Table 3) and upland rice accessions recorded 127 days (UNIMAS-10 and UNIMAS-15) to 153 days (UNIMAS-02) of FD (Table 4).

DISCUSSION

Qualitative Traits as Morphological Marker

All qualitative traits observed in this study showed variations. Qualitative traits are considered morphological markers for the identification of rice landraces (Sinha & Mishra, 2013).

In the present study, it was observed that the leaf blade of lowland and upland rice accessions was grouped into three different classes of blade colour (BC) (Supplementary Figure 1). This trait is not reliable as a marker due to its dependence on environmental conditions. For example, the degree of the greenness observed on the leaf could be influenced by fertilizer applications, i.e. the nitrogen content of the leaf (Singh *et al*., 2002; Yang *et al*., 2015). Based on Leaf Colour Chart, pale green BC indicates nitrogen deficiency. Green BC indicates an elevated dose of nitrogenous fertilization. High nitrogenous content results in dark green BC (Bhupenchandra *et al*., 2021). The BC of this study may suggest there are variations in soil nitrogenous content even though same soil mixture was used and equal amount of fertilizers was applied. Another possibility to allow such colour variation would be genetic factor. According to Li *et al.* (2002), the colour of leaves is determined by the presence and concentration of pigments such as chlorophyll (green), carotenoids (yellow and orange), and anthocyanins (red and purple). The rice accessions of this study may have different concentrations of the different pigments, which results in colour variations.

Ligule is present in all the rice accessions in this study (Supplementary Figure 2). The morphology of ligule is important in the identification of grass species (de la Fuente & Ortunez, 2001; Rzanny *et al*., 2022). However, this trait may be insufficient for the identification of varieties of the same species. In this study, there were two ligule shapes (LS) observed for lowland rice accessions and only one for upland rice accessions. Based on the 44 rice accessions, LS may serve as one of the morphological markers to differentiate rice accessions, but not possible to differentiate between lowland and upland rice. The ligule colour may also serve as a morphological marker. There was one upland rice accession, UNIMAS-07 (Supplementary Figure 2), having purple ligule and auricle. The environmental dependency of this trait is unknown.

Seed shape (SS) is useful in identifying rice hybrids and is also valuable in the seed certification process to control seed standards (Kalaichelvan, 2009; Misra *et al*., 2023). Among the rice accessions in this study, they can be differentiated based on three SS: oblong, elliptic and linear (Supplementary Figure 5 & 6). Based on SS, this study speculates there is a presence of the sub-species tropical *japonica* (*javanica*) and *indica* among the 44 accessions. Rice accessions that have oblong or elliptic SS may be *javanica* rice. Those rice accessions with linear SS should be *indica* rice. This is based on the description available on the website of International Rice Research Institute (http://www.knowledgebank.irri.org/ericeproduction/0.5_Rice_races.htm).

Grain colour (GC) is a heritable character and has been used to categorise rice varieties (Maeda *et al*., 2014; Zhao *et al*., 2022). In the present study, the GC of the rice accessions were mostly milky white, followed by reddish-brown, black, dark brown and light brown. Pigmented rice may contain phenolic compounds and anthocyanin. It has been consumed as functional rice, as anthocyanin has been recognized as compound with health benefits due to its antioxidant activity, anticancer, hypoglycemia and its anti-inflammatory effects (Maulani *et al*., 2018). GC is another morphological marker that is environmentally dependent. For example, grain discolouration due to disease may affect colour interpretation (Baite *et al*., 2020).

Cluster analysis based on nine qualitative traits has grouped the 44 rice accessions into two big clusters. Cluster I had a higher number of rice accessions compared to Cluster II. Cluster analysis revealed that there was no clustering according to seed origin (division), nor according to lowland or upland rice. The clustering was mainly based on secondary branching (SB) of the panicle. The rice accessions in Cluster I had light and heavy SB, which is of interest for yield breeding (refer to the discussion in the next section). The nine qualitative traits may not be sufficient to depict the rice accessions of one cluster are more genetically related nor genetically diverse from the accessions in the other clusters (Tejaswini *et al*., 2016).

According to Yeo *et al*. (2018), the registrations of a variety based on the name given by the farmers are unreliable. There is a possibility for a variety with a similar name, having different morphological characteristics. To support that, upland accessions UNIMAS-06 and UNIMAS-07 were clustered into a different group from UNIMAS-22 despite having the same name (Padi Merjat). Cultural practice by the local farmers where the rice seeds were inherited, transferred or exchanged between farmers might attribute to the diversity.

Direct and Indirect Yield Traits

According to IRRI (2002), plant height (PH) is divided into short (< 110 cm), medium (110 cm-130 cm) and tall (> 130 cm). Most of the rice accessions (41 accessions) in this study are considered tall. Only upland rice accession UNIMAS-09 is short (91 cm). Another two upland rice accessions, namely UNIMAS-01 (127.3 cm) and UNIMAS-19 (120.9 cm), are medium in height. In average, the lowland rice accessions of this study were taller than upland rice accessions (Table 5). Based on the plant height dynamic model of Wu *et al*. (2022), the lowland rice accessions in this study may have a higher risk of lodging compared to upland rice accession. Moreover, the culm lengths of lowland accessions were statistically longer than upland accessions in the present study. Lodging will reduce yield (Sunian *et al*., 2017).

The leaf length (LL) is known to vary between rice genotypes (Mehla & Kumar, 2008). All rice accessions in this study have long leaves based on IRRI (2002) except for upland rice accession UNIMAS-02, which has medium LL. Long leaves may not be preferable as compared to short leaves which will be more erect. Short leaves are uniformly distributed throughout the canopy, therefore mutual shading is reduced, and light is used more efficiently, thus contributing to yield (Tillier *et al*., 2023). Based on leaf width (LW), the rice accessions in this study are considered as having medium LW, except UNIMAS-28, UNIMAS-30, UNIMAS-31, UNIMAS-38 and UNIMAS-03 which have broad LW. Broad LW may not be preferable. A previous study suggested that narrower leaves are more beneficial under hot, dry and high-light habitats due to the ability to increase leaf heat exchange, avoid leaf damage and maintain leaf water content (Kang *et al*., 2021).

The rice accessions in this study had flowering time ranging from 115 to 159 days. According to the agronomy guide of IRRI (2015), the rice accessions in this study are most likely to have long crop duration, where from planting to harvest can take up to 160 days or longer. For lowland rice which has a long crop duration, it is recommended to be planted in irrigated or flood-prone fields (IRRI, 2015). The lowland rice accessions of this study were collected from farmers planting in rain-fed field. Their production may be improved if planted in irrigated or flood-prone field.

There are five lowland rice accessions and one upland rice accession of this study that did not flower during the observation period. Many factors affect the flowering phase of rice. One of it is being photoperiod. Some Sarawak rice landraces, such as Biris and Bali are known to be photoperiod sensitive (Teo n.d; Saidon *et al*., 2017). This may be true for these six rice accessions in this study. These six rice accessions were germinated on the 30 November 2018. Seven other lowland rice accessions and two upland rice accessions which were germinated on the same date, however, manage to produce inflorescences. In future characterisation, all accessions should be germinated and transplanted at the same time.

The number of panicles (NP) observed in this study, at most, was up to 10 panicles per plant. The NP with filled grain is a key indicator of rice yield (Efisue *et al*., 2014). To support this, UNIMAS-32 and UNIMAS-06 of lowland and upland accessions, respectively, had higher NP, produced higher number of filled grains (NFG) (observation without statistical evidence). These results suggest that UNIMAS-32 and UNIMAS-06 can be considered for Sarawak rice breeding program to increase rice production.

Beside NP, panicle type (PT) and secondary branching (SB) were also observed (Supplementary Figure 3 & 4). PT of rice is referring to the mode of branching, the angle of the primary branches and the spikelet density (IRRI, 2002). Among the rice accessions in this study, three PT were observed, i.e. compact panicles, intermediate-type of panicles and open panicles (Supplementary Figure 3). Only three rice accessions had compact PT. Breeders usually selectively breed for compact PT to increase yield (Kalaichelvan, 2009). For SB, it is mainly regulated by the number of primary and secondary branches, which directly influences the total grain number (Agata *et al*., 2020). The stronger the branching pattern, the higher the yield. In this study, it is observed that the NFG was lower for those rice accessions, which have light SB or absent (observation without statistical evidence).

Among the rice accessions in this study, only lowland rice accession UNIMAS-37 and upland rice accession UNIMAS-15 were observed to have compact PT with heavy secondary branching. Unfortunately, these two accessions have low NP. They also have higher lodging risk (Wu *et al*., 2022) as their height can reach up to 180 cm and 169 cm, respectively. Lowland rice accession UNIMAS-32 and upland rice accession UNIMAS-06 have high NP but have intermediate PT and light SB. Using these accessions for breeding may require multi-parent crossing to stack the desired NP, PT and SB characters.

Grain size and shape are among the quality criteria being considered in developing rice varieties for commercial production (Custodio *et al*., 2019). Statistically, lowland rice accessions had shorter grain length and wider grain width compared to upland rice accessions (Table 5). However, according to the classification of ChePa *et al*. (2016) on Malaysian rice, all the observed accessions were having long to extra-long grains, ranging from 0.6-0.9 cm, except UNIMAS-23 (0.5 cm). Grains width (GW) observed in this study showed a range of 0.15 cm to 0.3 cm.

Based on grain size and seed shape as pointed out above, this study suggests that the rice accessions of this study may consists of *indica* and *javanica* rice. The grain length-width ratio for *indica* rice is usually above 2.2. For *japonica* rice, it falls below 2.01 (Rahman *et al*., 2020). Most rice accessions in this student have length-width ratio of *indica* rice. There are two accessions, UNIMAS-37 and UNIMAS-38, which has a length-width ratio of *japonica* rice (approximately 2.0), further supporting the speculation based on seed shape.

There were variations in terms of grain shape recorded in this study. The Malaysian consumers mostly preferred rice having long shape (Ahmad Hanis *et al*., 2012). The rice accessions in this study, which has long shape characteristics, can be considered for Sarawak rice breeding program to achieve rice grain quality that meets customer preferences. Breeding programs need to engage with farmers through participatory approaches to better understand their preferences. Collaborative efforts between farmers, researchers, extension services, and consumers, help to ensure that newly developed rice varieties are aligned with the local needs and preferences.

CONCLUSION

In conclusion, a good variety of rice should be a well-balanced combination of high yield, quality and adaptability to different or targeted environments. The development and adoption of such varieties contribute to food security, economic viability for farmers, and the overall sustainability of rice production systems. Continuous collaboration between researchers, farmers, and other stakeholders is crucial for the successful development and dissemination of improved rice varieties.

The 44 rice accessions of lowland and upland rice collected from the North-Western region of Sarawak were successfully characterised based on their morphological traits. The morphological traits showed variations which may be useful for future rice breeding programs. Morphological markers are very important and all breeders are continuously looking for these markers that will enable them to characterise the plant materials for diversity study and to perform marker assisted selection. The current rice accessions showed a wide range of variability for the characters evaluated, which may be attributed to the diverse genetic background of the rice accessions. These variations could be the genetic resources for future breeding programs.

ACKNOWLEDGEMENTS

This study was funded by Ministry of Higher Education, Malaysia under Fundamental Research Grant Scheme (FRGS/1/2017/STG03/UNIMAS/03/2). The authors would like to acknowledge Universiti Malaysia Sarawak, for the facilities provided.

REFERENCES

Agata, A., Ando, K., Ota, S., Kojima, M., Takebayashi, Y., Takehara, S., Doi, K., Ueguchi-Tanaka, M., Suzuki, T., Sakakibara, H., Matsuoka, M., Ashikari, M., Inukai, Y., Kitano, H. & Hobo, T. (2020). Diverse panicle architecture results from various combinations of Prl5/GA20ox4 and Pbl6/APO1 alleles. Communications Biology, 3(1): 302. DOI:10.1038/s42003-020-1036-8

Ahmad Hanis, I.A.H., Jinap, S., Mad Nasir, S., Alias, R. & Muhammad Shahrim, A.K. (2012). Consumers' demand and willingness to pay for rice attributes in Malaysia. *International Food Research Journal*, 19(1): 363-369.

Baite, M.S., Raghu, S., Prabhukarthikeyan, S.R., Keerthana, U., Jambhulkar, N.N. & Rath, P.C. (2020). Disease incidence and yield loss in rice due to grain discolouration. Journal of Plant Diseases and Protection, 127(1): 9-13. DOI: 10.1007/s41348-019-00268-y

Bhattarai, G., Shi, A., Kandel, D.R., Solis-Gracia, N., da Silva, J.A. & Avila, C.A. (2021). Genome-wide simple sequence repeats (SSR) markers discovered from whole-genome sequence comparisons of multiple spinach accessions. *Scientific Report,* 11(1): 1-16.

Bhupenchandra, I., Athokpam, H.S., Singh, N.B., Soibam, H., Chongtham, S.K., Singh, L.K., Sinyorita, S., Devi, E.L., Bhagowati, S., Bora, S. S., Kumar, A., Devi, C.H.P. & Olivia, L.C. (2021). Leaf Color Chart (LCC): An instant tool for assessing nitrogen content in plant: A review. *The Pharma Innovation Journal*, 10(4): 1100-110.

Cheok, Y.H., Yeo, F.K.S. & Chong, Y.L. (2019). Oviposition behavior of *Scirpophaga incertulas*, the yellow stemborer (Lepidoptera: Crambidae) in a non-choice study. *Pertanika Journal of Tropical Agricultural Science*, 42(3): 1167-1172.

ChePa, N., Yusoff, N. & Ahmad, N. (2016). Determinants for grading Malaysian rice. American Institute of Physics Conference Proceedings, 1761(1): 020035. DOI: 10.1063/1.4 960875

Custodio, M.C., Cuevas, R.P., Ynion, J., Laborte, A. G., Velasco, M.L. & Demont, M. (2019). Rice quality: How is it defined by consumers, industry, food scientists, and geneticists?. Trends in Food Science & Technology, 92: 122-137. DOI: 10.1016/j.tifs.2019.07.039

de la Fuente, V. & Ortunez, E. (2001). Festuca Sect. Eskia (Poaceae) in the Iberian Peninsula. Folia Geobotanica, 36(4): 385-421. DOI: 10.1007/BF0 2899988

Department of Agriculture Sarawak. (2020). *Agriculture Research Centre: Programmes*. Retrieved November 20, 2021, from https://doa.sarawak.gov.my/page-0-0-415-AGRICULTURE-RESEARCH-CENTRE-PROGRAMMES.html

Doyle, J.J. & Doyle, D.J.L. (1987). A rapid DNA isolation procedure for small quantities of fresh leaf tissue. *Phytochemistry*, 19: 1115.

Efisue, A.A., Bianca, C.U. & Orluchukwu, J.A. (2014). Effects of yield components on yield potential of some lowland rice (*Oryza sativa* L.) in coastal region of Southern Nigeria. Journal of Plant Breeding and Crop Science, 6(9): 119-127. DOI: 10.5897/JPBCS2014.0449

Food and Agriculture Organization of the United Nations. (2019). *GIEWS - Global information and early warning system.* Retrieved October 11, 2021, from https://www.fao.org/giewscountrybri ef/country.jsp?code=MYS

Hamsein, N.N., Yeo, F.K.S., Sallehuddin, R., Mohamad, N.K., Kueh, F.T.F., Hussin, N.A. & Wan Ismail, W.N. (2020). Oviposition behaviour of *Scirpophaga incertulas* (Walker) (Lepidoptera: Pyralidae) on Sarawak rice landraces. Taiwania, 65(1): 95-99. DOI: 10.6165/tai.2020.65.95

International Board for Plant Genetic Resources & International Rice Research Institute Rice Advisory Committee. (1980). *Descriptors for rice, Oryza sativa L*. International Rice Research Institute.

International Rice Research Institute. (2002). *Standard evaluation system for rice (SES)*. Retrieved July 23, 2022, from http://www.knowledgebank.irri.org/images/docs/ rice-standard-evaluation-system.pdf

International Rice Research Institute. (2015). *Steps to successful rice production*. Retrieved July 29, 2022, from http://knowledgebank. irri.org/images /docs/12-Steps-Required-for-Successful-Rice-Production.pdf

International Rice Research Institute (n.d.). *What is the difference between aerobic rice and upland rice?* Retrieved December 10, 2022, from http://www.knowledgebank.irri.org/step-by-step-production/growth/water-management/faqs-abou t-water-management/item/what-is-the-difference-between-aerobic-rice-and-upland-rice

Kalaichelvan, C. (2009). *Studies on identification of rice (Oryza sativa L.) cultivars using morphological and molecular markers* (Master thesis), Acarya Nayukulu Gogineni Ranga Agricultural University.

Kang, X., Li, Y., Zhou, J., Zhang, S., Li., C., Wang, J., Liu, W. & Qi, W. (2021). Response of leaf traits of eastern Qinghai-Tibetan broad-leaved woody plants to climatic factors. Frontiers in Plant Science, 12: 679726. DOI: 10.3389/fpls.2021.679726

Khazanah Research Institute. (2019). *The status of the paddy and rice industry in Malaysia*. Kuala Lumpur, Khazanah Research Rice Institute.

Lai, K.Y., Hussin, N.A., Mohammad, N.K., Hui, Y.T., Lai, L.S. & Yeo, F.K.S. (2019). Qualitative resistance of Sarawak rice landraces against *Pyricularia oryzae*. Borneo Journal of Resource Science and Technology, 9(2): 115-118. DOI: 10.33736/bjrst.1721.2019

Li, W., Zhang, Y., Mazumder, M.A.R., Pan, R. & Akhter, D. (2022). Research progresses on leaf color mutants. *Crop Design*, 1: 100015.

Ling, A.X.R., Yeo, F.K.S., Hamsein, N.N., Ting, H.M., Sidi, M., Wan Ismail, W.N., Taji, A.S. & Cheok, Y.H. (2020). Screening for Sarawak paddy landraces with resistance to yellow rice stem borer, *Scripophaga incertulas* (Walker) (Lepidoptera: Crambidae). Pertanika Journal of Tropical Agricultural Science, 43(4): 491-501. DOI: 10.47836/pjtas.43.4.06

Maeda, H., Yamaguchi, T., Omoteno, M., Takarada, T., Fujita, K., Murata, K., Iyama, Y., Kojima, Y., Morikawa, M., Ozaki, H., Mukaino, N., Kidani,

Y. & Ebitani, T. (2014). Genetic dissection of black grain rice by the development of a near isogenic line. Breeding Science, 64(2): 134-141. DOI: 10.1270/jsbbs.64.134

Masni, Z. & Wasli, M.E. (2019). Yield performance and nutrient uptake of red rice variety (MRM 16) at different NPK fertilizer rates. International Journal of Agronomy, 2: 1-6. DOI: 10.1155/2019/5134358

Maulani, R.R., Sumardi, D. & Adi, P. (2018). Total flavonoids and anthocyanins content of pigmented rice. *Drug Invention Today*, 12(2): 369-373.

Mehla, B.S. & Kumar, S. (2008). Use of morphological traits as descriptors for identification of rice genotypes. *Agricultural Science Digest*, 28(2): 101-104.

Misra, M.K., Harries, A. & Dadlani, M. (2023). Role of seed certification in quality assurance. Seed Science and Technology, 1: 172-199. DOI: 10.1007/978-981-19-5888-5_12

Rahman, M., Castillo, C.C. & Murphy, C. (2020). Agricultural systems in Bangladesh: The first archaeobotanical results from early historic Wari-Bateshwar and early Medieval Vikrampura. Archaeological and Anthropological Sciences, 12(1): 37-54. DOI: 10.1007/s12520-019-00991-5

Rzanny, M., Wittich, H.C., Mäder, P., Deggelmann, A., Boho, D. & Wäldchen, J. (2022). Image-based automated recognition of 31 *Poaceae* species: The most relevant perspectives. Frontiers in Plant Science, 12: 804140. DOI: 10.3389/fpls.2021.804 140

Saidon, S.A., Hussain, Z.P.M.D., Ramli, A., Omar, O., Man, A., Ahmad, R. & Yusob, S.M. (2017). *Preliminary evaluation: New rice lines through improvement of selected Sarawak's traditional rice variety* [Poster Presentation]. Mardi Science Technology Exhibition.DOI: 10.13140/RG.2. 2.15795.53281

Singh, B., Singh, Y., Ladha, J.K., Bronson, K.F., Balasubramanian, V., Singh, J. & Khind, C.S. (2002). Chlorophyll meter–and leaf color chart–based nitrogen management for rice and wheat in Northwestern India. Agronomy Journal, 94(4): 821-829. DOI: 10.2134/agronj2002.8210

Sinha, A.K. & Mishra, P.K. (2013). Agro-morphological characterization and morphology based genetic diversity analysis of landraces of rice variety (*Oryza sativa* L.) of Bankura district of West Bengal. *International Journal of Current Research*, 5(10): 2764-2769.

Spada, A., Mantegazza, R., Biloni, M., Capoali, E. & Sala, F. (2004). Italian rice varieties: historical data, molecular markers, and pedigrees to reveal their genetic relationships. *Plant Breed*, 123: 105-111.

Sunian, E., Ramli, A., Omar, O., Misman, S.N., Mohamad Saad, M., Jack, A. & Hashim, S. (2017). Evaluation on yield, yield component and physico-chemicals of advanced rice lines. *Journal of Tropical Agriculture and Food Science*, 45(2): 131-143.

Tang, A.S.O., Yeo, F.K.S., Chin, S.F., Wee, B.S. & Ngu-Schwemlein, M. (2023). Antifungal properties and phytotoxicity of ZnO nanoparticles - a genotypic dependent effect. Archives of Phytopathology and Plant Protection, 1(1): 1-20. DOI: 10.1080/03235408.2023.2251433

Tejaswini, K.L.Y., Manukonda, S., Rao, P.V.R., Kumar, B.N.V.S.R.R., Mohamad, L.A. & Raju, K. (2016). Cluster analysis studies in rice (*Oryza sativa* L.) using wards minimum variance method. *Journal of Agricultural and Crop Research*, 4(9): 129-139.

Teo, G. K. (n.d.). *Rice biodiversity*. Retrieved January 14, 2022, from https://doa.sarawak.gov.my/page-0-0-158-Rice-Bioderversity.html

Tillier, L.C., Murchie, E.H. & Sparkes, D.L. (2023). Does canopy angle influence radiation use efficiency of sugar beet? Field Crops Research, 293: 108841. DOI: 10.1016/j.fcr.2023 108841

Wu, D.H., Chen, C.T. & Yang, M.D. (2022). Controlling the lodging risk of rice based on a plant height dynamic model. Botanical Studies, 63(1): 25. DOI: https://doi.org/10.1186 /s40529-022-00356-7

Yang, X., Li, G., Luo, W. & Chen, L. (2015). Quantifying the relationship between leaf nitrogen content and growth dynamics and yield of muskmelon grown in plastic greenhouse. American Society for Horticultural Science, 50(11): 1677-1687. DOI: 10.21273/ HORTSCI.5 0.11.1677

Yeo, F.K.S., Meekiong, K., Shabdin, Z., Mohamad, N.K., Hussin, N.A. & Chung, H.H. (2018). Diversity of rice in Kampung Lebor, Serian - A first insight. In Yeo, F.K.S., Chong, Y.L. & Khan, F.A.A. (eds.). *Glimpses of Bornean Biodiversity*.

Kuching, Malaysia, Universiti Malaysia Sarawak Publisher. pp. 155-167.

Yeo, F.K.S., Rafael, E., Ewe, Z.H., Ang, P.S., Hussin, N., Vu Thanh, T.A., Chung, H.H., Lai, L.S., Ting, H. M. & Bao, Y. (2024). New variants of AvrPiz-t identified in *Pyricularia oryzae* from Malaysia. Plant Stress, 11(2024): 1-11. DOI: 10.1016/j.stress.2023.100322

Zhao, D., Zhang, C., Li, Q. & Liu, Q. (2022). Genetic control of grain appearance quality in rice. Biotechnology Advances, 60: 108014. DOI: 10.1016/j.biotechadv.2022.108014

Zhu, Y.F., Qin, G.C., Yang, W., Wang, J.C. & Zhu, S.J. (2012). Fingerprinting and variety identification of rice (*Oryza sativa* L.) based on simple sequence repeat markers. *Plant Omics Journal*, 5(4): 421-426.