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GENETIC AND PHENOTYPIC DIVERSITY OF UPLAND RICE IN BUNGO REGENCY FOR CLIMATE-RESILIENT BREEDING

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SUMMARY

The upland rice (*Oryza sativa* L.) genotypes are crucial genetic resources for climate resilience and productivity under challenging conditions grown in rainfed environments. This study aimed to characterize the local upland rice cultivars from Bungo Regency, Jambi Province, Indonesia, focusing on morphological and agronomic traits to support conservation and breeding. Field exploration was successful through sampling across six subdistricts to capture the genotype and environmental variations. In assessing key traits, a field experiment with 25 upland rice cultivars continued in a randomized block design. Data analysis included variance assessment, post-hoc testing via Tukey's HSD (honestly significant difference), and cluster analysis using the Euclidean distance, visualized through a dendrogram. The results revealed significant phenotypic variability among the upland rice cultivars for culm, leaf, tiller, panicle, and grain traits. Cluster analysis identified six distinct genetic groups, indicating a broad genetic base and unique adaptive traits among cultivars. Some cultivars exhibited high genetic similarity, while others showed distinct genetic divergence, suggesting potential for targeted breeding and conservation efforts. This diversity emphasizes the adaptive evolution of rice cultivars to local environmental conditions and their breeding values. The study underscores the importance of conserving genetic resources to support climate-resilient breeding and food security.

Keywords: Upland rice (*O. sativa* L.), genetic diversity, genetic resources, climate resilience, morphological traits, cluster analysis, genetic relationship

Key findings: Significant phenotypic variability among the upland rice (*O. sativa* L.) cultivars for culm, leaf, tiller, panicle, and grain traits showed considerable diversity. Six distinct genetic clusters highlighted the unique genetic relationship and potential adaptive strategies.

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INTRODUCTION

Rice (*Oryza sativa* L.) is one of the most important staple food crops, supporting the food security of around half of the global population (Roy *et al*., 2016). Upland rice, a specific type cultivated in rainfed ecosystems, plays a crucial role in sustaining smallholder farmers, especially in tropical regions where low-input systems prevail (Nurhasanah *et al*., 2017). The unique production for its environmental conditions presents challenges due to varied water availability, soil nutrient limitation, and effects of biotic and abiotic stresses (Wambugu *et al*., 2018). Despite these conditions, upland rice genotypes exhibited substantial genetic diversity and an invaluable trait for breeding programs aimed at improving climate resilience and grain yield under adverse environmental conditions (Kankwatsa *et al*., 2019; Jamal *et al*., 2023).

The characterization of local upland rice cultivars has gained attention due to their genetic richness and adaptability, which contribute to enhanced environmental resilience and productivity (Kankwatsa *et al*., 2019). Local rice cultivars harbor diverse traits that reflect adaptive responses to specific ecological niches, allowing the identification of valuable genetic traits contributing to breeding for biotic and abiotic tolerance (Nurhasanah *et al*., 2019). Additionally, upland rice cultivars often possess unique agronomic and morphological traits as key indicators of genetic potential for improving grain yield and stress adaptation (Tanaka *et al*., 2022, 2023).

Bungo Regency in Jambi Province, Indonesia, is commonly home to the diverse local upland rice cultivars grown by traditional farming communities. The region's ecological zones support the identification of rice cultivars with adaptive traits. Characterizing the genetic diversity of these genotypes is vital for conservation and breeding programs, as local landraces contain unique traits valuable for addressing challenges in rice production (Nurhasanah *et al*., 2017; Hour *et al*., 2020). Understanding the phenotypic variability of these accessions also aids in developing climate-resilient genotypes suited to upland farming systems (Da-Mata *et al*., 2023).

Although numerous studies have examined the genetic diversity of upland rice in various regions, specific studies on the genetic and phenotypic characterization of local upland rice in Bungo Regency are still limited. Therefore, this study proceeded to fill this gap by exploring and analyzing the morphological diversity and genetic potential of local upland rice varieties to support breeding and conservation programs. Previous studies have emphasized the role of morphological and agronomic traits in assessing genetic diversity, linking them to environmental adaptability and yield potential (Fiore *et al*., 2019).

The presented study focused on exploring and characterizing the local upland rice cultivars in Bungo Regency, Indonesia, based on phenotypic diversity through morphological and agronomic traits analysis. By combining qualitative and quantitative traits, the research aimed to identify the genetic groups and assess the potential of these cultivars for breeding and conservation (Lee *et al*., 2020). Additionally, the study provides valuable insights into the genetic diversity of upland rice, which can serve as a foundation for targeted breeding programs and conservation strategies. The identified genetic and phenotypic traits will aid in developing superior rice cultivars with enhanced adaptability to environmental stressors, ensuring sustainable upland rice production in the face of climate change.

MATERIALS AND METHODS

Upland rice exploration

The exploration of local upland rice cultivars in Bungo Regency, Indonesia, used a survey-based approach with purposive stratified sampling. This strategy selected specific locations and rice cultivars from diverse ecological zones, ensuring a representative sample of rice genotypes and environmental conditions. The study covered six subdistricts in Bungo Regency, Indonesia, i.e., Batin-II Pelayang, Jujuhan, Jujuhan Ilir, Pelepat, Tanah Sepenggal, and Tanah Tumbuh (Table 1).

Table 1. Upland rice cultivars originated from the Bungo Regency, Jambi Province, Indonesia.

ID	Cultivars	Village	Subdistrict
V1	Perak	Pelayang	Batin II Pelayang
V2	Seni Sungkai	Peninjau	Batin II Pelayang
V3	Seni Untai	Peninjau	Batin II Pelayang
V4	Ogan	Tanjung Belit	Jujuhan
V5	Pelepah Kecil	Tanjung Belit	Jujuhan
V6	Rotan	Tanjung Belit	Jujuhan
V7	Seni Bungin I	Tanjung Belit	Jujuhan
V8	Seni Kuku Balam	Tanjung Belit	Jujuhan
V9	Seni Ting	Tanjung Belit	Jujuhan
V10	Bungin	Lubuk Tenam	Jujuhan Ilir
V11	Kuku Balam	Lubuk Tenam	Jujuhan Ilir
V12	Mayang Merindu	Lubuk Tenam	Jujuhan Ilir
V13	Belanda	Pulau Batu	Jujuhan Ilir
V14	Ibul	Pulau Batu	Jujuhan Ilir
V15	Jintan	Pulau Batu	Jujuhan Ilir
V16	Padi Empat Bulan	Rantau Keloyang	Pelepat
V17	Perak Halus	Rantau Keloyang	Pelepat
V18	Saigon	Rantau Keloyang	Pelepat
V19	Seni Bungin II	Rantau Keloyang	Pelepat
V20	Seni Murai	Rantau Keloyang	Pelepat
V21	Ugan	Rantau Keloyang	Pelepat
V22	Kuning	Tanjung	Tanah Sepengal
V23	Kuning Besar	Tanjung	Tanah Sepengal
V24	Tulak Pelepah	Tanjung	Tanah Sepengal
V25	Pandan Wangi	Pedukun	Tanah Tumbuh

Experimental procedure

Twenty-five upland rice cultivars were evaluated in a field experiment for their agro-morphological traits at the University of Jambi, Jambi, Indonesia. Seeds planted in 3 m² plots had an arrangement in a randomized block design (RBD) with three replications. Blocks in RBD are experimental groups formed based on environmental factors that can cause variations in research results. The blocks attained assignment based on natural variations in soil conditions within the experimental field to minimize environmental effects on plant growth and ensure fair comparisons among cultivars. Each block contained all 25 cultivars, arranged randomly within the block. Following standard cultivation practices ensued throughout the crop life.

Quantitative and qualitative traits observation

Morphological observations characterized the rice cultivars based on culm, leaf, ligule, auricle, panicle, floret, and spikelet traits. Yield components when assessed used the International Board for Plant Genetic Resources and the International Rice Research Institute (IBPGR-IRRI, 1980) guidelines, ensuring systematic traits recording for phenotypic comparison among the upland rice cultivars.

Data analysis

Quantitative data analysis for variance determined significant differences among the upland rice cultivars, followed by a post-hoc test using the honest significant difference

(HSD) approach in SPSS 29.0.1.0. The HSD test was an option due to its robustness in comparing multiple means while controlling Type I error, guaranteeing reliable identification of significant phenotypic variations.

Cluster analysis, when performed, employed the Euclidean distance and single linkage to classify the upland rice cultivars into distinct groups, visualized through a dendrogram. Euclidean distance was a choice as it effectively measures genetic divergence based on multiple traits, while single-linkage clustering allows the identification of closely related genotypes, making it suitable for assessing genetic relationships in breeding programs. Before analysis, all the qualitative and quantitative attributes' data underwent standardization according to the rice descriptor guidelines. Additionally, the Pearson correlation as applied evaluated the relationship among the quantitative features, providing insights into trait association and their potential influence on the agronomic performance of the upland rice genotypes.

RESULTS AND DISCUSSION

Traits characterization

Collecting local upland rice accessions totaled 25 from six subdistricts in Bungo District, Jambi Province, Indonesia, and mostly the samples came from Tanjung Belit and Rantau Kloyang in Jujuhan and Pelepat Districts. Characterization revealed significant diversity among the rice genotypes for qualitative and quantitative traits, particularly in stem angle, internode color, and lemma-palea color, while the leaf traits showed minimal variations. Five upland rice cultivars, Pelepah Kecil, Seni Kuku Balam, Seni Ting, Kuning, and Tulak Pelepah, had an erect stem angle, enhancing lodging resistance (Shah *et al*., 2019). Limited variations in leaf traits suggested minimal environmental influence (Sadimantara *et al*., 2021).

Qualitative traits, such as stem angle, leaf color, flower morphology, and grain characteristics (Table 2), emerged to be crucial for genetic analysis and population differentiation (Mahendra *et al*., 2019). These qualitative traits are mostly under the control of a few genes, allowing for straightforward classification, which can support conservation and breeding strategies. For example, culm angle influences lodging resistance, which is essential for yield stability in upland rice (Shah *et al*., 2019). Leaf color variations may indicate differences in chlorophyll content, affecting photosynthesis efficiency and plant vigor (Sadimantara *et al*., 2021). Additionally, features such as lemma and palea color, stigma pigmentation, and awn presence disclosed a linkage to stress tolerance and reproductive success, providing useful markers for breeding programs aimed at improving climate resilience and productivity (Naing and Kim, 2021; Li and Ahammed, 2023). Quantitative analysis revealed substantial diversity in stem, leaf, ligule, and seed traits. The HSD test exposed significant phenotypic variability, particularly in plant height, tiller number, and grain morphology, as shown in Tables 3 and 4. Notably, the plant height, leaf length, and tiller number exhibited wide distribution, emphasizing the phenotypic diversity of the local upland rice cultivars.

Compared to previous studies on upland rice diversity in Southeast Asia (Kankwatsa *et al*., 2019; Persaud *et al*., 2022), our findings highlight a broader range of phenotypic variability, particularly in plant height (84 to 171 cm) and tiller number (6.8 to 23.2 tillers). The wider variation observed in this study suggests stronger environmental selection pressures acting on Bungo cultivars. Additionally, the grain length-to-width ratio (2.19 to 4.78) showed more variation than previously reported for upland rice in East Kalimantan (Nurhasanah *et al*., 2019), indicating distinct genetic adaptations in Bungo upland rice.

In upland rice cultivars, the variations in plant height and culm diameter can play a key role in lodging resistance and better yield stability. Shorter plants with thicker culms, like the cultivar Seni Untai, showed enhanced resistance in windy and rainy areas (Persaud *et al*., 2022). Leaf length variation affects photosynthesis and water efficiency and is

Table 2. Qualitative characteristics of local upland rice cultivars.

ID	Cultivars	Culm angle	Internode color	Leaf blade color	Leaf sheath color	Leaf angle	Flag leaf angle	Stigma color	Awning	Awn color	Apiculus color	Lemma and palea color	Sterile Lemma color	Threshability	Grain shape
V1	Perak	Intermediate	Green	Green	Green	Intermediate	Intermediate	White	Absent	-	White	Straw	Straw	Intermediate	Bold
V2	Seni Sungkai	Intermediate	Green	Green	Green	Intermediate	Intermediate	White	Absent	-	White	Straw	Straw	Intermediate	Bold
V3	Seni Untai	Spreading	Green	Green	Green	Intermediate	Erect	White	Long and partly awned	Straw	White	Straw	Straw	Intermediate	Slender
V4	Ogan	Intermediate	Green	Green	Green	Intermediate	Intermediate	White	Short and partly awned	Straw	White	Brown spots	Straw	Easy	Bold
V5	Pelepah Kecil	Erect	Purple lines	Green	Green	Intermediate	Erect	White	Short and fully awned	Straw	Purple	Purple furrows	Purple	Easy	Bold
V6	Rotan	Intermediate	Green	Green	Green	Intermediate	Erect	White	Absent	-	White	Gold	Straw	Easy	Slender
V7	Seni Bungin I	Open	Green	Green	Green	Intermediate	Intermediate	White	Absent	-	White	Straw	Straw	Easy	Slender
V8	Seni Kuku Balam	Erect	Green	Green	Green	Intermediate	Intermediate	White	Absent	-	White	Straw	Straw	Easy	Slender
V9	Seni Ting	Erect	Purple lines	Green	Green	Intermediate	Intermediate	White	Absent	-	Purple	Purple furrows	Purple	Intermediate	Slender
V10	Bungin	Open	Green	Green	Green	Intermediate	Intermediate	White	Absent	-	White	Straw	Straw	Easy	Slender
V11	Kuku Balam	Intermediate	Green	Green	Purple lines	Intermediate	Intermediate	White	Absent	-	White	Straw	Straw	Intermediate	Bold
V12	Mayang Merindu	Intermediate	Green	Green	Green	Intermediate	Intermediate	White	Absent	-	White	Gold	Straw	Easy	Slender
V13	Belanda	Intermediate	Green	Green	Green	Intermediate	Intermediate	White	Absent	-	Purple	Gold	Straw	Easy	Bold
V14	Ibul	Open	Green	Green	Green	Intermediate	Intermediate	Purple	Absent	-	White	Straw	Straw	Easy	Slender
V15	Jintan	Intermediate	Green	Green	Green	Intermediate	Intermediate	White	Absent	-	White	Gold	Straw	Easy	Bold
V16	Padi Empat Bulan	Intermediate	Green	Green	Green	Intermediate	Intermediate	White	Absent	-	Purple	Straw	Straw	Easy	Bold
V17	Perak Halus	Intermediate	Light Gold	Green	Green	Intermediate	Erect	White	Absent	-	White	Straw	Straw	Easy	Bold
V18	Saigon	Intermediate	Green	Green	Green	Intermediate	Intermediate	White	Absent	-	White	Straw	Straw	Easy	Bold
V19	Seni Bungin II	Open	Green	Green	Green	Intermediate	Intermediate	White	Absent	-	White	Straw	Straw	Easy	Slender
V20	Seni Murai	Open	Green	Green	Green	Intermediate	Intermediate	White	Short & partly awned	Straw	White	Brown	Straw	Intermediate	Slender
V21	Ugan	Open	Green	Green	Green	Intermediate	Erect	White	Absent	-	White	Gold	Straw	Easy	Bold
V22	Kuning	Erect	Light Gold	Green	Green	Intermediate	Intermediate	White	Absent	-	White	Brown	Straw	Intermediate	Slender
V23	Kuning Besar	Intermediate	Green	Green	Green	Intermediate	Intermediate	White	Absent	-	White	Brown	Straw	Easy	Slender
V24	Tulak Pelepah	Erect	Green	Green	Green	Intermediate	Intermediate	White	Absent	-	White	Straw	Straw	Easy	Bold
V25	Pandanwangi	Spreading	Green	Green	Green	Intermediate	Erect	White	Absent	-	White	Gold	Straw	Intermediate	Slender

crucial in water-limited environments (Da-Mata *et al*., 2023). Differences among the rice genotypes for tiller number, panicle length, and grain traits influence yield potential and market preferences (Takai, 2024; Fang *et al*., 2024).

The promising results highlight the genetic richness and adaptive potential of the rice cultivars, which align with similar studies in Southeast Asia (Roy *et al*., 2016). The genetic diversity of these local rice cultivars provides valuable resources for future breeding programs (Siddiq and Vemireddy, 2021), such as in selecting superior varieties, increasing resistance to environmental factors, or developing cultivars with higher productivity. This study emphasizes the importance of conserving local rice cultivars to maintain the genetic diversity, vital for food security and future crop breeding. Unlike Kankwatsa *et al*. (2019), who focused on the adaptability of upland rice in Uganda, this study explored both quantitative and qualitative traits and their potential to improve yield, plant architecture, and environmental resilience.

Table 3. Quantitative characteristics of local upland rice cultivars.

ID	Cultivars	PH (cm)		CD (mm)		LBL (cm)		LBW (cm)		LL (cm)		TN		PTN		PL (cm)		W100S (g)		GL/GW	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
V1	Perak	116.8	3.11	5.6	0.87	52.6	1.52	1.42	0.19	1.58	0.26	6.8	1.10	5.8	0.45	31.6	1.52	2.97	0.06	2.52	0.05
V2	Seni Sungkai	113.2	9.20	5.7	1.10	45.6	3.91	1.18	0.13	2.16	0.21	23.2	0.84	20.4	3.91	31.2	3.77	2.19	0.06	2.95	0.24
V3	Seni Untai	90.2	14.46	6.3	1.05	31.4	9.02	1.06	0.21	1.32	0.30	14.2	4.71	6.8	1.92	33.2	2.39	2.69	0.08	4.03	0.52
V4	Ogan	127	3.81	5.1	0.56	53.6	11.08	1.6	0.20	1.98	0.20	15.4	3.58	9.8	1.10	30.8	1.30	2.35	0.10	2.24	0.22
V5	Pelepah Kecil	117.2	4.97	6.13	0.81	45	8.43	1.32	0.37	1.56	0.29	10.4	4.51	8.6	1.82	27.2	2.17	2.91	0.09	2.64	0.16
V6	Rotan	123.4	5.27	5.03	0.81	44	3.16	1.56	0.05	1.4	0.16	16.8	3.96	13.8	2.17	28	1.58	2.72	0.18	3.03	0.34
V7	Seni Bungin I	139	10.54	6.17	0.85	58.6	11.28	1.64	0.22	1.38	0.24	17.4	3.97	16.4	2.07	25.4	2.88	2.6	0.02	3.74	0.17
V8	Seni Kuku Balam	115.4	6.84	5.07	0.42	40.4	4.39	1.46	0.09	1.08	0.26	17.8	1.92	11.6	0.89	25.4	3.36	1.89	0.12	3.13	0.12
V9	Seni Ting	114.2	7.43	5.33	1.37	46	5.34	1.82	0.40	1.38	0.16	9.4	2.30	7.6	0.55	25.6	3.29	1.99	0.06	4.78	0.19
V10	Bungin	128.6	6.43	5.13	0.59	46	3.94	1.52	0.16	1.5	0.29	17	3.16	12	3.67	22.6	3.05	1.94	0.04	3.31	0.24
V11	Kuku Balam	120.8	10.13	5.67	0.85	48.4	9.29	1.72	0.11	1.22	0.23	12	0.55	9	2.92	28.4	1.67	2.03	0.05	2.92	0.07
V12	Mayang Merindu	118.2	7.50	2.34	2.74	50.2	2.17	1.64	0.17	0.88	0.08	13.6	1.95	9.6	1.14	23	1.22	1.95	0.03	3.81	0.11
V13	Belanda	132.4	6.69	5.3	0.70	51	3.94	1.88	0.19	1.56	0.13	16.2	3.90	10.8	1.64	27.8	1.92	1.95	0.03	2.92	0.04
V14	Ibul	137.2	8.07	6.43	1.79	60	3.94	1.84	0.21	1.62	0.22	15.8	3.27	11.2	0.84	29	1.41	1.93	0.08	3.06	0.21
V15	Jintan	128	26.04	6.03	0.74	49.2	5.17	1.56	0.18	1.24	0.24	15.4	2.88	11.8	3.90	23.8	4.55	2.4	0.24	3.15	0.07
V16	Padi Empat Bulan	123.4	8.23	5.27	0.35	47	4.18	1.6	0.20	1.56	0.35	10.2	2.28	9.2	3.19	29.4	2.07	3.25	0.12	2.64	0.11
V17	Perak Halus	134.2	3.49	6.07	0.74	50.6	9.63	1.7	0.25	1.7	0.25	16.8	5.40	15	2.35	23.6	2.19	1.57	0.09	2.8	0.13
V18	Saigon	129.8	10.43	5.4	0.70	50.4	4.28	1.64	0.19	1.54	0.35	14.2	3.27	8.8	2.17	27	2.45	2.82	0.18	2.19	0.03
V19	Seni Bungin II	118	10.42	4.93	0.21	44.2	6.94	1.58	0.25	1.34	0.44	10.2	1.79	5.8	1.92	23.6	2.30	2.13	0.10	3.28	0.16
V20	Seni Murai	171	7.97	6.87	1.30	65.8	4.32	1.8	0.16	2.36	0.22	16.4	3.65	11.4	4.77	30.6	2.51	2.47	0.02	3.25	0.04
V21	Ugan	128.2	6.69	5.87	0.47	48	3.74	1.78	0.22	1.26	0.23	9.4	3.36	7.2	2.59	23.8	3.83	2.35	0.01	2.53	0.12
V22	Kuning	107.8	5.02	4.47	0.93	49.8	8.70	1.32	0.13	1.44	0.50	11.2	2.17	10	2.55	29.4	2.07	2.41	0.01	3.34	0.18
V23	Kuning Besar	117.4	1.67	5.43	2.06	51	6.24	1.68	0.23	1.18	0.35	12.2	3.63	10.8	2.77	25.2	2.59	2.16	0.02	3.29	0.17
V24	Tulak Pelepah	109.6	10.16	6 b	0.20	46.4	5.94	1.58	0.11	1.52	0.08	8.2	2.59	7	1.58	25	4.12	3.04	0.02	2.8	0.05
V25	Pandanwangi	84	6.89	4.77	0.55	27.4	6.73	0.98	0.13	1.3	0.16	17.6	5.37	6.8	1.92	22.6	1.52	2.09	0.02	3.83	0.14
	ANOVA	**		*		**		**		**		**		**		**		**		**	
	HSD value	22.17		3.39		15.45		0.49		0.64		7.97		5.84		6.28		0.23		0.46	

Note: SD - Standard Deviation; *Significant (α = 5%); **Very significant (α = 1%), PH = Plant Height; CD = Culm Diameter; LBL = Leaf Length; LBW =- Leaf Width; LL = Ligule Length; TN = Tiller Number; PTN = Productive Tiller Number; PL = Panicle Length; W100S = Weight of 100 seeds; and GL/GW = Grain Length/Grain Width.

Table 4. Descriptive analysis of quantitative characteristics of local upland rice cultivars.

Traits	Minimum	Maximum	Range	Mean	Standard Deviation	Kurtosis	Skewness
PH	84.00	171.00	87.00	121.80	16.43	3.31	0.41
CD	2.34	6.87	4.53	5.46	0.87	6.28	-1.83
LBL	27.40	65.80	38.40	48.10	7.85	2.18	-0.51
LBW	0.98	1.88	0.90	1.56	0.23	0.63	-0.99
LL	0.88	2.36	1.48	1.48	0.32	1.84	1.03
TN	6.80	23.20	16.40	13.91	3.82	-0.06	0.13
PTN	5.80	20.40	14.60	10.29	3.44	1.88	1.18
PL	22.60	33.20	10.60	26.93	3.14	-1.05	0.29
W100S	1.57	3.25	1.68	2.35	0.43	-0.64	0.40
GL/GW	2.19	4.78	2.59	3.13	0.59	1.38	0.88

Note: PH = Plant Height; CD = Culm Diameter; LBL = Leaf Length; LBW = Leaf Width; LL = Ligule Length; TN = Tiller Number; PTN = Productive Tiller Number; PL = Panicle Length; W100S = Weight of 100 seeds; and GL/GW -= Grain Length/Grain Width.

Table 5. Correlation analysis among quantitative and qualitative traits of local upland rice cultivars.

Traits	PH	CD	CA	CC	LBL	LBW	LSC	FLA	LL	AW	AWC	APC	SC	LPC	SLC	TN	PTN	PL	GL	GS
CD	0,46*																			
CA	0,12	0,15																		
CC	-0,12	0,01	-0,50*																	
LBL	0,49*	0,19	-0,19	0,08																
LBW	0,49*	0,47*	-0,43*	0,08	0,48*															
LSC	-0,12	0,09	-0,05	-0,08	0,04	0,04														
FLA	0,16	0,01	-0,31	-0,25	0,36	0,36	0,11													
LL	0,14	0,37	0,11	-0,05	0,32	0,02	-0,02	0,07												
AW	-0,15	0,15	0,21	0,27	-0,30	0,07	-0,07	-0,49*	0,03											
AWC	-0,06	0,19	0,15	0,19	0,09	0,09	-0,09	-0,27	0,27	0,78**										
APC	-0,06	0,19	-0,36	0,57**	0,09	0,09	-0,09	-0,01	-0,05	0,18	0,11									
SC	0,25	0,09	0,19	-0,08	0,04	0,04	-0,04	0,11	-0,02	-0,07	-0,09	-0,09								
LPC	-0,18	0,02	-0,40*	0,76**	0,28	0,04	-0,14	-0,07	0,09	0,26	0,43*	0,48*	-0,14							
SLC	-0,17	0,13	-0,42*	0,89**	0,06	0,06	-0,06	-0,18	-0,03	0,35	0,27	0,68**	-0,06	0,78**						
TN	0,01	0,12	-0,18	0,20	0,06	0,06	-0,06	-0,06	-0,30	-0,09	-0,12	0,13	-0,06	0,17	0,26					
PTN	-0,37	0,05	0,08	0,19	-0,23	-0,23	0,23	-0,26	-0,10	0,29	0,05	0,27	-0,18	0,02	0,33	0,50*				
PL	-0,11	0,22	0,24	-0,21	0,10	0,10	-0,10	-0,19	0,52**	0,31	0,33	-0,22	-0,10	-0,09	-0,15	-0,14	-0,04			
GL	0,10	0,13	-0,07	0,13	0,06	0,06	-0,06	-0,18	-0,03	-0,01	0,27	-0,13	-0,06	0,01	-0,09	-0,08	-0,26	-0,15		
GS	-0,17	0,42*	0,32	-0,02	-0,20	-0,20	-0,21	0,02	-0,12	0,03	-0,02	-0,24	0,20	0,14	-0,01	-0,10	-0,28	0,08	-0,31	
TS	0,40*	0,17	-0,14	-0,16	0,08	0,30	-0,30	0,02	-0,42*	-0,18	-0,17	0,07	0,14	-0,19	-0,11	-0,01	-0,26	-0,51	0,20	-0,14

Note: **Correlation is significant at a 0.01 level; *Correlation is significant at a 0.05 level. PH = Plant Height; CD = Culm Diameter; CA = Culm Angle; CC = Collar Color; LBL = Leaf Length; LBW = Leaf Width; LSC = Leaf Sheath Color; FLA = Flag Leaf Angle; LL = Ligule Length; AW = Awning; AWC = Awn Color; APC = Apiculus Color; SC = Stigma Color; LPC = Lemma Palea Color; SLC = Sterile Lemma Color; TN = Tiller Number; PTN = Productive Tiller Number; PL = Panicle Length; GL = Grain Length; GS = Grain Shape; and TS = Threshability.

Traits correlation

Correlation coefficient analysis revealed a significant relationship among the morphological and agronomic traits, highlighting their interdependence (Table 5). Strong correlations were evident among the pigmentation attributes (collar, apiculus, lemma, palea, and sterile lemma colors), suggesting a shared genetic basis and a vital role in environmental adaptation and stress tolerance (Naing and Kim, 2021; Li and Ahammed, 2023). Jan *et al*.'s (2024) findings disclosed that rice pigmentation enhances drought resilience, reflecting selective adaptation.

Significant correlations were also noticeable between the plant height and the traits stem diameter, leaf length, and leaf width, underscoring their role in plant architecture and lodging resistance, crucial for crop stability under extreme weather conditions (Nurhasanah *et al*., 2016). Shorter rice plants with thicker stems showed better lodging resistance. Leaf dimensions, linked to photosynthetic efficiency and biomass accumulation, play an influential role in improving growth and grain yield (Li *et al*., 2022; Gong *et al*., 2024).

The correlation between productive and total tiller numbers supports the importance of optimizing tiller production for higher grain yield. Efficient resource allocation to grain-producing tillers while minimizing non-productive ones can boost the grain yield, especially in low-input agricultural systems (Takai, 2024).

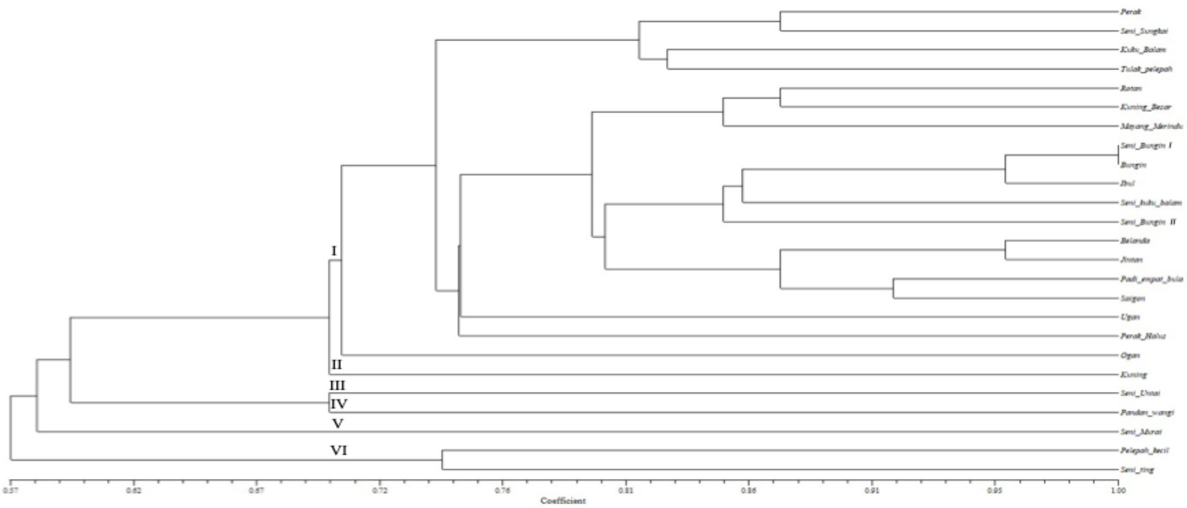

Figure 1. Cluster analysis of local upland rice cultivars based on quantitative and qualitative traits.

Cluster analysis

The Euclidean distance and single-linkage analysis used for clustering the local upland rice cultivars displayed distinct genetic groups (Figure 1). This approach provides insights into genetic diversity, identifying clusters that reflect adaptation strategies and ancestral lineages. Recognizing these diverse groups is valuable for targeted breeding programs, as it supports the integration of unique genetic traits for improved resilience. The cluster analysis offers a comprehensive understanding of genetic diversity by incorporating both qualitative and quantitative traits (Mazal *et al*., 2021).

In the study analysis, 25 local rice cultivars incurred clustering into six groups at a 70% similarity threshold (Figure 1), highlighting genetic variation and relationships relevant for breeding and conservation. Group 1, containing 19 cultivars, enunciated the highest genetic similarity, likely due to shared geographic origins and similar selective pressure. This affinity could have resulted from convergent evolution driven by common cultivation practices, environmental conditions, and the genotypes' selection for specific traits made by the farming community (Bailey-Serres *et al*., 2019; Fornasiero *et al*., 2022; Seck *et al*., 2023). Cultivars like Kuning, Seni Untai, Pandan Wangi, and Seni Murai formed separate clusters outside Group 1, indicating distinct lineages and unique selection criteria. Rice cultivars Pelepah Kecil and Seni Ting, in the sixth cluster, showed the greatest genetic distance, suggesting isolation, mutation, and adaptation to specific environmental conditions. These upland rice cultivars provide valuable genetic resources to enhance the genetic diversity in breeding programs.

Cluster analysis identified six distinct genetic groups, which is a novel finding compared with previous studies that typically reported fewer clusters (Nurhasanah *et al*., 2019; Seck *et al*., 2023). This suggests a richer genetic structure within Bungo cultivars, providing a valuable resource for breeding programs aimed at improving stress resilience and grain quality. Moreover, the presence of high genetic similarity in some cultivars, such as Seni Bungin I and Bungin, suggests potential redundancy, whereas the distinct genetic divergence observed in other groups offers opportunities for hybridization to enhance climate resilience.

In the beneficial study, the remarkable finding was the 100% genetic similarity observed between the rice cultivars Seni Bungin I and Bungin, suggesting that these genotypes were genetically identical and closely related. This similarity might indicate a shared genetic source with minimal genetic differentiation. Such observations prompt a reassessment of the classification of local cultivars, highlighting the need for genetic fingerprinting and verification to ensure accurate identification of the local cultivars (Vieira *et al*., 2022). Overall, these clustering results indicated substantial genetic diversity within local rice cultivars, as some genotypes displayed close genetic affinities and others showed significant divergence.

The findings of this study provide valuable insights into the genetic and phenotypic diversity of upland rice, which can have direct application in breeding programs. The identified traits, such as variations in plant height, tiller number, and grain morphology, can be helpful for selecting high-yielding and climate-resilient cultivars. Furthermore, unlike previous studies, which focused primarily on yield-related traits, this research emphasizes the genetic mechanisms underlying adaptation to local environmental conditions. This highlights the need for a breeding strategy that will integrate both phenotypic and genetic diversity to ensure long-term sustainability in upland rice production. The genetic clusters identified in this study offer a basis for targeted hybridization strategies to enhance desirable agronomic traits. From a conservation perspective, the diversity observed among these cultivars underscores the need for preserving local landraces as essential genetic resources. Conservation efforts should focus on maintaining in-situ and ex-situ collections to ensure the sustainability of these valuable traits for future breeding. Policies promoting farmer participation in conservation programs and the integration of traditional knowledge with modern breeding approaches will be crucial in safeguarding upland rice biodiversity.

CONCLUSIONS

In the practical study, significant phenotypic variability was notable in both qualitative and quantitative traits, indicating these rice cultivars have adapted to local ecological conditions. The diversity in agronomic traits suggests a broad genetic base, and these cultivars emerged to be more valuable for breeding programs focused on enhancing climate resilience, adaptability, and grain yield. Cluster analysis identified six distinct genetic groups, highlighting genetic affinity among most of the cultivars, while outliers observed with unique genetic backgrounds have opportunities for discovering novel traits. This genetic diversity is crucial for breeding climate-resilient rice cultivars and ensuring food security. The findings of this study have significant implications for rice conservation and breeding programs. The identified genetic diversity can serve as a beneficial resource for developing improved rice varieties with enhanced resilience to environmental stresses. Likewise, integrating modern breeding technologies, such as marker-assisted selection and genomic selection, could further optimize the utilization of these genetic resources for sustainable agricultural development.

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