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Characterization of indigenous upland rice varieties for high yield potential and grain quality characters under rainfed conditions in Thailand

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ABSTRACT

Indigenous upland rice is a staple food for local people in the North and Northeast regions of Thailand. As a result, variations of grain yield and G*x*E interactions have been utilized for wider adaptability of upland rice varieties. A high yielding genotype that performs well under a good yielding environment as well as in poor environments is greatly needed. Our experiment, therefore, aimed to identify high potential indigenous upland rice varieties for grain yield and yield stability under rainfed conditions. Fifty upland rice genotypes were evaluated from 2013 to 2015, in which a randomized complete block design with three replications was laid out over the three years. Based on grain yield, eight indigenous upland rice varieties, including ULR026, ULR042, ULR075, ULR078, ULR080, ULR081, ULR089 and ULR105; demonstrated superior performance, high yield stability, and greater adaptability over the other varieties, including the Sew Mae Jan check variety. Additional qualities of the superior varieties included high amylose content (ULR081 and ULR075), high aroma (ULR078), and intermediate gelatinization temperature test (GT) (ULR078, ULR026, and ULR105). The participatory varietal selection (PVS) test for farmer(s) acceptance, and promotion of these varieties under rainfed conditions will be further studied.

1. Introduction

Rice is the main staple food in Southeast Asia, and more than 50% of people worldwide consume rice as a main dish. Rice production has thus played a critical role in both household and national food security (Totok et al., 2008). Up to 60% of Thailand's rice production is found in the rainfed areas of the Northeast region (Napasintuwong and Pray, 2014), which to date, has been dominated by improved, high yield cultivars, such as RD6 and KDML105. Current production is driven by increasing consumer demand and high prices (Rerkasem, 2015). However, insufficient water, salinity, low soil fertility, and various biotic stresses may limit the yields of improved rice cultivars. Moreover, the expansion of new, improved cultivars has replaced the usual landraces varieties, resulting in the reduction of genetic diversity; consequently, resulting in the loss of valuable genetic resources needed to improve rice yield and stability (Karladee et al., 2012).

Indigenous upland rice varieties have been derived from nature through human selection for tolerance to particular constraints, such as biotic and abiotic stress, which ultimately affect yield performance, cooking, eating qualities, and food security for household consumption of the local people, especially the ethnic groups living in those areas (Xiongsiyee et al., 2018). Due to low soil fertility, poor water supply, and yield constraints, this region is defined as a “low productivity” area, with an average rice yield of 0.9 t/ha (Karladee et al., 2012). Several researchers have identified numerous upland rice genotypes upon traits of interest; such as functional properties constituted by high anthocyanin (Sutharut and Sudarat, 2012), high γ-Aminobutyric acid (GABA) content (Karladee and Suriyonga, 2012), phenolic compounds (Vichapong et al., 2010), and ferulic acid content (Tian et al., 2004; Wanyo et al., 2014). The northeastern upland rice growing area has increased due to an increasing niche market demand, in which high quality rice is needed. Moreover, upland rice varieties are well-known for high water-use efficiency (Lui et al., 2019), deep root systems (Bernier et al., 2008), and tolerance to drought (Narenoot et al., 2017).

Khon Kaen province is the top sixth important province of Northeast Thailand. This province has 0.75 M ha of arable land. Among this, 0.32 M ha is belonging to the upland undulation area. Upland rice has been grown as a major crop as well as a rotation crop for both generating incomes and soil improvement. The potential yield evaluation of 250 indigenous upland rice germplasm from diverse origins throughout

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Thailand ranged from 700 to more than 3400 kg/ha (Jaruchai et al., 2018). These results suggested that some varieties were well adaptable. The distribution of rainfall in this area is unpredictable, so yield stability of varieties in a particular area should be determined.

Moreover, an evaluation of yield and cooking quality has lacked for these upland areas. Good eating and cooking quality are the most critical traits considered in the varietal selection of the niche market – which affect an increase in grain price. We, therefore, make the supposition that the identification of a variety with both high-yield potential and quality from indigenous upland rice germplasm will effectively establish a new adaptive variety for both general and specific usage. Our study, therefore, aimed to identify a high-potential indigenous upland rice variety with good eating and cooking quality, under rainfed conditions.

2. Materials and methods

2.1. Plant material and cultural practices

Forty-eight indigenous upland genotypes were selected following Jaruchai et al. (2018), based on superior grain yields under on-station upland experiments. The Sew Mae Jan and Sakon Nakhon varieties, released by the BRRD in Thailand in 1979 through 2002, were used as check varieties. The target region for this cultivar was the plateau uplands of North and Northeast, Thailand. All genotypes were collected by the Rice Germplasm Collection Project, Khon Kaen University, Khon Kaen, Thailand. The 48 indigenous upland genotypes and the two check varieties [Sakon Nakhon (ULR003) and Sew Mae Jan (ULR008)] were evaluated under three field environments in the Ban Had district of Khon Kaen (148110N 1218150E, 21 m above sea level), Thailand; from 2013 to 2015 (Table 1). Trials were conducted under rainfed upland conditions. The soil type was Andaqueptic Haploquol with a pH range of 6.0 to 6.5, and the experiments were conducted on June 26, 2013; July 1, 2014; and June 19, 2015. Plot size averaged 1.5 m × 1.5 m with spacing of 0.30 × 0.25 m (30 plants/plot). The seed materials were laid in RCBD with three replications. Topdressing of fertilizers were applied at the rate of 23.44 kg/ha N, P_2O_5, and K_2O; at 30 and 80 days after seeding (DAS). Pests were chemically controlled as required, and plants were thinned at 15 DAS, with a single 1 seedling/hill remaining, concurrent with weed control. Total yield and the yield components; such as tiller number, plant height, seeds per panicle, 1000-grain weight, and grain yield were measured from 4 middle plants of each plot in all environments.

Table 1
Code, accession number, sources (province and area of Thailand), selection history, and mean yield (kg/ha) of genotypes.

Entry	Accession no.	Selection history	Grain yield (kg/ha)		
			2013	2014	2015
1	ULR003 (ck.)	Release variety	2103.8	3051.5	1504.3
2	ULR004	Indigenous	2208.5	1885.4	1876.2
3	ULR008 (ck.)	Local variety	2430.2	2790.0	1614.2
4	ULR013	Indigenous	1801.9	1079.2	2007.6
5	ULR023	Indigenous	1623.4	1313.2	1425.1
6	ULR024	Indigenous	1664.7	2388.8	1557.2
7	ULR026	Indigenous	2230.3	**3893.3**	**3046.5**
8	ULR031	Indigenous	1871.5	1050.1	1323.4
9	ULR035	Indigenous	1623.0	984.4	2395.5
10	ULR038	Indigenous	2276.6	2059.3	1806.6
11	ULR041	Indigenous	2293.8	1968.7	1999.8
12	ULR042	Indigenous	**2806.2**	2574.1	2494.6
13	ULR043	Indigenous	2032.8	2376.0	2448.4
14	ULR057	Indigenous	2233.1	1840.6	1842.3
15	ULR058	Indigenous	1942.3	1158.6	1575.3
16	ULR061	Indigenous	1682.8	1549.3	2636.1
17	ULR075	Indigenous	2557.8	3126.4	2280.7
18	ULR077	Indigenous	2688.4	2597.3	1719.8
19	ULR078	Indigenous	2451.6	3284.6	2137.7
20	ULR080	Indigenous	2276.9	2683.3	**2706.2**
21	ULR081	Indigenous	**3009.1**	**3524.4**	2418.5
22	ULR085	Indigenous	1955.3	2579.8	1582.5
23	ULR089	Indigenous	2766.2	**3988.0**	2199.4
24	ULR090	Indigenous	1597.7	1641.1	1375.7
25	ULR091	Indigenous	1902.0	2104.8	1965.5
26	ULR104	Indigenous	1568.9	1322.5	2151.2
27	ULR105	Indigenous	2730.5	3054.9	2046.6
28	ULR107	Indigenous	2280.8	1951.1	1983.4
29	ULR109	Indigenous	1680.0	1669.8	2202.7
30	ULR134	Indigenous	1597.6	1656.4	1824.5
31	ULR135	Indigenous	1818.0	1295.5	1970.6
32	ULR159	Indigenous	2129.1	2629.8	1912.5
33	ULR187	Indigenous	1431.1	1544.1	1638.0
34	ULR191	Indigenous	2166.8	2420.4	1926.7
35	ULR192	Indigenous	2433.3	2220.2	2275.2
36	ULR205	Indigenous	2078.1	2093.5	1983.9
37	ULR209	Indigenous	2178.6	1389.2	**2865.0**
38	ULR223	Indigenous	1561.7	2294.9	1789.6
39	ULR233	Indigenous	1611.1	1384.1	922.3
40	ULR236	Indigenous	1999.3	1839.6	1555.2
41	ULR238	Indigenous	1909.7	1858.6	2419.0
42	ULR241	Indigenous	2125.7	1333.2	1276.6
43	ULR243	Indigenous	1541.8	1443.2	1994.1
44	ULR246	Indigenous	2334.6	2809.8	2195.7
45	ULR250	Indigenous	2305.5	1813.0	2031.7
46	ULR255	Indigenous	2017.5	1272.6	2177.7
47	ULR273	Indigenous	1929.5	1801.0	2213.7
48	ULR274	Indigenous	**3077.7**	2600.7	1534.6
49	ULR291	Indigenous	2033.0	2837.3	1671.0
50	ULR324	Indigenous	1767.1	1329.2	1583.0
	Mean		2086.7	2107.1	1961.7
Genotypes			**	**	**
$LSD_{.05}$			736.2	1023.9	915.8
CV (%)			21.8	30.0	28.8
Combine analysis					
Genotypes				ns	
Environment				**	
GxE				**	

Bold letters represent the top three grain yields in each year. ck = check variety, ns = non-significant at p ≤ 0.05, ** = significant at $p \leq 0.01$. LSD = lest significant different at 5%, CV = coefficient of variation. GxE = genotypes and environment interaction.

2.2. Quality evaluations

The rice grains of each variety from 2015 experimental year were used for gelatinization temperature test, amylose content and sensory test for aroma as mention below.

2.2.1. Gelatinization temperature test (GT)

The Alkali Digestion test (1.7% KOH) was used to determine GT (Chemutai et al., 2016). In brief, the disintegration of starch granules was detected by standing six polished grains of each variety in 10 ml of 1.7% (*w*/*v*) KOH solution for 23 h at 30°C. The starchy endosperm was rated visually based on a seven-point numerical spreading scale as a standard evaluation system for rice (IRRI, 2013). According to the scores, the GT of the rice grains were then classified into four groups: high (1–2), high-intermediate (3), intermediate (4–5), and low (6–7) (Chemutai et al., 2016).

2.2.2. Amylose content (AC)

In our sample test, 0.1 g of well-powdered milled rice was inserted into a 100 ml volumetric flask, and 1 ml of 95% ethanol and 9 ml of 1 N NaOH was added. Distilled water was added in order to create 100 ml of solution and then shaken with a magnetic stirrer for 10 min. Next, 5 ml was pipetted from the 100 ml solution into another 100 ml volumetric flask, where then 1 ml of 1 N acetic acid and 2 ml of iodine solution were added; again, creating a volume of 100 ml. The mixture was stirred and allowed to stand for 10 min, and the percentage of transmittance at 620 nm was determined via a spectrophotometer Jain et al. (2012). The amylose content of the sample was determined in reference to the standard curve and is expressed as a percentage.

2.2.3. Sensory test for aroma

The aromatic characteristics of the rice varieties were evaluated by the olfactory test prescribed by Das et al. (2018). The gain rice of each variety was powdered milled, and 0.1 ml quantities were inserted into a micro-tube with 5 ml of 1.7% KOH (*w*/*v*) at 65 °C for 20 min. The tubes were then opened and smelled directly by ten volunteers (3 male and 7 female trained staff in our project), who can be distinguished among aroma and non-aroma of rice. The volunteers, who scored the aromas as present (3), less present (2) and absent (1); utilizing the KDML105, RD6, and SPT1 as check varieties, respectively.

2.2.4. Quantification of ferulic acid content

The seeds of indigenous upland rice varieties, previously studied under field conditions in the upland rice-growing area of the Ban Had district, Khon Kaen province, Thailand in 2014 and 2015, were used for ferulic acid extraction using the method described by Siriamornpun et al. (2014). Briefly, the crude phenolic compounds present in the rice seeds were extracted with 80% aqueous methanol (1:10, *w*/*v*) at 25 °C, and shaken in an incubator (150 rpm/16 h). The mixtures were centrifuged (2500 rpm/20 m), forming supernatants. The residues were re-extracted under the same conditions, and supernatants from both extractions were combined. The solvent was removed under a vacuum at 40 °C, and the resulting concentrated slurries were purified through a 0.45 μm nylon filter and stored at −20 °C pending analysis of the phenolic compounds with HPLC analysis.

2.3. Data analysis

Statistical analyses were performed on grain yield, yield components, and quality traits to identify elite stable genotypes. An analysis of variance (ANOVA) was performed using R-program 2.10.0 (R Development Core Team, 2010) across the tested environments, in which the treating environment was assigned as a random effect, and the genotype was fixed. The mean comparison between genotypes was calculated by the least significant difference test (LSD) at 5% level ($P \leq 0.05$) of probability. The correlation coefficient among yield and yield components were calculated for all possible comparisons using Pearson correlation coefficient using R-program 2.10.0 (R Development Core Team, 2010). In the GGE bi-plot, the genotype and genotype *x* environment interactions were examined through dissection of the observed means (Gollob, 1968). The first two principal components (PC1 and PC2) were used to display a two-dimensional GGE biplot, according to Yan and Hunt (2002). All analyses were performed with the R-program 2.10.0 (R Development Core Team, 2010). The genotypes were cluster analysis to measure the hierarchical similarity among genotypes. A Euclidean distance matrix was established to

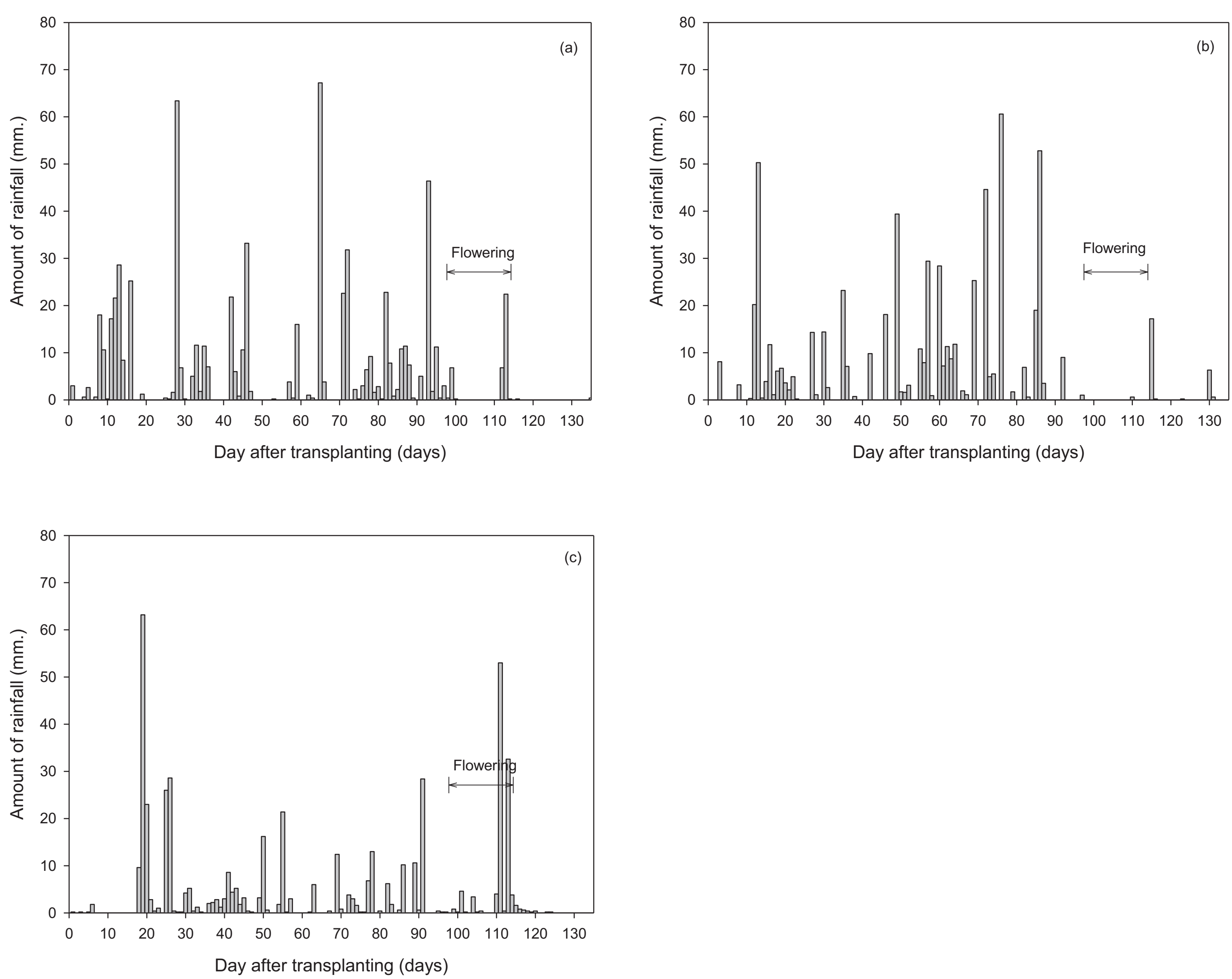

Fig. 1. Amount of rainfall through the growing periods of 2013 (a), 2014 (b), and 2015 (c). The arrows indicate the respective flowering period in each year.

Table 2
Correlation coefficient between traits of 48 Thai indigenous upland rice varieties over three years (2013–2015).

	Tiller	Plant height	Seed/panicle	1000-grain weight	Grain yield
Tiller	1.000				
Plant height	−0.480**	1.000			
Seed/panicle	−0.254	0.173	1.000		
1000-grain weight	−0.664**	0.263	−0.355*	1.000	
Grain yield	0.724**	−0.494**	0.027	−0.489**	1.000

* Significant at $p \leq 0.05$.
** Significant at p ≤ 0.01.

obtain a relative dendrogram. The entries were clustered using Ward's method (Flores et al., 1997).

3. Results

3.1. Yield and yield components performances of indigenous upland rice

The amount of rainfall and rain distribution in 2013, 2014, and 2015 played important roles in the yields of rice genotypes, which presented yields of 2087, 2107, and 1962 kg/ha, respectively (Table 1). The total rainfall amount throughout each growing season was 663, 640, and 466 mm, respectively (Fig. 1). Lower rainfall in the mid-growing period of 2015 affected crop growth when moisture was limited, which resulted in the experiment's lowest grain. Genotypes were significant in all parameters, both within and between years, indicating that traits were affected by GxE interaction, demonstrating the difference among genotypes within each particular year. Supplementary materials are available online for more information.

Traits related to grain yield, including tiller number, plant height, seed/panicle, and 1000- grain weight were measured. Based on over three year, grain yield had a high positive correlation with the tiller number ($r = 0.724^{**}$), in contrast to the negative correlations with plant height ($r = -0.494^{**}$) and 1000-grain weight ($r = -4.489^{**}$); and a non-correlation with seed per panicle ($r = 0.027$ ns) (Table 2). The correlation coefficient of agronomic traits and grain yield of 48 Thai indigenous upland rice varieties each year is also presented in Supplementary online material. The results showed that the correlation among traits of each year was a trend to similar, such as grain yield had a positive correlation with the tiller number in all year, in contrast to the negative correlations with 1000-grain weight in year 2013 and 2014 while non-correlation in year 2015. Among the traits, tiller number was highest correlated with other traits in all year test. Supplementary materials are available online for more information. The results indicate that parameters: high tiller number/plant, low plant height, and small seed size promote high grain yields of upland rice. The correlations between traits related to grain yield can be used as selection criteria for indigenous upland rice selection. Based on grain yield, eight of the 48 indigenous upland rice genotypes (ULR026, ULR042, ULR075, ULR078, ULR080, ULR081, ULR089, and ULR105) proved superior to the comparative genotypes, as well as the Sew Mae Jan (ULR008) upland rice check variety (Fig. 2).

Because the grain yield showed a high correlation with several yield components, the genotype groups (GG) were analyzed based on both yield and yield components. The results demonstrated that three GGs (GG1, GG2, and GG3) were clustered (Fig. 2), and consisted of 8, 14, and 28 upland rice genotypes, respectively (Fig. 2). The check varieties, Sew Mae Jan (ULR008) and Sakon Nakhon (ULR003), were clustered together with the GG3 genotype group.

The yearly grand mean of five traits in each Genotype Group (GG) are presented in Fig. 3. GG1; consisting of rice genotypes ULR026, ULR042, ULR075, ULR078, ULR080, ULR081, ULR089, and ULR105; showed consistently higher grain yield, tiller number, shorter plants, and lower seed weight than GG1 and GG2 (Fig. 3). The higher amount of rainfall in the year 2014 generated an elevated variation in grain yield among the three GGs; in which GG1 displayed the highest yield (Fig. 3a). In contrast, the effect of the lessor rainfall in 2015 caused GG1 to produce shorter plants, but a higher tiller number than the other groups (Fig. 3b, c). The results indicated that the higher yielding genotype group (GG1) performed well in high-yielding environments, and will adapt to low-yielding environments as well.

However, environmental means were not included within these genotypic classifications. Stability was evaluated through GGE bi-plot analysis, in order to examine both the genotype (G) and genotype *x* environment (*GxE*) interactions. In this analysis, the first two principal components (PCs) together accounting for 89.29% of the total GxE variation (Fig. 4). While years 2013 and 2014 presented higher grain yields and yield stability than in year 2015 (Fig. 4), all eight GG1 genotypes (ULR026, ULR042, ULR075, ULR078, ULR080, ULR081, ULR089, and

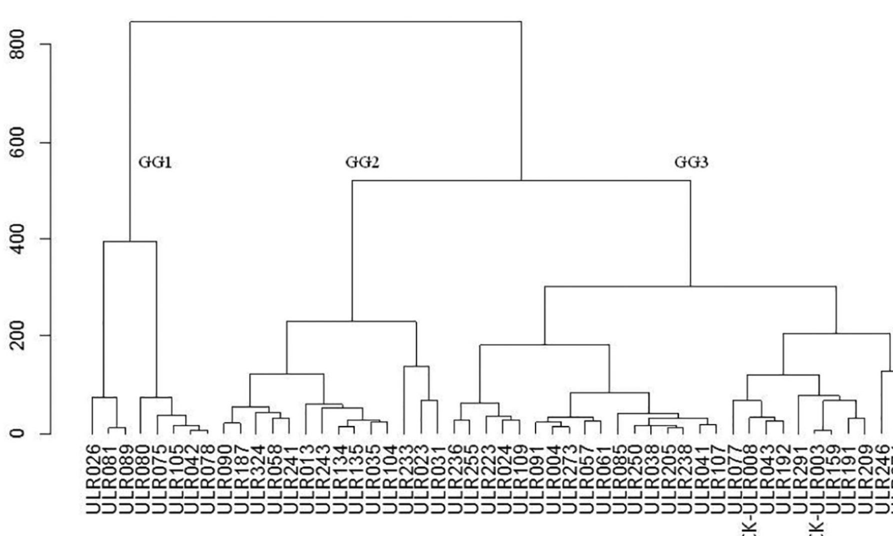

Fig. 2. Dendrograms displaying the genotype groups based on tiller number, plant height, seed/panicle, 1000/seed weight, and grain yield of 48 indigenous upland rice genotypes (and the two check varieties). GG = genotypes group, CK = check varieties.

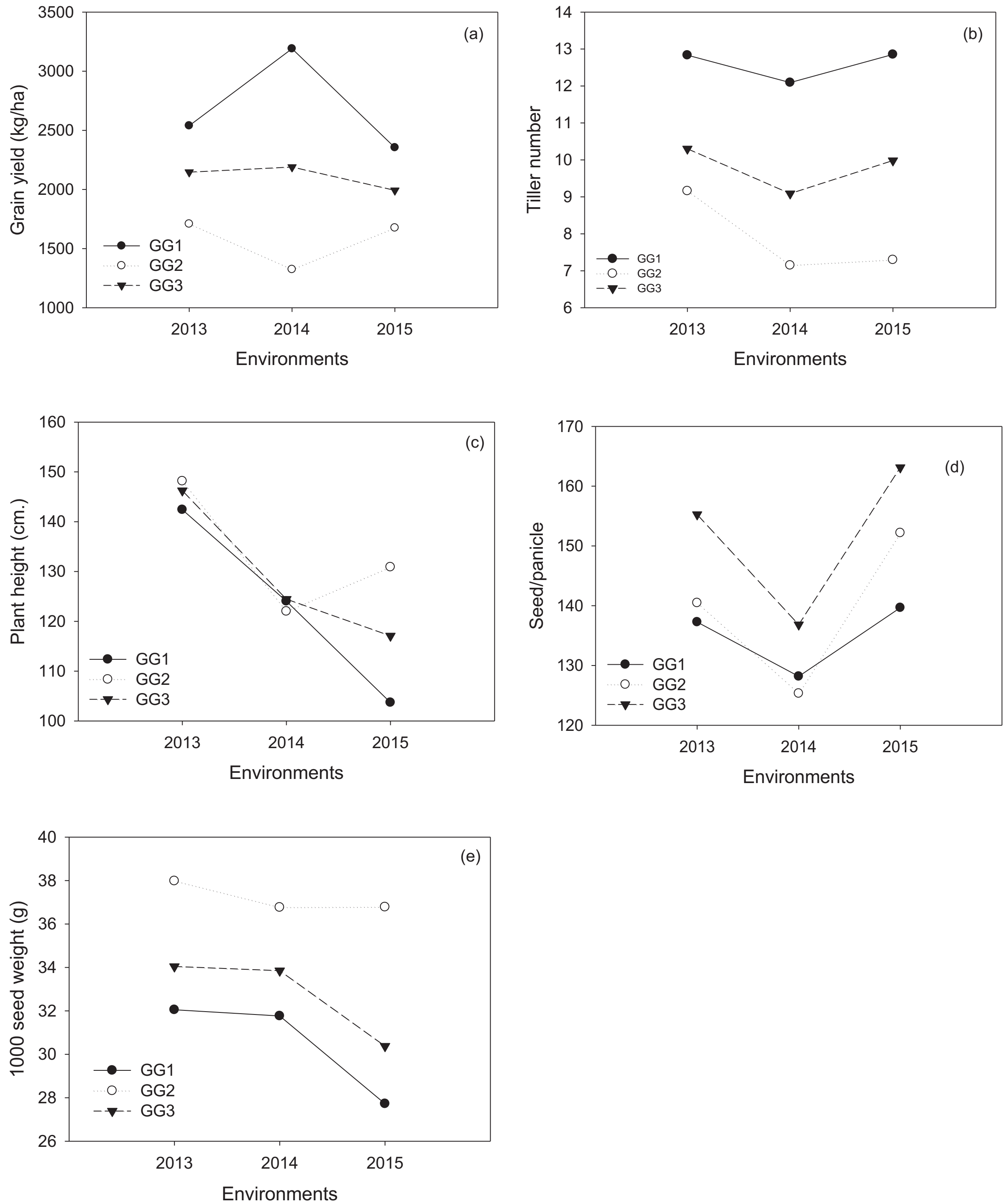

Fig. 3. The grand mean for grain yield, tiller number, plant height, seed/panicle, and 1000/seed weight of 48 indigenous upland rice varieties in three rice genotype groups (GG) over a three-year experiment.

ULR105) provided satisfactory yield performance over all three years. Three of the GG1 genotypes, ULR026, ULR081, and ULR089; outperformed the other genotypes in the group. The genotypes plotted on the left of the X-axis and close to the zero of the Y-axis had the highest yield stability across the three years (Fig. 4). The results demonstrated that the indigenous upland rice varieties ULR026, ULR042, ULR075, ULR078, ULR080, ULR081, ULR089, and ULR105 produced the highest yield stability and adaptability under the upland conditions of the study, surpassing than the Sew Mae Jan (ULR008) upland rice check variety.

3.2. Quality related traits analysis

Total amylose content of the rice powder utilized in this study ranged between 5.17 and 37.42%. The amylose content checks, KDML105 and RD6, were classified as having moderate (19.94%) and

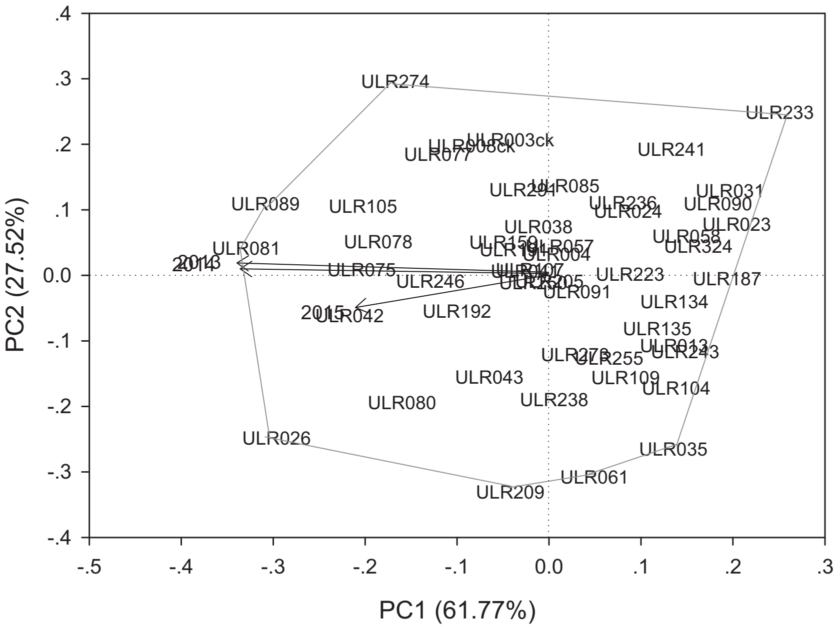

Fig. 4. Bi-plots for Principal Components (PCs) 1 and 2 obtained from the coordination of environment-standardized grain yield data of 48 indigenous upland rice varieties over three years (2013 to 2015). The ULR003 and ULR008 were used as check varieties (ck).

low (7.33%) amylose content, respectively. Several of the indigenous upland rice varieties revealed higher (and lower) amylose contents than the check varieties [Sew Mae Jan (ULR008) and Sakon Nakhon (ULR003)], establishing the high variation of amylase content of Thailand's indigenous upland rice varieties (Table 3). The sensory tests of the 50 rice varieties resulted in mostly 'less present' aromas (<2.0), while only a few varieties scored "present" or high aromas (>2.5), equal to that of the KDML105 variety; in which nine indigenous upland rice varieties (ULR058, ULR024, ULR078, ULR243, ULR013, ULR192, ULR274, ULR031, and ULR105) were deemed more rich in aroma than the ULR003 (Sakon Nakhon variety) (Fig. 5, Table 3). The estimated values for gelatinization temperature (GT) averaged 3.4 compared to 4.0 for the KDML105 (check) and 2.0 for the SPT (check). The ferulic acid content (FA) content in the fifty comparative rice cultivars differed significantly different between cultivars, ranging from 0.000 to 0.036 mg/g seed, with a mean of 0.007 mg (Table 3). Varying each year, the top varieties; ULR013, ULR236, ULR233, ULR038, ULR250, ULR031, ULR274, ULR058, ULR273, and ULR109 demonstrated high FA contents, greater than 0.015 mg/g seed in 2014. In 2015, the FA contents of the ULR187, ULR291, ULR109, ULR043, ULR209, ULR238, and ULR250 varieties presented a higher FA content, greater than 0.015 mg/g seed (Table 3).

4. Discussion

4.1. The rainfed upland rice production system

Our test area, Khon Kaen province, contributes 0.3 M ha to the more than 4.8 M ha of rice production in Thailand's Northeast rainfed region. Production time is dependent on the precipitation during the growing season and the bi-modal pattern of rainfall. The farmers initiate their practice at the beginning of the rainy season around early June, or when they feel that there is enough soil moisture content to optimize the length of the vegetative phase and photoperiod sensitivity of indigenous upland rice. To date, periods of standing water have proven to be both inconsistent and unpredictable, resulting in the possibility of drought occurrence across different rainfall regimes (Monkham et al., 2015).

In the present study, the amounts of rainfall during the growing seasons of 2013, 2014, and 2015 at Khon Kaen's Ban Had district varied distinctly (Fig. 1). The results confirmed that early, intermittent, and terminal drought can appear through inconsistent rainfall throughout the growing season. Additionally, terminal drought may also create greater yield loss due to its ability to reduce grain fertility in the flowering and grain filling stage (Monkham et al., 2015). However, upland rice is not often influenced by terminal drought, due to the bi-modal rainfall in October during the flowering stage. We experienced intermittent drought only in 2015 (Fig. 1), which affected plant growth and weight reduction (1000/seed) (Table 1, Fig. 4). Nevertheless, some upland rice genotypes, such as ULR026, ULR080, and ULR209; proved greater in grain yield sustainability (Table 1), indicating that they are intermittent-drought tolerant.

4.2. The potential yield component traits for rainfed upland rice production

Upland rice yields were drastically reduced by limited water supply through unpredictable distribution and insufficient or uneven rainfall during the growing period. However, some upland rice genotypes adapted to the upland conditions, maintaining superior rice yields. Numerous traits, such as tiller number, plant height, and seed weight, have been utilized as selection criteria (Guimarães et al., 2013). Tiller number has been found to have a positive correlation with grain yield due to its ability to maintain plant strands, which contributes to grain yield (Guimarães et al., 2013). Tiller fertility implies that the tillers are capable of producing seed, panicle, and final grain yield. In this study, GG1 maintained the highest tiller numbers over three years, as well as the highest grain yield (Fig. 3); including year 2015, which was classified as an intermittent drought environment.

Plant height related to growth was positively correlated with grain yield (Guimarães et al., 2013). However, excessive plant height caused lodging under windy conditions during harvesting time (Zhu et al., 2016). As a result, many improved rice varieties were reduced in plant height with a semi-dwarf gene (Hirano et al., 2017). In the present study, plant height showed a negative correlation with grain yield (Table 2 and Fig. 3c), indicating that taller plants are not a favorable characteristic for grain yield under upland conditions. Because the

Table 3
Amylose content, aromatic score, and gelatinization temperature of the 48 indigenous upland genotypes and the two standard checks.

Entry	Accession no.	AC	Aroma	GT	Ferulic acid content (mg/g seed)	
					Year 2014	Year 2015
1	ULR003 (ck.)	6.00	2.13	3.5	0.004	0.000
2	ULR004	14.61	1.00	3.2	0.000	0.007
3	ULR008 (ck.)	10.39	1.13	3.8	0.004	0.000
4	ULR013	8.50	2.75	2.1	0.036	0.005
5	ULR023	12.58	1.00	3.5	0.000	0.000
6	ULR024	15.11	2.88	3.7	0.001	0.005
7	ULR026	23.11	1.00	4.8	0.000	0.000
8	ULR031	6.22	2.63	2.5	0.027	0.004
9	ULR035	13.28	1.00	2.1	0.012	0.004
10	ULR038	7.92	1.13	2.6	0.030	0.003
11	ULR041	13.75	1.38	4.4	0.000	0.004
12	ULR042	10.33	1.25	3.7	0.000	0.002
13	ULR043	10.92	1.00	3.8	0.002	0.018
14	ULR057	5.19	1.50	4.0	0.002	0.003
15	ULR058	15.42	3.00	3.4	0.017	0.000
16	ULR061	5.47	1.00	3.7	0.000	0.000
17	ULR075	27.97	1.00	2.1	0.004	0.006
18	ULR077	28.56	1.13	2.0	0.005	0.003
19	ULR078	10.17	2.88	5.4	0.001	0.003
20	ULR080	10.78	1.00	4.2	0.005	0.002
21	ULR081	37.42	1.13	2.4	0.000	0.003
22	ULR085	35.81	1.13	5.7	0.002	0.006
23	ULR089	11.03	1.25	3.3	0.000	0.003
24	ULR090	10.25	1.25	2.4	0.013	0.000
25	ULR091	5.67	1.13	3.3	0.007	0.006
26	ULR104	NA	1.00	3.9	NA	0.000
27	ULR105	9.81	2.38	4.2	0.003	0.000
28	ULR107	10.42	1.13	3.3	0.002	0.002
29	ULR109	NA	1.13	2.4	0.016	0.018
30	ULR134	NA	NA	NA	NA	NA
31	ULR135	9.78	1.25	3.9	NA	0.002
32	ULR159	29.22	1.13	2.0	0.003	0.000
33	ULR187	12.83	1.13	3.4	NA	0.04
34	ULR191	9.78	1.25	4.9	0.007	0.002
35	ULR192	6.11	2.75	3.6	0.005	0.003
36	ULR205	10.17	NA	NA	NA	NA
37	ULR209	20.72	1.00	2.4	0.000	0.017
38	ULR223	8.50	1.25	3.5	0.006	0.002
39	ULR233	NA	1.00	4.4	0.035	0.000
40	ULR236	NA	1.25	2.6	0.035	0.003
41	ULR238	10.39	1.13	2.7	NA	0.012
42	ULR241	10.22	1.25	4.4	NA	0.000
43	ULR243	9.53	2.88	3.1	0.007	0.003
44	ULR246	23.33	1.00	4.9	0.008	0.003
45	ULR250	11.22	1.00	3.2	0.03	0.011
46	ULR255	14.08	1.00	3.0	0.000	0.002
47	ULR273	NA	2.00	2.7	0.017	0.005
48	ULR274	NA	2.75	2.1	0.019	0.004
49	ULR291	21.92	1.00	2.0	NA	0.028
50	ULR324	5.17	1.13	3.5	0.006	0.007
51	SPT	NA	1.63	2.0	NA	NA
52	RD6	7.33	1.38	3.7	NA	NA
53	RD31	NA	1.00	3.0	NA	NA
54	KDML105	19.94	3.00	4.1	NA	NA
	F-test	**	**	**	**	**
	LSD (0.05)	1.16	0.35	0.7	0.022	0.004
	CV (%)	5.14	23.87	12.44	62.63	25.9

AC = amylose content, Aroma = aromatic score, GT = gelatinization temperature, NA = data not available, ck = check variety.
** **S**ignificant at p ≤ 0.01.

habitat of upland rice is usually affected by water deficit during the growth period, rice genotypes with greater plant height displayed water deficiency through transpiration, leading to low water status (Kamoshita et al., 2004). The intermittent drought tolerance varieties (ULR026, ULR081, and ULR089) are capable of surviving stress through decreased plant height, in order to maintain the water status that contributes to biomass and final grain yield (Fig. 3c).

In this study, grain yield had a negative correlation with 1000 grain weight and seed per panicle (Table 2), in which rice genotypes with large seed sizes tended to produce low in grain yields and number of seed per panicle (Xu et al., 2015). The compensated between yield and yield components in rice is necessary for plant breeder decisions during the selection process. In the present work, the variation in seed size was associated with changes in the rate of grain filling due to it allows the crop to compensate for low seed per panicle (Griffiths et al., 2015). Beside, upland rice production was limited by several production factors. Terminal drought may also create greater yield loss due to its ability to reduce grain fertility caused of un-grain filled (Monkham et al., 2015). So the large seed size might limited grain yield due to rice necessary to balance between the sink and sources organ abilities for completed their life cycle. The commercial rice genotypes in Thailand have long and slender characteristics, with an average approximate 1000-grain weight of 27–32 g (Vanavichit et al., 2018). In this study, the high grain yield rice genotypes; ULR026, ULR042, ULR075, ULR078, ULR080, ULR081, ULR089, and ULR105, also averaged 27–32 g; indicating the suitability for acceptance by farmers, due to the high grain yield and grain quality that meets the Thai rice standard.

Although the tiller number, plant height, and 1000 seed weight were significant in all three years (Table 2), the final grain yield was not significant due to the lower tiller numbers (Guimarães et al., 2013) (Figs. 2a, 4b, Table 2). Thai upland rice farmers generally initiate the growing season at the end of May or early June, planting 4–5 seeds per hill. If the growing season were to start later, the seed rate would be increased to guarantee the optimal population—however, the later the seed sowing, the lower the tillering occurrence. To compensate for the low tillering, the farmer will implement a higher seed rate into their practice; therefore, effectively maintaining yield by maintaining tillering (Fig. 2a). Grain yield of the indigenous upland rice varieties (ULR026, ULR041, ULR075, ULR078, ULR080, ULR081, ULR089, and ULR105) showed a high positive correlation with their respective tiller number and a negative correlation with plant height and 1000-grain weight. The results demonstrated that the major factors affecting grain yield, positively and negatively, were tiller number and plant height, respectfully, which can therefore be used as grain yield selection criteria.

4.3. Yield stability

Genotype *x* Environment (G*x*E) presented a major effect upon grain yield due to the low heritability of this trait. To identify superior genotypes for a specific area, a multiple-year test for yield potential and adaptability of genotype must be performed. In this study, we used 48 indigenous upland rice varieties to identify the genotypes with yields superior to the Sew Mae Jan (check variety) under the rainfed upland conditions of Khon Kaen. Based on grain yield and their related traits, eight indigenous upland rice varieties were identified as a highly adaptive to this area (Fig. 4), demonstrating favorable desirable agronomic attributes under upland conditions in both high and low yielding environments (Fig. 4), suitable for growth in the unpredictable and insufficient rainfall distribution patterns which occur through the area's growing period.

4.4. The qualities of indigenous upland rice varieties

Although rice is a staple food in several countries, the price of rice remains low. Rice with not only high yield but with special characteristics is needed for trading to the niche market. Cooking quality is one of the most important traits for meeting consumer behavior/needs. Rice breeders, therefore, attempt to create high yielding varieties that incorporate high cooking and eating qualities. In our study, amylose content, aromatic character, GT, and FA were determined.

In this study, up to 79% of the test varieties were of low amylose content (<20%), including glutinous and non-glutinous rice varieties

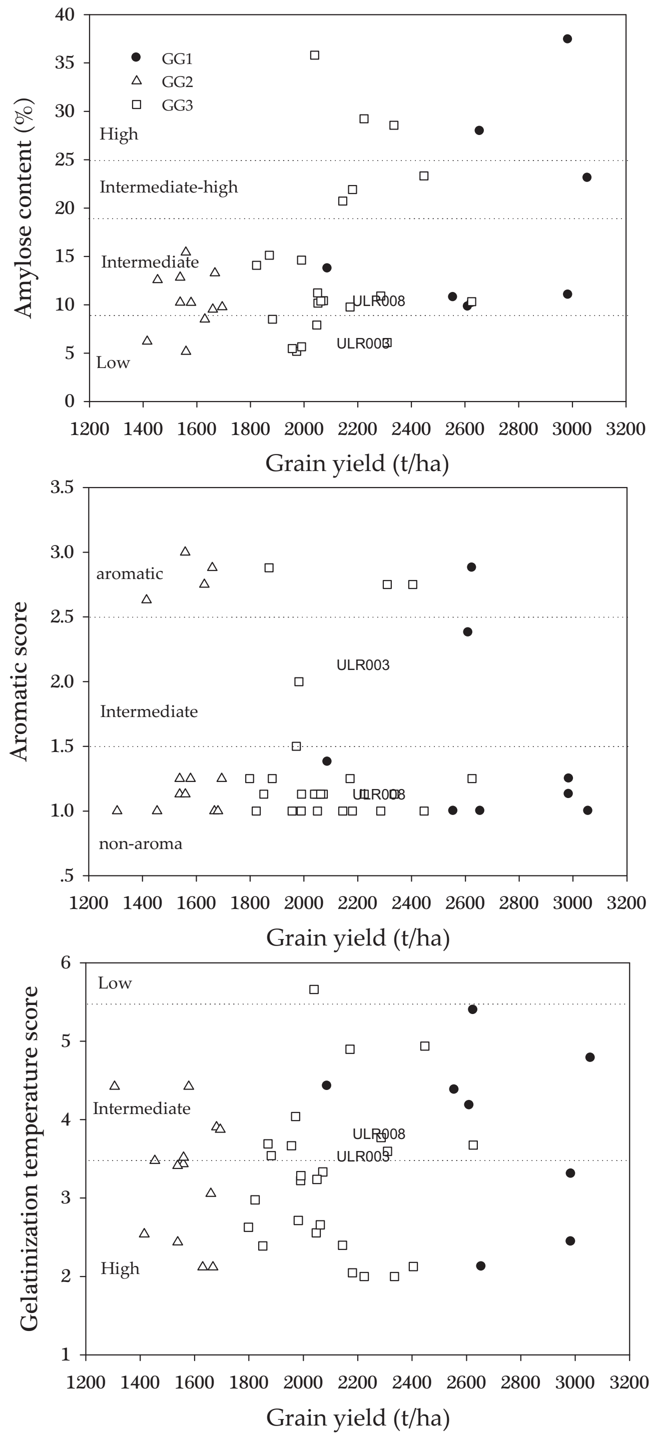

Fig. 5. The grand mean for amylose content, aromatic score, and gelatinization temperature (GT) of 48 indigenous upland rice varieties (and two check varieties) in three rice genotype groups (GG) against grain yield. The ULR003 and ULR008 were used as check varieties.

(Fig. 5) due to Thailand's Northeastern region is well-known for its consumption of glutinous or soft texture of rice, like the KDML105, RD6, and Sakon Nakhon rice varieties. On the other hand, ULR081 rice variety with high and stable yields, and the highest available amylose content (37.42%) (Table 3). This variety proved suitable for industrial starch production and addressed numerous health care concerns (Fitzgerald et al., 2011; Denardin et al., 2012).

Nine indigenous upland rice varieties (ULR058, ULR024, ULR078, ULR243, ULR013, ULR192, ULR274, ULR031, and ULR105) were considered as a potential aroma genetic sources in rice production and warrants further improvements in the future.

The indigenous upland rice varieties tested within our study were also shown to be highly significant for FA content (Table 3). The results indicated that the tested rice varieties had a moderate potential for FA content. Tian et al. (2004) reported the FA content in rice ranking from 0.07 to 0.48 mg/g seed, and suggested that differences in FA concentration were due to several factors; such as rice variety, rice parts, and the extraction and detection methods. Wanyo et al. (2014) later reported FA concentrations of 0.04, 0.07, and 0.09 mg/g seed in rice bran, rice husk, and ground rice husk, respectively. Ferulic acid content rarely occurs free-form in plants and is usually found as ester, covalently conjugated within the cell walls of polysaccharide, proteins, lignin, and other insoluble carbohydrate biopolymers (Barnerousse et al., 2008).

5. Conclusion

In our study, eight indigenous upland rice varieties, including ULR026, ULR042, ULR075, ULR078, ULR080, ULR081, ULR089, and ULR105 showed superior stable grain yield performance over the Sew Mae Jan (ULR008) check variety. Moreover, some of the high-yielding varieties were also presented favorable qualities, such as high amylose content (ULR081 and ULR075), high aroma (ULR078), and intermediate gelatinization temperature (GT) (ULR078, ULR026, and ULR105). These varieties have proven beneficial for future trait selection in upland rice breeding programs.

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Declaration of competing interest

The authors declare that they have no conflict of interest.

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