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Article

Phenotypic Diversity of Farmers' Traditional Rice Varieties in the Philippines

Roel C. Rabara [†,*], Marilyn C. Ferrer, Celia L. Diaz, Ma. Cristina V. Newingham and Gabriel O. Romero

Philippine Rice Research Institute, Maligaya, Science City of Muñoz, Nueva Ecija 3119, Philippines; E-Mails: mc.ferrer@philrice.gov.ph (M.C.F.); celialeanod@yahoo.com (C.L.D.); mcvnewingham@email.philrice.gov.ph (M.C.V.N.); goromero2002@yahoo.com (G.O.R.)

[†] Current Address: Texas A & M AgriLife Research and Extension Center, Dallas, TX 75252, USA

* Author to whom correspondence should be addressed; E-Mail: roel.rabara@tamu.edu; Tel.: +1-972-952-9236.

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Abstract: Traditional rice varieties maintained and cultivated by farmers are likely sources of germplasm for breeding new rice varieties. They possess traits potentially adaptable to a wide range of abiotic and biotic stresses. Characterization of these germplasms is essential in rice breeding and provides valued information on developing new rice cultivars. In this study, 307 traditional rice varieties newly conserved at the PhilRice genebank were characterized to assess their phenotypic diversity using 57 morphological traits. Using the standardized Shannon-Weaver diversity index, phenotypic diversity indices averaged at 0.73 and 0.45 for quantitative and qualitative traits, respectively. Correlation analyses among agro-morphological traits showed a high positive correlation in some traits such as culm number and panicle number, flag leaf width and leaf blade width, grain width and caryopsis width. Cluster analysis separated the different varieties into various groups. Principal component analysis (PCA) showed that seven independent principal components accounted for 74.95% of the total variation. Component loadings for each principal component showed morphological characters, such as culm number, panicle number and caryopsis ratio that were among the phenotypic traits contributing positive projections in three principal components that explained 48% of variation. Analyses of results showed high diversity in major traits assessed in farmers' rice varieties. Based on plant height and maturity, 11 accessions could be potential donor parents in a rice breeding program. Future collection trips and characterization studies would further enrich diversity, in particular traits low in diversity, such as anthocyanin coloration, awn presence, awn color, culm habit, panicle type and panicle branching.

Keywords: rice germplasm; phenotypic diversity; traditional rice varieties; diversity index; germplasm conservation; morphological characterization

1. Introduction

Rice is a major crop in the Philippines with a production of 16.7 million MT ranking the Philippines eighth in the world [1]. It is a major calorie source for most Filipinos and a major income source for 12 million farmers and their families [2]. Rice production contributes 2.2% to the Gross Domestic Product (GDP) of the country [3]. It is also a culturally important crop to Filipinos as rice is featured in many festivals and rituals [4,5]. The Executive Order No. 1061 in 1985 acknowledged the importance of rice to the country's economy and livelihood by creating the Philippine Rice Research Institute (PhilRice) mandated to lead the country's rice research and development programs [6]. In the Philippines, the growth of the rice sector is highly dependent on yield improvements, which can be achieved through breeding new varieties and developing and promoting yield-enhancing technologies [2].

Rice breeders are constantly engaged in developing new rice varieties with higher yield potential to enhance the actual yield obtained by farmers in the field. One approach in plant breeding, proposed as early as 1968 is new ideotypes development [7]. This "plant-type concept of breeding" resulted from pioneering studies showing close associations between yield and certain morphological characters in response to nitrogen application [8,9]. In 1966, the selection for the semi-dwarf rice plant type led to the release of the first modern high yielding variety, IR8, which commenced the "green revolution" in Asia [8]. After 28 years of successful release of the IR8, a yield plateau was observed and prompted rice breeders to propose a new plant type (NPT) during the International Rice Research Institute (IRRI) strategic planning workshop in 1993 [8,10]. As such, morphological characters rather than physiological traits were considered for NPT rice because they were easy to distinguish in a breeding program [11].

Rice genetic resources are key components to breeding programs, and farmers have played important roles in contributing to rice diversity by developing and nurturing thousands of rice varieties for several years [12]. This vast wealth of rice germplasm including landraces and traditional varieties is a good source of important alleles to develop new rice varieties. These germplasms serve as the foundation of any rice breeding program because they are the source of important traits necessary for improving and developing new breeds of rice varieties [13]. Several reports have shown the utilization of rice landraces in developing new varieties. IR8, dubbed a miracle rice [14], was the product from crosses between two landraces: a semi dwarf rice Dee-geo-woo-gen and tall, vigorous rice Peta [15]. The submergence tolerance SUB1 QTL was identified from submergence tolerant rice landrace FR13A. Its identification and characterization led to successful introgression of the QTL to rice mega-varieties [16]. Recently, the *NAL1* allele that was identified from tropical *Japonica* rice landrace Daringan significantly increased the yield of modern rice cultivars [17].

Characterization of rice germplasms increases its utility in any breeding program. The use of agro-morphological traits is the most common approach utilized to estimate relationships between genotypes [18]. This approach was employed to assess diversity on ancestral lines of improved rice varieties in the Philippines [13], the indigenous rice in Yunnan, China [19] and the rice landraces in Nepal [18]. The conservation and characterization of these genetic resources is a necessity not only for posterity, but also for utilization in different improvement programs such as breeding for improved yield and tolerance to various stresses. It is important to assess the diversity of these germplasms materials to provide insights in the diversity of these germplasms.

Thus, this study assessed the phenotypic diversity of new rice germplasm farmers' varieties conserved at the PhilRice genebank. Information generated from phenotyping these germplasms can be used as basis for future collection trips to augment diversity in the genebank collections as well as baseline information for utilization in rice breeding programs.

2. Results and Discussion

2.1. Germplasm Characterization

2.1.1. Diversity in Qualitative Traits

Phenotyping is an important activity to evaluate the utilization of the germplasm collection in a genebank. In this study, 307 traditional rice varieties recently conserved at the PhilRice genebank were scored and measured using 39 qualitative and 18 quantitative morphological characters. These germplasms were comprised of 215 *Indica*, 89 *Javanica* and three *Japonica* varieties (appendix Table A1). Among the qualitative characters scored, ligule shape and culm kneeling ability were observed invariants. All the germplasm characterized had a two-cleft ligule shape and the culms had no kneeling ability (Table 1). Twenty of the qualitative traits scored were dominated by one character in each trait with a distribution ranging between 76%–95%. As a result, these twenty agronomic traits had low diversity indices ranging between 0.12–0.45. These were mainly awn-related characters such as presence, color, distribution, and type. Awn color and panicle were the lowest calculated indices ($H' = 0.12$) because 95% of the varieties scored had no awn and 92% had a medium length panicle type. Most of the varieties had thick culms and an erect culm habit. Moderately diverse traits were observed for 15 descriptors with indices ranging between 0.46–0.74. Most of these traits were inflorescence-related traits such as panicle and spikelet characters. Diversity in caryopsis pericarp color (seed coat color) (Figure 1) was also evident with all states being represented in the rice varieties evaluated. White seed coat color was the predominant state (50.5%), followed by red seed coat color (30.0%), variable purple (5.9%), light brown (4.6%) and purple (4.2%).

Four of the 39 traits scored had a high diversity with an average index of 0.87. Two of these traits were culm-related which assessed rice sturdiness during maturity and harvest. Although the predominant character was intermediate lodging resistance, 37% of the rice varieties had strong to very strong lodging resistance at the mature stage. The endosperm type trait had the highest calculated diversity index of 0.99. The reason for this is that all the endosperm type descriptors (1 = non-glutinous, 2 = Intermediate, 3 = glutinous) were identified in the characterized germplasm.

Table 1. Qualitative traits showing the predominant state observed, distribution (%) and the calculated Shannon diversity indices (H′) for each descriptor scored.

Descriptor	Predominant State	%	States Observed	H′ Index
Invariant				
Ligule Shape	2-cleft	100.00	1	0.00
Culm Kneeing Ability	Absent	100.00	1	0.00
Low diversity				
Awn Color (Late)	Awnless	95.11	4	0.12
Panicle Type	Medium (~25 cm)	91.86	3	0.12
Awn Color (Early)	Awnless	91.53	6	0.18
Awn Distribution	Awnless	91.53	5	0.20
Culm Diameter Type	Thick	96.42	2	0.22
Awn Type	Awnless	91.21	5	0.22
Panicle Secondary Branching	Sparse	89.58	3	0.25
Culm Habit/Angle	Erect (<15°)	85.67	4	0.26
Sterile Lemma Type	Medium	62.54	3	0.27
Culm Anthocyanin Coloration on Nodes	Absent	90.55	4	0.28
Awn Presence	Absent	91.53	3	0.29
Leaf Blade Pubescence	Intermediate	91.86	3	0.29
Flag Leaf Attitude/Angle	Erect	83.71	4	0.30
Leaf Blade Attitude	Erect	89.90	3	0.31
Sterile Lemma Color	Straw	88.27	4	0.32
Panicle Attitude	Drooping	84.36	5	0.37
Stigma Color	White	77.85	4	0.41
Auricle Color	Whitish	75.90	6	0.45
Moderate diversity				
Lemma & Palea Color (Late Observation)	Straw	66.45	8	0.46
Panicle Attitude of Main Axis	Slightly drooping	70.03	3	0.49
Leaf Blade Length Type	Intermediate (~50 cm)	60.59	3	0.54
Culm Underlying Node Color	Green	73.29	3	0.56
Leaf Blade Width Type	Intermediate	65.15	2	0.59
Flag Leaf Attitude (Late Measurement)	Descending	71.01	4	0.63
Culm Length Type	Intermediate to long	36.81	6	0.63
Culm Number Type	Intermediate (~15 culms)	75.24	3	0.65
Late Lemma Apiculus Color	Straw	47.56	9	0.65
Lemma & Palea Pubescence	Short hairs	60.91	5	0.66
Panicle Exsertion	Well exerted	55.37	5	0.67
Caryopsis Pericarp Color (Seed Coat Color)	White	50.49	7	0.68
Caryopsis Shape	Long spindle-shaped	43.97	5	0.71
Productivity	Intermediate	70.03	3	0.71
Apiculus Shape	Curved	78.83	2	0.74
High diversity				
Early Lemma Apiculus Color	Straw	26.71	8	0.79
Culm Lodging Resistance	Intermediate	42.02	5	0.84
Culm Strength	Intermediate	41.04	5	0.84
Endosperm Type	Non-glutinous	41.37	3	0.99
Average diversity				0.45

Overall, the diversity in qualitative traits was low with an average index of 0.45. Several traits that were classified as low diversity might be prioritized in future collection trips to enhance their diversity in our genebank. Although not all these traits are linked to yield, some traits such as panicle and culm diameter types are useful parameters for improving yield. Wu *et al.*, have shown that large culm rice varieties have a higher number of grains per panicle and a longer spike length [20].

Figure 1. Diversity in grain color and caryopsis pericarp color of the different traditional rice varieties screened. Numbers in parenthesis are the collection numbers of the rice germplasm.

2.1.2. Diversity in Quantitative Traits

The 307 varieties showed diverse phenotypes in terms of plant height, leaf blade, flag leaf culm number and panicle number, among others. Table 2 sums up the quantitative morphological characters showing the highest and lowest values measured for each character. Most of the traits had moderate (5) to high (12) diversity indices. Awn length was the only trait that showed low diversity ($H' = 0.02$). This could be attributed to only 14 varieties exhibiting awns in their grains. Traits with moderate diversity included caryopsis (length, width and ratio) and culm descriptors (diameter and number). Culm number could be associated with yield if all tillers produced inflorescence. Culm strength and culm lodging resistance had diversity indices of 0.84. Maturity of characterized germplasm ranged from 71 to 154 days. Rice variety Inuway (CollNo. 10869) had the shortest maturity. This variety was collected in an upland ecosystem in the Aurora province. Plant height varied from 68 cm to 161 cm, observed in Kinakaw (CollNo. 10857) and Dinorado (CollNo. 11049), respectively. Dinorado is an upland variety popular in the Arakan Valley of North Cotabato known for its sweet aroma, pinkish grain and good eating quality [4]. Additionally, the majority of the farmers' varieties (82%) were >100 cm tall with an average height of 116 cm and a median of 117 cm contradicting breeders' preference of 90–100 cm tall rice varieties among other characteristics to serve as potential donor for NPT breeding program [6].

Table 2. Quantitative descriptors and calculated Shannon-Weaver index (H′) of evaluated rice varieties, and calculated numbers enclosed in parenthesis are the collection numbers of the rice germplasm.

Descriptors	H′	Min Trait Value	Variety	Max Trait Value	Variety	Mean Trait Value (± Standard Deviation)
Low Diversity						
Awn Length (mm)	0.02	1.98	Puchagwan (11241)	69.64	Burdagol (11083)	0.80 (6.01)
Moderate Diversity						
Caryopsis Length (mm)	0.64	4.37	Milagrosa (11102)	13.72	Binaka (10838)	6.49 (1.04)
Caryopsis Width (mm)	0.70	4.15	Kaimpas (11315)	1.28	Doriat Pula (10934)	2.23 (0.37)
Culm Diameter at Basal Internode (mm)	0.72	0.58	Fancy-1 (11105)	12.40	Speaker (11080)	8.06 (1.92)
Culm Number	0.73	5.20	Lubang (11341)	34.80	Rc 18 (Pula) (11312)	16.30 (4.48)
Caryopsis Length/Width Ratio Score	0.74	1.42	Kaimpas (11315)	5.12	Binaka (10838)	2.98 (0.60)
High Diversity						
Panicle Length (cm)	0.77	20.90	Pinarompong (10932)	38.80	Unoy (Umangan) (11245)	27.27 (2.67)
Maturity (day)	0.77	71.00	Inuway (10869)	154.00	18-Pula (11061); Galo (11205)	106.84 (35.69)
Grain Width (mm)	0.78	1.51	Duriat (10943)	6.56	Kipil (10837)	2.58 (0.53)
Panicle Number Per Plant	0.78	5.20	Lubang (11341)	34.80	Rc 18 (Pula) (11312)	16.26 (4.46)
Flag Leaf Length (cm)	0.79	23.80	Bolinao (11256)	72.80	Kinakaw (10857)	38.57 (7.56)
Leaf Blade Length (cm)	0.80	34.80	C-4 Dinorado (11317)	88.40	Lubang (11356)	58.36 (9.13)
Sterile Lemma Length (mm)	0.81	1.56	M10-2 (11086)	3.86	Minindoro (Pula) (10844)	2.47 (0.39)
100 Grain Weight (g)	0.81	1.10	Kinakaw (10857)	5.50	Binaka (10810)	2.45 (0.54)
Culm Length (cm)	0.82	67.80	Kinakaw (10857)	160.60	Dinorado (11049)	116.03 (15.67)
Grain Length (mm)	0.84	5.29	Dinorado (10860)	10.76	Binaka (10810)	8.48 (1.05)
Flag Leaf Width (cm)	0.85	1.10	Elon-Peta (11346)	2.60	Binisaya (10826)	1.95 (0.32)
Leaf Blade Width (cm)	0.85	0.96	Rc 18 (Pula) (11312)	2.48	Binisaya (10826)	1.64 (0.30)
Average Diversity	0.73					

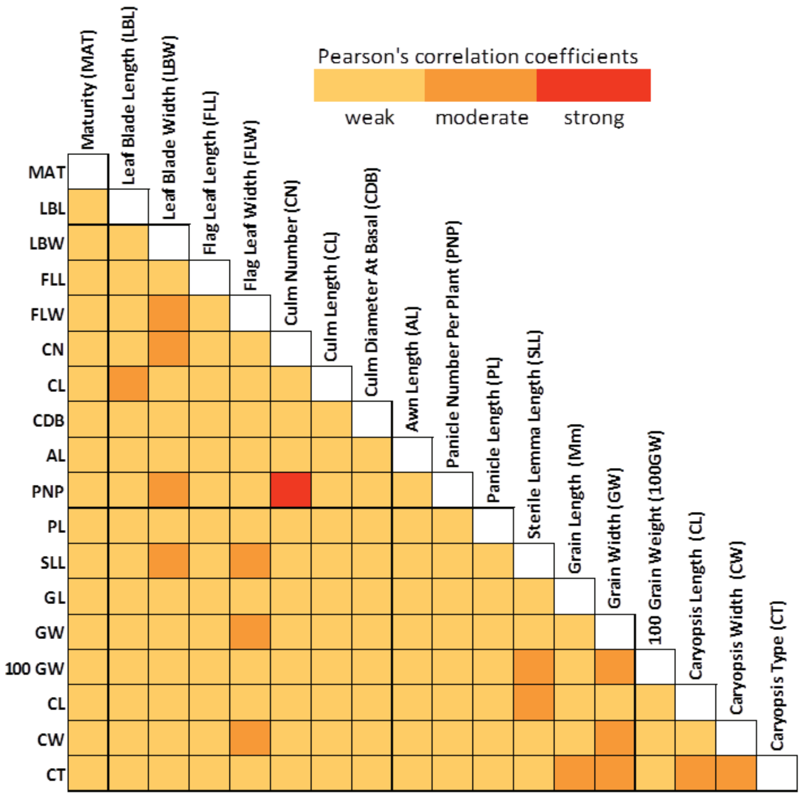
Grain trait diversity was also observed in the germplasm (Figure 1). Of the 307 accessions, only 14 rice varieties had awns present on the grains with their lengths ranging from 2 mm to 70 mm with the variety Burdagol (CollNo. 11083) having the longest awn. The presence of awns is considered an important trait in rice domestication. Grains of wild rice have long awns that protect the grains from animal pilfering. Some reports suggest that the presence of awns in grains aids bird resistance in agricultural crops [21,22]. Early studies in sorghum breeding have shown that varieties with long awns or that are strongly awned are more resistant to bird attacks than varieties with no awns [23]. Awned grains along those with few tillers and long panicles were found to be the characteristics of the bulu or *Javanica* group within the tropical *Japonica* varieties [24]. On the other hand, cultivated rice varieties have short awns allowing for easier harvesting than varieties with long awns [25]. Low tillering capability (three to four tillers) was one of the criteria used by IRRI rice breeders in selecting donor parents to be used in developing NPTs of rice [8]. Tillering ability among the 307 farmers' rice varieties ranged from five to 35 tillers. Rc 18-Pula (CollNo. 11312) showed the highest tillering ability among the farmers' varieties. It is a red-coated rice variety collected in the Bohol province and considered one of the popular varieties in the area based on Bertuso's survey [26]. This variety is a rice farmer's selection in 1997 [26] from his field planted with PSB Rc 18 (has a white seed coat), a modern rice variety released in 1994 for irrigated rice ecosystem [2]. Sturdy culm was another criterion used for donor parent selection for NPTs. The majority of the germplasms characterized (96%) had thick culms with a ≥5 mm culm diameter. However, when rice varieties were assessed for lodging resistance, only 37% showed strong or very strong lodging resistance. This could be attributed to the plant height, a major factor in lodging resistance in rice [27]. Having a short plant structure is currently the preferred trait for improving lodging resistance in rice [28].

In general, diversity in quantitative traits was moderate with an average index of 0.73. Nearly all the traits measured showed moderate to high diversity.

2.2. Correlation among Traits

Using Pearson's product-moment correlation, an analysis was done to assess the relationship among the morphological traits. It is useful to determine the relationship among the morphological traits since this information will be useful in the utilization of the germplasm as well in the collection of the germplasm based on the target traits. Several traits showed significant correlations (r = 0.195; $p < 0.05$) among each other. A heat map (Figure 2) was constructed to visualize the traits that had weak ($r \leq 0.35$), moderate (r = 0.36–0.67) and strong (r = 0.68–1.00) correlations [29]. An analysis showed that 89% of the trait combinations had weak correlations while 10% had moderate correlations. Only the correlation between the panicle number per plant and the culm number (r = 0.998) was strong. This showed that all tillers were productive tillers and able to bear inflorescence. The panicle number per plant ranged from five to 35. Sterile lemma length and 100-grain weight showed a moderate correlation (r = 0.50). This was expected since any increase in sterile lemma length would positively affect the grain weight. A high correlation was also observed between the flag leaf width and leaf blade width (r = 0.59) indicating that an increase in leaf blade width might also result in an increase of flag leaf width. A positive correlation was also observed between flag leaf width and grain width (*r* = 0.40). Flag leaves are important in grain filling, as 80% of the total carbohydrate stored in the grains is produced by the top two leaves in rice [30].

Figure 2. Heat map showing calculated Pearson's product-moment correlation coefficients among morphological traits measured in all germplasms screened. Correlation coefficients were classified as weak ($r \leq 0.35$), moderate ($r \geq 0.36$) and strong ($r > 0.68$) [29].



These characteristics are essential to rice breeders as it has been demonstrated that the flag leaf area increased grain yield by increasing the number of spikelets per panicle [31]. Flag leaves were reported to be the major source of phloem-delivered photoassimilates during the grain-filling stage in rice [32]. Previous studies have shown that cutting of flag leaves could result to up to 45% grain yield loss [33]. A recent review by Biswal and Kohli outlined the importance of flag leaf traits in cereal breeding for drought tolerance [34]. Flag leaf sheath is one of the main sources of carbohydrate for rice grain filling under drought condition [35].

Although the correlation analyses showed only one combination trait that had a strong correlation, there were 16 combination traits that had moderate correlations. These traits that had moderate to high correlations could be used as a basis for the utilization of these sets of germplasm for breeding purposes as well as for planning future collection trips targeting specific traits. Trait correlations can be used by breeders either to simultaneously improve correlated traits or reduce undesirable side effects when trying to improve only one of the correlated traits [36].

2.3. Cluster and Principal Component Analyses of Rice Germplasm

The relationship among the 307 farmers' rice varieties as revealed by Unweighted Pair Group Method with Arithmetic Mean (UPGMA) cluster analysis is shown in Figure 3. Truncating the tree at the Euclidean distance of 1.13 resulted in 24 clusters. In the truncated tree, 10 clusters had single accession, another 10 clusters had two to ten accessions; three clusters had 23–50 accessions and one big cluster had 137 accessions. The fact that 83% of the clusters formed contained one to a few accessions implied a diversity in the collection. Among the single-accession clusters, most accessions were collected from the Palawan and Kalinga provinces. The majority of these germplasms were of the *Indica* type while two accessions belonged to *Javanica*. These single-accession clusters were considered distinct from each other and the rest of the clusters. Cluster 3 (variety C-4 Dinorado; CollNo. 11317), for example, had similar traits to the accessions in Cluster 2 for most traits, such as leaf blade width type, flag leaf width, type, and erect flag leaf attitude at early stage, but differed by having very short leaf blades and horizontal flag leaf attitude at a late stage. Similarly, the variety Kinakaw (CollNo. 10857, Cluster 24) was distinct from the rest of the clusters because it had a short plant stature, the longest flag leaf length and the lightest 100-grain weight. Other single-accession clusters such as Cluster 21 (Burdagol CollNo. 11083), Cluster 22 (variety Chay-ot; CollNo. 11246) and Cluster 23 (variety Ifo; CollNo. 11255) were peculiar because of their long awns (30–70 mm). Most of the accessions (90%) had no awns while the rest had short awns (2–16 mm). Variety Benangkar (CollNo. 10923) was another single-accession cluster, which was characterized by the presence of purple lines in its culm nodes, which is a trait not very common among the rest of the accessions screened. Cluster 1, one of the four big clusters, was characterized as having a short plant stature (average height of 94.8 cm) compared to Clusters 2 (110.53 cm) and 4 (121.03 cm). Most of the accessions in Cluster 2 belonged to the *Indica* type (90%).

Overall, cluster analysis provided an insight into the diversity of the collections as shown by the number of clusters formed with one to 10 members when the dendrogram was truncated at 1.13 distance. A distinct variety was separated from the rest of the germplasm pool as exemplified by the single-accession clusters.

Principal component analysis (PCA) was employed to reduce the complexity of the data set while retaining the variation within the data set as far as possible [37]. The PCA resulted in 18 independent principal components that had a cumulative explained variance of 100% (Table 3). Following the Proportion of Variance Criterion [38], seven principal components (PCs) were retained that had a cumulative variance of 75%. The first component accounted for 22.5% of the total variation in the data set while the second and third principal components contributed 14.5% and 10.6%, respectively. Together, these three components could explain 47.6% of the total variation in the characterized rice germplasm. Analysis of the factor loadings of the characters in the retained PCs showed that phenotypic traits that contributed to yield showed high positive loadings in PC 1 (Table 4). These traits were culm number, panicle number per plant and caryopsis ratio score with factor loadings of 0.649, 0.651 and 0.529, respectively. These three morphological characters could have contributed to the maximum variability in PC 1 which explained 22.5% of the total variation in the data set. Among these three traits, only panicle number per plant was classified as high diversity while the other traits had moderate diversity indices. In PC 2, leaf blade length presented the highest factor loading of 0.482. This showed that leaf blade length was the major morphological character that contributed to the variation in PC 2 which explained 14.5% of the variation. In PC 3, plant height (culm length) showed a high loading of 0.454.

Figure 3. Dendrogram generated by cluster analysis of morphological characters using Unweighted Pair Group Method with Arithmetic Mean (UPGMA).

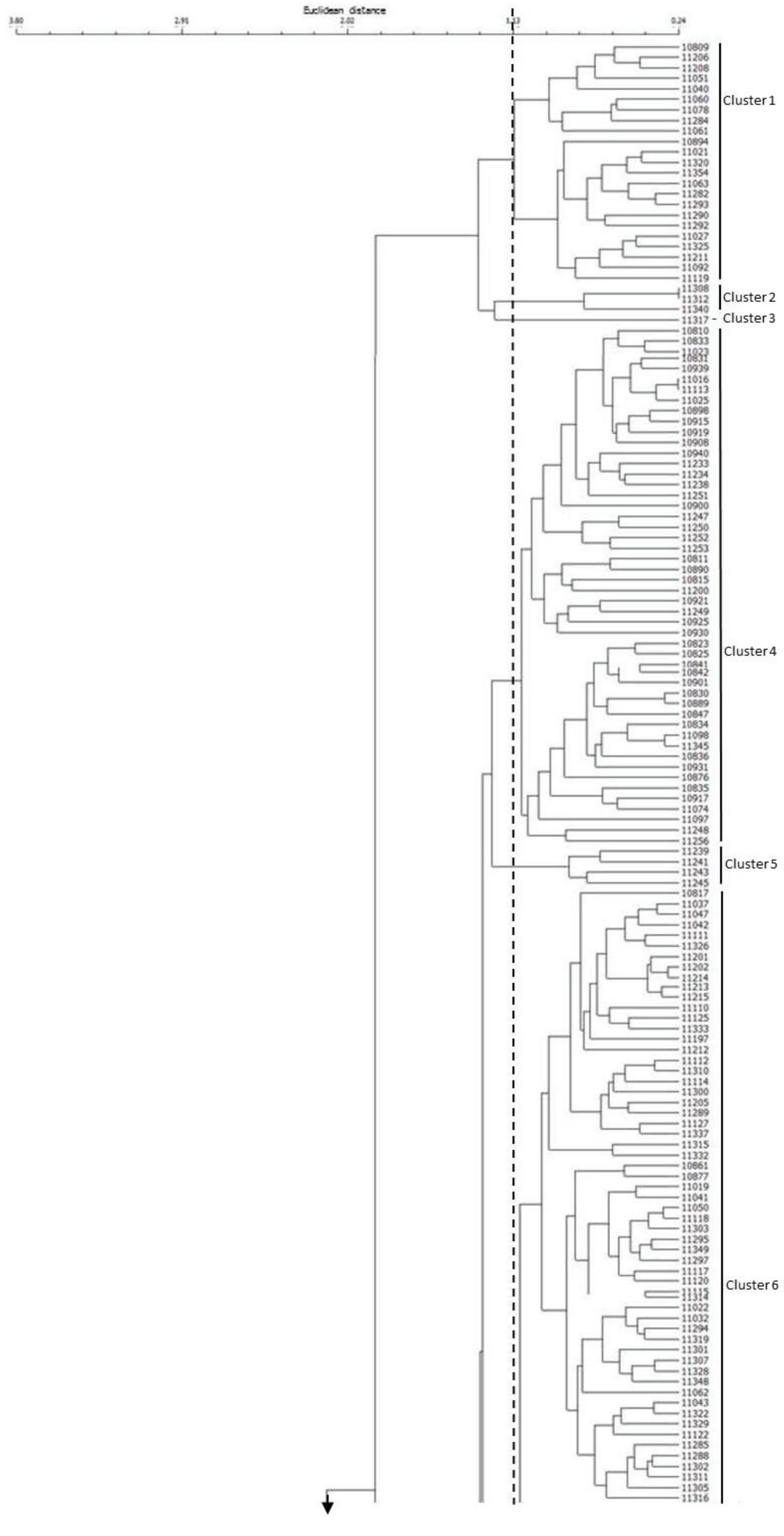


Figure 3. *Cont.*

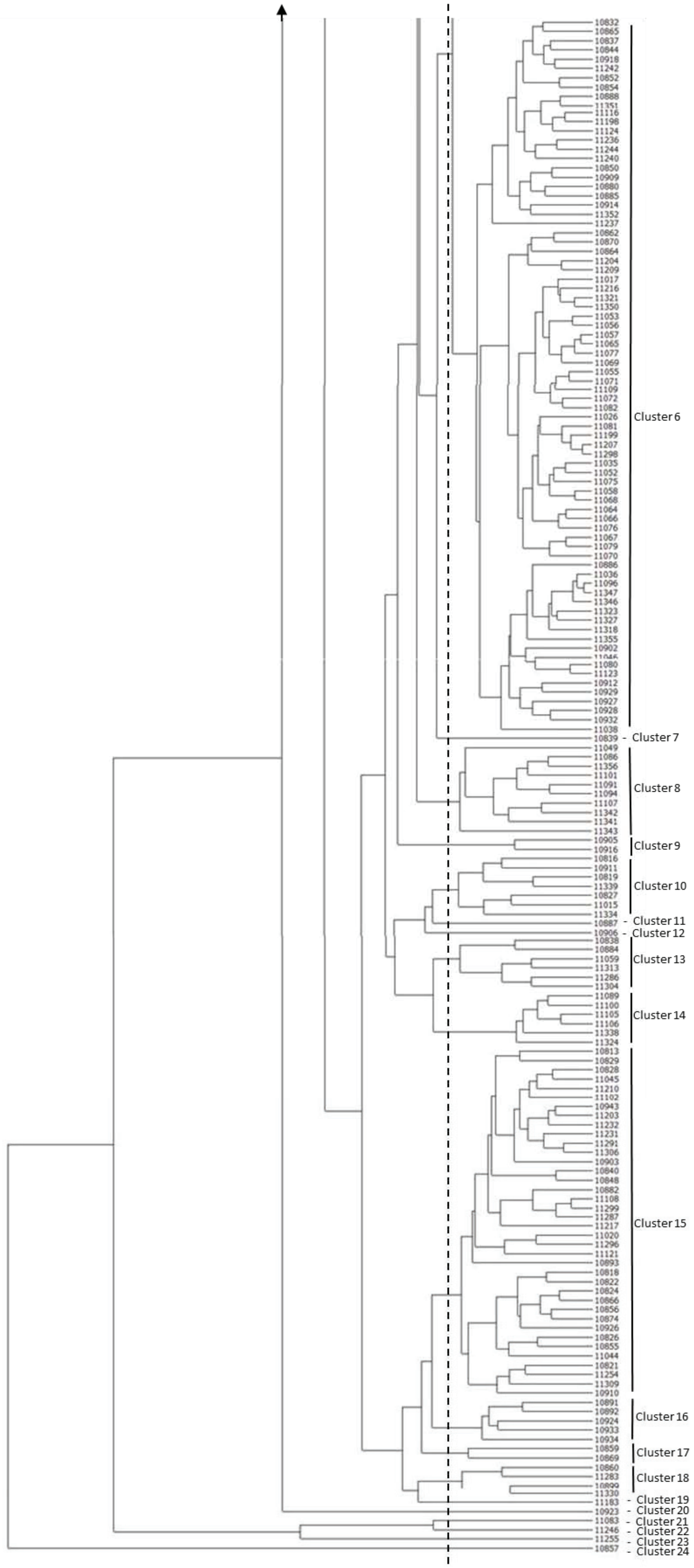


Table 3. Computed eigenvalues of the different principal components with corresponding proportion and cumulative explained variance.

Components	Eigenvalue	Explained Variance	
		Percent	Cumulative
1	4.04	22.46	22.46
2	2.61	14.52	36.98
3	1.91	10.61	47.59
4	1.61	8.97	56.56
5	1.26	7.01	63.58
6	1.05	5.84	69.41
7	1.00	5.53	74.95
8	0.82	4.57	79.52
9	0.71	3.96	83.48
10	0.64	3.53	87.01
11	0.57	3.19	90.21
12	0.49	2.75	92.95
13	0.41	2.30	95.26
14	0.33	1.85	97.11
15	0.29	1.61	98.72
16	0.21	1.16	99.87
17	0.02	0.12	99.99
18	0.00	0.01	>100%

Table 4. Factor loadings (eigenvectors) for the different morphological characters for the principal components retained.

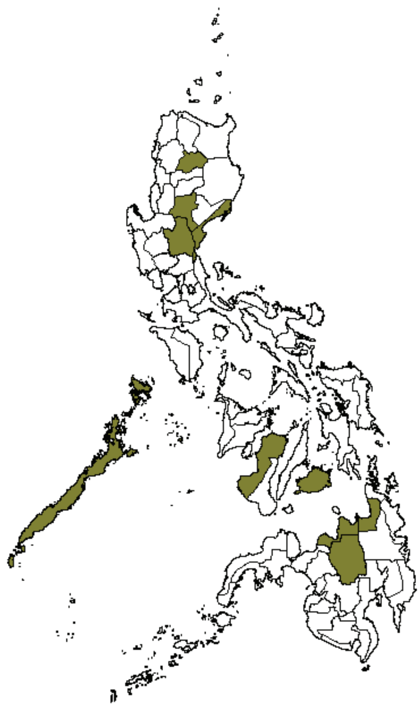
Descriptors	Principal Components						
	PC 1	PC 2	PC 3	PC 4	PC 5	PC 6	PC 7
Maturity (day)	0.33	0.29	0.34	0.10	0.40	0.23	0.23
Leaf Blade Length (mm)	−0.11	0.48	0.53	0.14	0.12	−0.08	−0.31
Leaf Blade Width (mm)	−0.67	−0.21	−0.04	−0.26	−0.25	0.25	0.04
Flag Leaf Length (mm)	−0.17	0.21	0.43	0.46	−0.11	0.13	−0.26
Flag Leaf Width (mm)	−0.73	−0.12	−0.01	0.00	−0.14	0.21	0.21
Culm Number	0.65	−0.28	−0.36	0.52	−0.08	0.17	−0.09
Culm Length (cm)	−0.34	0.37	0.45	0.11	−0.14	0.33	0.02
Basal Culm Diameter (mm)	−0.33	−0.33	−0.01	0.15	−0.32	0.54	0.17
Awn Length (mm)	−0.11	−0.01	0.06	0.22	−0.54	−0.57	0.41
Panicle Number/plant	0.65	−0.28	−0.36	0.51	−0.08	0.18	−0.10
Panicle Length (cm)	−0.27	0.01	0.33	0.59	−0.27	−0.20	0.01
Sterile Lemma Length (mm)	−0.51	−0.67	0.10	−0.12	0.18	−0.03	−0.08
Grain Length (mm)	0.06	−0.47	0.37	0.26	0.46	−0.06	0.46
Grain Width (mm)	−0.66	0.13	−0.29	0.34	0.39	−0.09	0.10
100-Grain Weight (g)	−0.51	−0.46	−0.03	0.28	0.29	−0.06	−0.02
Caryopsis Length (mm)	−0.10	−0.73	0.31	−0.08	−0.05	−0.14	−0.43
Caryopsis Width (mm)	−0.72	0.08	−0.38	0.18	0.10	−0.13	−0.33
Caryopsis Length/Width Ratio Score	0.53	−0.60	0.52	−0.18	−0.10	−0.02	−0.05

3. Experimental Section

3.1. Germplasm Characterization

A total of 307 rice germplasms conserved at the Philippine Rice Research Institute (PhilRice) genebank which were collected from different parts of the country (Figure 4) were used to evaluate the genetic diversity of farmers' traditional rice varieties and landraces. Characterization of the collected rice germplasms was done at the at the PhilRice Central Experimental Station, Maligaya, Science City of Munoz, Nueva Ecija (15°40′ N, 120°53′ E, 57.6 masl) during the wet cropping season (WS) in 2009. Prior to sowing, seeds were incubated in the oven set at 37 °C for 12 h to break inherent seed dormancy. Seeds were sown in a raised seedbed in the greenhouse and covered with coconut coir dust. Seven-day-old seedlings were transplanted into the field following a planting distance of 25 cm × 25 cm. A total of 20 plants per accession in three replicates were planted in the field for characterization. Agronomic characters were measured and scored following the Rice Descriptors [39]. A total of 18 quantitative and 39 qualitative characters were selected to score the germplasm collections.

Figure 4. Philippine map showing the provinces (areas in green) where the rice germplasm were collected. The map was generated using DIVA-GIS ver.7.5.0 [40].



3.2. Data Analyses

Descriptive statistics was done using PROC UNIVARIATE procedure in SAS ver. 9.3 (SAS Institute, Cary, NC, USA [41]). Correlations among morphological traits measured were analyzed using PROC CORR procedure in SAS. Shannon-Weaver diversity index (H′) was used to calculate the phenotypic diversity of the characterized farmers' varieties following the protocol used by Sotto and Rabara [42]. An arbitrary scale was adapted from Jamago and Cortes [43] to categorize the computed indices into maximum (H′ = 1.00), high (H′ = 0.76–0.99), moderate (H′ = 0.46–0.75) and low diversity (0.01–0.45). Diversity indices of collected germplasm were calculated based on phenotypic frequency using standardized Shannon-Weaver Diversity index formula:

$$H' = -\Sigma pi(\log_2 pi)/\log_2 N$$

wherein

pi = frequency proportion of the descriptor state

N = number of states

The standardized Shannon-Weaver provided a constrained index between zero and one with the highest value indicating maximum abundance [44,45]. Multivariate statistical analyses of characterization data were conducted using principal component (PCA) and cluster (CA) analyses. PCA was employed to identify the different morphological characters that contributed to the most variance in the measured variables. In PCA, the raw data were standardized and the distance matrix using the variance-covariance coefficients was computed. The Proportion of Variance criterion was used to identify the different principal components that contributed to the total variance in the dataset [23]. PCA and CA were done using NTSYSpc version 2.1 software [46]. The distance matrix was generated using the Euclidean Distance Coefficients and was used as input for clustering using the unweighted pair group of arithmetic means (UPGMA) method.

4. Conclusions

Phenotyping of germplasm materials is an important undertaking in genetic resource conservation to ensure efficient conservation management as well as its effective utilization especially in breeding programs. In this study, 307 rice varieties were characterized to assess their phenotypic diversity. Diversity analyses showed that 46% of the qualitative traits scored had low diversity indices compared to only 5% in quantitative traits. Overall, the rice germplasm showed moderate diversity based on quantitative characters (average index of 0.73). In contrast, the qualitative characters had a low diversity (average index of 0.45). In comparison to other landraces collections, the diversity in qualitative traits of our germplasm was higher than what Bajracharya *et al.*, observed in the landraces from Nepal [18]. The complete qualitative data set of our collection is available in appendix Table A1.

In order to enrich the diversity of qualitative traits in our collection at the PhilRice genebank exploration trips may be conducted. Collection gaps should be identified in the genebank's germplasm collection and should be prioritized in future collection trips. An emphasis on farmers' varieties that have been planted in a community for several generations should be considered when planning for collection trips. It should also considered to look for diversity in qualitative characters that have shown low diversity indices such as presence of awns, panicle type, and culm habit type among other characters. Other factors that can be considered during collection of these rice germplasms are the characters that have high correlations with other characters. Collecting diversity for certain traits or characters could also lead to a high diversity if the characters are highly correlated.

The success of any conservation program could also be measured by the amount of which these genetic resources are being utilized. Data generated from characterization of these 307 rice varieties can be utilized as baseline information for the utilization of these germplasms for any rice breeding program such as breeding for ideoypes. For example, 37 accessions meets the plant height criterion (90–100 cm) for NPT among which 11 accessions also meets the maturity requirement (110–120 days). Short stature variety was one of the criteria to select a variety for use in a breeding program to address lodging. The optimal growth duration to achieve maximum yield is about 120 days [8]. A linear increase in total biomass had been observed when the growth duration was increased from 95 days to 135 days [47]. Efforts should be invested in promoting various stakeholders in rice production to utilize these germplasms. Effective utilization of these germplasms can be enhanced if these materials are fully characterized and evaluated for their potential use in breeding programs. Evaluation of these germplasms should be conducted to assess their potential as donor parents for the breeding of new varieties with improved responses to various abiotic and biotic stresses. Broadening of the genetic base through utilization of diverse germplasms in breeding for new rice varieties may be able to break the yield barrier that rice breeders are currently trying to address.

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Author Contributions

Roel C. Rabara designed the experiment, analyzed the data and written the manuscript. Marilyn C. Ferrer conducted the phenotyping experiments, assisted in data analysis and contributed in writing the manuscript. Celia L. Diaz contributed in phenotyping the germplasm. Ma. Cristina V. Newingham contributed in data encoding and database management. Gabriel O. Romero contributed in writing the manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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Appendix

Table A1. Ecogeographic race of the different traditional rice varieties.

Collection Number	Cultivar Name	Province	Eco-geographic Race
10809	Galo	Aurora	*Indica*
10810	Binaka (Malagkit)	Aurora	*Indica*
10811	Palawan	Aurora	*Indica*
10813	Galo (Malagkit)	Aurora	*Indica*
10815	Galo	Aurora	*Indica*
10816	Galo (Malagkit)	Aurora	*Indica*
10817	Brilyante	Aurora	*Indica*
10818	Galo	Aurora	*Indica*
10819	Malagkit	Aurora	*Indica*
10821	Inuway	Aurora	*Indica*
10822	Lubag/Galo	Aurora	*Indica*
10823	Palawan	Aurora	*Javanica*
10824	Lubag (With Awn)	Aurora	*Indica*
10825	Palawan	Aurora	*Javanica*
10826	Binisaya	Aurora	*Indica*
10827	Galo (Malagkit)	Aurora	*Indica*
10828	Gayanggang	Aurora	*Indica*
10829	Lubag	Aurora	*Indica*
10830	Malagkit (Puti)	Aurora	*Javanica*
10831	Inuhay	Aurora	*Indica*
10832	Palawan	Aurora	*Javanica*
10833	Inuhay	Aurora	*Indica*
10834	Galo	Aurora	*Javanica*
10835	Galo (Malagkit)	Aurora	*Javanica*
10836	Galo (Haba)	Aurora	*Indica*
10837	Kipil	Aurora	*Japonica*
10838	Binaka (Malagkit)	Aurora	*Javanica*

Table A1. *Cont.*

Collection Number	Cultivar Name	Province	Eco-geographic Race
10839	Gayanggang	Aurora	*Indica*
10840	Palawan	Aurora	*Javanica*
10841	Sinagat	Aurora	*Javanica*
10842	Minindoro (Puti)	Aurora	*Indica*
10844	Minindoro (Pula)	Aurora	*Indica*
10847	Malagkit-Itim	Aurora	*Javanica*
10848	Palawan	Aurora	*Javanica*
10850	Lubag (Malagkit)	Aurora	*Javanica*
10852	Binernal	Aurora	*Javanica*
10854	Francis Rice	Aurora	*Javanica*
10855	Inuway	Aurora	*Indica*
10856	Galo	Aurora	*Indica*
10857	Kinakaw	Aurora	*Indica*
10859	Binisaya	Aurora	*Javanica*
10860	Dinorado	Aurora	*Javanica*
10861	Sinabado	Aurora	*Indica*
10862	Galo	Aurora	*Indica*
10864	Binisaya	Aurora	*Indica*
10865	Kinamalig	Aurora	*Javanica*
10866	Galo	Aurora	*Indica*
10869	Inuway	Aurora	*Indica*
10870	Galo	Aurora	*Indica*
10874	Azucena	Aurora	*Indica*
10876	Pirurutong (Malagkit)	Aurora	*Javanica*
10877	Kapirit	Aurora	*Indica*
10880	Milagrosa (Pilit)	Palawan	*Indica*
10882	Minantika	Palawan	*Indica*
10884	Pinutyukan	Palawan	*Indica*
10885	Milagrosa (Pula)	Palawan	*Indica*
10886	Doryat	Palawan	*Indica*
10887	Blandi	Palawan	*Indica*
10888	Doryat	Palawan	*Indica*
10889	Tipak	Palawan	*Indica*
10890	Rambo	Palawan	*Indica*
10891	Kinadoy	Palawan	*Indica*
10892	Kinadoy	Palawan	*Indica*
10893	Malagkit	Palawan	*Indica*
10894	Unknown	Palawan	*Indica*
10898	Tipak	Palawan	*Javanica*
10899	Dinorado	Palawan	*Indica*
10900	Malagkit (Pula)	Palawan	*Javanica*
10901	Dinorado	Palawan	*Indica*
10902	Dinorado	Palawan	*Indica*

Table A1. *Cont.*

Collection Number	Cultivar Name	Province	Eco-geographic Race
10903	Buringan	Palawan	*Indica*
10905	Mating	Palawan	*Indica*
10906	Lawang	Palawan	*Indica*
10908	Muring-Oring	Palawan	*Javanica*
10909	Kinoron	Palawan	*Indica*
10910	Pinangpang	Palawan	*Indica*
10911	Red Rice	Palawan	*Indica*
10912	Binoring-Boring	Palawan	*Javanica*
10914	Sagang (Malagkit Puti)	Palawan	*Javanica*
10915	Fortuna	Palawan	*Indica*
10916	Calubid	Palawan	*Indica*
10917	Black Rice	Palawan	*Javanica*
10918	Milagrosa	Palawan	*Indica*
10919	Benareng	Palawan	*Indica*
10921	Minaola	Palawan	*Javanica*
10923	Benangkar	Palawan	*Javanica*
10924	Mangatas	Palawan	*Indica*
10925	Dinayudo	Palawan	*Indica*
10926	Dinamit	Palawan	*Indica*
10927	Tipak	Palawan	*Indica*
10928	Inamoy	Palawan	*Indica*
10929	Laok-Laok	Palawan	*Indica*
10930	Pinarongpong	Palawan	*Javanica*
10931	Kalinayin	Palawan	*Indica*
10932	Pinarompong	Palawan	*Javanica*
10933	Pinalawan	Palawan	*Indica*
10934	Doriat Pula	Palawan	*Indica*
10939	Pangpang	Palawan	*Indica*
10940	Inantote	Palawan	*Indica*
10943	Duriat	Palawan	*Indica*
11015	Metao	Negros Occidental	*Javanica*
11016	Kutsiam	Negros Occidental	*Indica*
11017	Aowot	Negros Occidental	*Javanica*
11019	Milagrosa	Negros Occidental	*Indica*
11020	Dinorado	Negros Occidental	*Indica*
11021	Vietnam Rice	Negros Occidental	*Indica*
11022	Pilit	Negros Occidental	*Indica*
11023	Azucena	Negros Occidental	*Indica*
11025	Unknown 2	Negros Occidental	*Indica*
11026	Kasolid	Negros Occidental	*Indica*
11027	Pilit	Negros Occidental	*Indica*
11032	M-45	Negros Occidental	*Indica*

Table A1. *Cont.*

Collection Number	Cultivar Name	Province	Eco-geographic Race
11035	Malagaya	Negros Occidental	*Javanica*
11036	Dinorado	Negros Occidental	*Indica*
11037	Jao Dam Khi Kwai	Negros Occidental	*Indica*
11038	Ngacheik	Negros Occidental	*Indica*
11040	Tapol	Agusan Del Norte	*Indica*
11041	Kapakra	Agusan Del Norte	*Indica*
11042	Pilit-Tapol	Agusan Del Norte	*Indica*
11043	Señorita	Agusan Del Norte	*Indica*
11044	Red Cotabato	Misamis Oriental	*Javanica*
11045	Mimis	Misamis Oriental	*Indica*
11046	Mal-Os	Misamis Oriental	*Javanica*
11047	Kutong	Misamis Oriental	*Indica*
11049	Dinorado	Misamis Oriental	*Javanica*
11050	Kayatan	Misamis Oriental	*Javanica*
11051	Unknown	Misamis Oriental	*Indica*
11052	Kabuyog	Misamis Oriental	*Javanica*
11053	Gakit	Misamis Oriental	*Javanica*
11055	Dinorado	Misamis Oriental	*Indica*
11056	Speaker	Misamis Oriental	*Javanica*
11057	Dinorado	Misamis Oriental	*Indica*
11058	Gakit	Misamis Oriental	*Javanica*
11059	Unknown	Misamis Oriental	*Indica*
11060	Mabango	Misamis Oriental	*Indica*
11061	18 (Pula)	Misamis Oriental	*Indica*
11062	Ir-9	Misamis Oriental	*Indica*
11063	18 (Puti)	Misamis Oriental	*Indica*
11064	Unknown	Misamis Oriental	*Javanica*
11065	Dinorado	Misamis Oriental	*Indica*
11066	Speaker	Misamis Oriental	*Javanica*
11067	Kabuyok	Misamis Oriental	*Javanica*
11068	Pilit	Misamis Oriental	*Javanica*
11069	Kabuyok	Misamis Oriental	*Javanica*
11070	Mixture from Kabuyok	Misamis Oriental	*Javanica*
11071	Dinorado	Misamis Oriental	*Indica*
11072	Speaker	Misamis Oriental	*Javanica*
11074	Kabuyok	Misamis Oriental	*Javanica*
11075	Gakit	Misamis Oriental	*Javanica*
11076	Dinorado	Misamis Oriental	*Indica*
11077	Speaker	Misamis Oriental	*Javanica*
11078	Kayatan	Misamis Oriental	*Indica*
11079	Pilit-Tapol	Misamis Oriental	*Indica*
11080	Speaker	Misamis Oriental	*Javanica*

Table A1. *Cont.*

Collection Number	Cultivar Name	Province	Eco-geographic Race
11081	Dinorado	Misamis Oriental	*Indica*
11082	Unknown	Misamis Oriental	*Javanica*
11083	Burdagol	Negros Occidental	*Indica*
11086	M10-2	Negros Occidental	*Javanica*
11089	M45	Negros Occidental	*Indica*
11091	M119-Nl	Negros Occidental	*Indica*
11092	A-G-17	Negros Occidental	*Indica*
11094	Mb-4	Negros Occidental	*Indica*
11096	Inday	Negros Occidental	*Indica*
11097	Pangasinan	Negros Occidental	*Indica*
11098	M108	Negros Occidental	*Indica*
11100	M11-6-1	Negros Occidental	*Indica*
11101	Tape	Negros Occidental	*Indica*
11102	Milagrosa	Negros Occidental	*Indica*
11105	Fancy-1	Negros Occidental	*Indica*
11106	Galicia F-1	Negros Occidental	*Indica*
11107	Elon-Elon	Negros Occidental	*Indica*
11108	Manabang	Negros Occidental	*Javanica*
11109	Solig	Negros Occidental	*Indica*
11110	Kabagte	Negros Occidental	*Javanica*
11111	Azucena	Negros Occidental	*Indica*
11112	Ebod	Negros Occidental	*Javanica*
11113	Kotsiam	Negros Occidental	*Indica*
11114	Kalisan	Negros Occidental	*Javanica*
11115	Katipak	Negros Occidental	*Indica*
11116	Palawan	Negros Occidental	*Javanica*
11117	Bonlaw	Negros Occidental	*Javanica*
11118	Mangasa	Negros Occidental	*Indica*
11119	Pula	Agusan Del Norte	*Indica*
11120	Denorado	Agusan Del Norte	*Indica*
11121	Unknown	Agusan Del Norte	*Indica*
11122	M-23	Agusan Del Norte	*Indica*
11123	Dinorado	Agusan Del Norte	*Indica*
11124	Dinorado	Agusan Del Norte	*Indica*
11125	Dinurado	Agusan Del Norte	*Indica*
11127	Tapul-Pilit	Agusan Del Norte	*Indica*
11183	Farasang	Kalinga	*Indica*
11197	Palawan	Nueva Ecija	*Indica*
11198	Binaka	Nueva Ecija	*Indica*
11199	Inuway	Nueva Ecija	*Indica*
11200	Galo	Nueva Ecija	*Indica*

Table A1. *Cont.*

Collection Number	Cultivar Name	Province	Eco-geographic Race
11201	Palawan	Nueva Ecija	*Javanica*
11202	Ginobyerno	Nueva Ecija	*Javanica*
11203	Sinumay	Nueva Ecija	*Indica*
11204	Dinorado	Nueva Ecija	*Indica*
11205	Galo	Nueva Ecija	*Indica*
11206	Palawan	Nueva Ecija	*Javanica*
11207	Inuway	Nueva Ecija	*Indica*
11208	Galo	Nueva Ecija	*Indica*
11209	Palawan	Nueva Ecija	*Javanica*
11210	Palawan	Nueva Ecija	*Javanica*
11211	Dinorado	Nueva Ecija	*Indica*
11212	Inuway	Nueva Ecija	*Indica*
11213	Palawan	Nueva Ecija	*Javanica*
11214	Minindoro	Nueva Vizcaya	*Javanica*
11215	Palawan	Nueva Vizcaya	*Javanica*
11216	Brilyante	Nueva Vizcaya	*Indica*
11217	Galo	Nueva Vizcaya	*Indica*
11231	White Intan	Kalinga	*Indica*
11232	Intan (Red)	Kalinga	*Indica*
11233	Waray	Kalinga	*Indica*
11234	Red Intan	Kalinga	*Indica*
11236	Ummunoy	Kalinga	*Javanica*
11237	Kintuman	Kalinga	*Javanica*
11238	Ingtan (Red)	Kalinga	*Indica*
11239	Tuhuwan	Kalinga	*Javanica*
11240	Gwayay (Chay-Ot)	Kalinga	*Javanica*
11241	Puchagwan	Kalinga	*Javanica*
11242	Unoy (Ummunoy)	Kalinga	*Javanica*
11243	Unoy (Tu-Par)	Kalinga	*Javanica*
11244	Chay-Ot (Ojak)	Kalinga	*Javanica*
11245	Unoy (Umangan)	Kalinga	*Javanica*
11246	Chay-Ot (Ifuwan)	Kalinga	*Javanica*
11247	Chomalingan	Kalinga	*Javanica*
11248	Chinannay	Kalinga	*Indica*
11249	Inasotiyan	Kalinga	*Javanica*
11250	Finongod 2	Kalinga	*Indica*
11251	Finongod	Kalinga	*Javanica*
11252	Innoway	Kalinga	*Javanica*
11253	Innoyan	Kalinga	*Indica*
11254	Mingol	Kalinga	*Indica*
11255	Ifo	Kalinga	*Indica*
11256	Bolinao	Kalinga	*Javanica*

Table A1. *Cont.*

Collection Number	Cultivar Name	Province	Eco-geographic Race
11282	7 Tonner	Bukidnon	*Indica*
11283	Red Rice	Bukidnon	*Indica*
11284	Red Tonner	Bukidnon	*Indica*
11285	Barako	Bukidnon	*Indica*
11286	Red Rice	Bukidnon	*Indica*
11287	Burdagol (Pilit)	Bukidnon	*Indica*
11288	Pilit	Bukidnon	*Indica*
11289	Pilit	Bukidnon	*Indica*
11290	Red Tonner	Bukidnon	*Indica*
11291	Red Rice	Bukidnon	*Javanica*
11292	Brown Rice	Bukidnon	*Indica*
11293	Dwarf Variety	Bukidnon	*Indica*
11294	M-3	Bukidnon	*Indica*
11295	Elon-Elon	Bukidnon	*Indica*
11296	Red Tonner	Bukidnon	*Indica*
11297	Baknap	Bukidnon	*Indica*
11298	Azucena	Bukidnon	*Indica*
11299	Bakiki	Bukidnon	*Indica*
11300	Lubang	Bohol	*Indica*
11301	Lubang	Bohol	*Indica*
11302	Unknown	Bohol	*Indica*
11303	Muddy Rice	Bohol	*Indica*
11304	Kaimpas	Bohol	*Indica*
11305	Milagrosa	Bohol	*Javanica*
11306	Milagrosa	Bohol	*Indica*
11307	Inibi (Red)	Bohol	*Indica*
11308	Kaliga	Bohol	*Indica*
11309	Muddy Rice	Bohol	*Indica*
11310	Malagkit (Puti)	Bohol	*Indica*
11311	Kaliga (Red)	Bohol	*Indica*
11312	Rc 18 (Pula)	Bohol	*Indica*
11313	Kaliso	Bohol	*Javanica*
11314	Muddy Rice	Bohol	*Indica*
11315	Kaimpas	Bohol	*Japonica*
11316	Malagkit	Bohol	*Indica*
11317	C-4 Dinorado	Bohol	*Indica*
11318	Kabus-Ok	Bohol	*Indica*
11319	Rc 10 (Pula)	Bohol	*Indica*
11320	Ir 36	Bohol	*Indica*
11321	Ping Rice	Bohol	*Indica*
11322	Pilit	Bohol	*Indica*
11323	Kabus-Ok	Bohol	*Indica*
11324	Kabus-Ok	Bohol	*Indica*

Table A1. *Cont.*

Collection Number	Cultivar Name	Province	Eco-geographic Race
11325	75 (Pula)	Bohol	*Indica*
11326	Unknown	Bohol	*Indica*
11327	Kabus-Ok	Bohol	*Indica*
11328	Unknown	Bohol	*Indica*
11329	Japan Red	Bohol	*Indica*
11330	Gl-2	Bohol	*Indica*
11332	Rmp/Kaimpas	Bohol	*Indica*
11333	Bilar Red	Bohol	*Indica*
11334	Kananoy	Bohol	*Indica*
11337	Pilit Tapol	Bohol	*Indica*
11338	Miracle Pilit	Bohol	*Javanica*
11339	7-7 Red	Bohol	*Indica*
11340	Red Rice	Bohol	*Indica*
11341	Lubang (M)	Bohol	*Indica*
11342	Hubahib	Bohol	*Javanica*
11343	Bares	Bohol	*Japonica*
11345	Mal-Us	Bohol	*Indica*
11346	Elon-Peta	Bohol	*Indica*
11347	Pungko	Bohol	*Indica*
11348	Melobina	Bohol	*Indica*
11349	Inabaka	Bohol	*Indica*
11350	Kayupo	Bohol	*Indica*
11351	Sulig	Bohol	*Indica*
11352	Ceres	Bohol	*Javanica*
11354	Torboho Red	Bohol	*Javanica*
11355	Pilit Taba	Bohol	*Indica*
11356	Lubang	Bohol	*Javanica*