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Phenotypic diversity of the tidal swamp rice (*Oryza sativa* L.) germplasm from South Kalimantan, Indonesia

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Abstract

Tidal swamp rice is a valuable source for developing new rice cultivars in the future because they possess some important traits for, adapted to a wide range of abiotic and biotic stresses. In this study, twenty-seven cultivars of the tidal swamp rice, comprising 26 from the South Kalimantan and one of Sumatera Island, Indonesia (an outgroup), were characterized phenotypically. Following Biodiversity International procedure, 14 qualitative and 15 quantitative traits were observed. The results show that this germplasm has a unique diversity in phenotypic traits. The secondary branch of panicle was the highest diversity of qualitative traits with an index of 0.93. Similarly, the plant height was the highest for quantitative traits (0.70). The correlation analysis confirmed that plant height, strongly correlated to culm diameter, the number of tillers and grain ratio. The PCA indicated that several independent traits, such as coleoptile anthocyanin coloration, basal leaf sheath color, and grain length, have positively contributed to the diversity, accounting 62.99%. Based on PCA analysis, the tidal swamp rice were clustered into four groups. According to UPGMA, this germplasm separated into six main groups, where *Sardani* (an outgroup) was very closely related to *Lakatan Pacar* and most distantly to *Siam Perak*. This information would be useful for the future rice breeding program, particularly in developing new rice cultivars in the tidal swamp areas.

Keywords: Rice; phenotypic diversity; tidal swamp area; breeding program.
Abbreviations: PCA_principal component analysis; UPGMA_unweighted pair group method with arithmetic mean.

Introduction

Indonesia and many other Asian countries with a massive population are encountering a crucial problem of food security (Muthayya et al., 2014). Thus, utilization of marginal land like the tidal swamp areas for the rice farming is one option to solve the problem (Sinaga et al., 2014). In Indonesia, there are a broad number of the tidal swamp areas, comprises of 24.71 million hectares, and most of this is suitable for the rice farming (Wijaya et al., 2007). In this country, there are thousands of traditional rice germplasm, including the tidal swamp rice cultivars which have not widely understood (Khairullah et al., 1998; Thomson et al., 2007; Mursyidin et al., 2017).
In general, the tidal swamp rice is essentially tall, non-elongating, and photoperiod sensitive (Hamid and Islam, 1984). In the natural growing areas, this germplasm shows a better adaptation to their local condition, such as the metal contamination and salinity (Ogunbayo et al., 2007). While these cultivars have the low productivity, only 1.0 – 2.5 tons ha^{-1} (Wijaya et al., 2007), some of them possess some beneficial genes for broadening gene pool of advanced cultivars (Ogunbayo et al., 2007). Besides, since they formed for a long time due to the intensive interaction between farmers and the local environment (Sanghera et al., 2013), they have a high genetic diversity that is beneficial to the breeding and conservation programs (Ford-Lloyd et al., 2011; Tandekar and Koshta, 2014).
For many years, characterization of rice germplasm is undertaken based on morphological traits (Anumalla et al., 2015). While this trait considers certain limitations, such as time-consuming and unreliable for discriminating species with closely related taxa, it still uses for both evaluating and characterizing rice germplasm (Anumalla et al., 2015). Semwal et al. (2014), Tandekar and Koshta (2014), Sinha et al. (2015), and Tuhina-Khatun et al. (2015) are successful in determining the genetic variability of traditional rice germplasm from a different part of India using this trait. Dai et al. (2013) and Chuan-Guang et al. (2014) are also successful in investigating the genetic variability of traditional rice cultivars in a diverse region of China, by this marker. In Indonesia, the characterization of this germplasm by the morphological marker has conducted by Kristamtini et al. (2012) and Shinta et al. (2014). However, characterization involving morphological characters is the first and essential step in evaluating rice germplasm (Anumalla et al., 2015). According to Thomson et al. (2009) studies of rice diversity on a local scale, the complex interaction between rice diversity and human cultivation practices can be better understood.

Here, the objectives of our study are evaluating the phenotypic diversity of the tidal swamp rice germplasm of the South Kalimantan Province, Indonesia and reconstructing its phenetic relationships using UPGMA method. The result of this study may be useful in supporting both the future rice breeding and conservation programs (Anumalla et al., 2015).

Results and Discussion

Phenotypic diversity of the tidal swamp rice

Tidal swamp rice cultivars show a relatively low in phenotypic diversity, both the qualitative and quantitative traits (Table 2 and Table 3). However, the secondary branches of panicle and awn distribution are part of the qualitative traits that indicate a high diversity index. Similarly, the grain ratio, the number of tillers, and the plant height also indicate the high diversity indices. The plant height and number of tillers are part of the quantitative traits that consider a primary contribution to the plant yield productivity (Constantino et al., 2015). Hussain et al. (2014) reported that the number of tillers is a dominant trait which determines culm architecture and grain productivity for most cereals (*Poaceae*).

In *Oryza* species, the number of panicles is very dependent on the number of tillers (Hussain et al., 2014). The higher the number of tillers is, the higher the yield can produce (Hussain et al., 2014). Thus, germplasm with such ability is a primary target of the rice breeding program since the eighteenth century (Jennings et al., 1979). In the study, *Lakatan Pacar* and *Siam Babirik* were the cultivars with the highest plant architecture. So they could be used as a parent's candidate in the future breeding programs, particularly for the tidal swamp areas. However, several other factors needed to be considered in the program, particularly the crop production and the preferences of farmers and consumers (Calingacion et al., 2014).

According to Mzengeza (2010), the crop production mainly affected by three major components (traits). First, the number and weight of panicles per plant unit. It could be used directly to estimate the crop yield. Second, the number of panicles, panicle length, number of days of flowering, and plant height. Third, the grain per panicle, as well as other traits that affect the number of fertile grains per panicle and grain weight (Mzengeza, 2010). In this study, *Ganal Perak* is a tidal swamp rice cultivar that shows a higher grain weight than others.

With regards to farmers and consumer preferences, the grain shape is one of an important key in developing new rice cultivar for the tidal swamp areas (Calingacion et al., 2014). According to Calingacion et al. (2014) most of the local people of South Kalimantan are favorable to cultivate and consume the rice grain with a medium size, like *Siam Saba*. The cultivars with such character may belong to the *Indica* sub-species (Katayama, 1993). The rice grain shape determined by some traits, such as grain weight, grain length, and grain width, also the grain thickness (Zheng et al., 2015). Fu et al. (2015) and Zhou et al. (2015) reported that this trait controlled by several genes (QTL), such as *Dwarf1* (D1), *GS3*, and *GW2*. *Dwarf1* (D1) causes the grain size reduction. *GS3* affected the grain length and weight. *GW2* linked to the grain width and weight.

The PCA analysis confirms that the phenotypic diversity of this germplasm contributed by some traits, such as coleoptile anthocyanin coloration, basal leaf sheath color, and leaf blade anthocyanin coloration, also the distribution of anthocyanin coloration of leaf blade (Table 4). These traits incorporate the first component of the analysis (PC1). In other PCs, the flag leaf attitude also contributes to the phenotypic diversity of this germplasm. Al-Tahir (2014) reported that this trait is intimately related to the crop yield. Through this organ, carbohydrates are translocated more into the rice grain. This trait is also an essential role in increasing 41-43 percent of the grain weight. It's related to the angular position (attitude) of this organ when receives sunlight (Zhang et al., 2013). Taguchi-Shiobara et al. (2015) stated that the flag leaf with an upright position would catch the sunlight more efficiently than the horizontal or bowing position. Hence, this trait is a primary target in the rice breeding program.

Taguchi-Shiobara et al. (2015) have studied the phenotypic diversity of the rice germplasm based on the flag leaf width trait. This trait incorporated the first component of the analysis and contributed 39% of the total diversity (Taguchi-Shiobara et al., 2015). Zhao et al. (2011) reported that the flag leaf with the large size founded from the rice cultivars of Java Island, Western China, and Latin America. Related to our founding (Table 4), the cultivar of *Banih Kuning* and *Siam Putih* shows the large size of this trait.

The result of correlation analysis shows the diameter of culm trait has a strongly correlated to plant height. Besides, the number of tillers is strongly correlated to plant height, panicle length, and culm diameter (Figure 3). Wu et al. (2011) reported that the rice germplasm with a large culm size has more amount of grain per panicle than others. The culm size also associated with the large panicle and the lodging resistance as well (Yang et al., 2000; Wu et al., 2011). In the rice breeding program, the lodging trait is a limiting factor which can reduce the crop yield potency, either by reducing a photosynthetic canopy, increasing respiration and disease susceptibility, or reducing the translocation efficiency of the nutrients and carbon in the rice grains (Wu et al., 2011). Wu et al. (2011) added that the thickness of culm is one of an essential trait in the breeding program to developed new superior rice cultivars.

The result of correlation analysis shows that the grain weight greatly influenced by the panicle length, the flag leaf length, the number of tillers, the blade leaf length, and the ligule length (Figure 3). The grain weight is one of a substantial component in determining the crop yield potency (Zhang, 2013). Hairmansis et al. (2010) have considered the relationship of the tidal swamp rice of North Sumatera, Indonesia, and reported that the number of productive tillers, the number of grains per panicle and the grain fertility had a beneficial effect on this trait. Mzengeza (2010) documented a unique result that yield potency has a positive correlation with plant height, panicle length, panicle weight, as well as the number of grains per panicle and the grain weight.

Phenetic relationship of the tidal swamp rice

Information on the phenetic relationship can be used to support the breeding strategies, particularly in the development of superior cultivars. In this study, the tidal

Table 1. List of the tidal swamp rice germplasm employed in this study.

Name of Cultivar	Code	Origin	Genetic Status
Siam Pandak	01	Banjar, South Kalimantan	Landrace
Siam Halus	02	Banjar, South Kalimantan	Landrace
Siam Gadis	03	Tanah Laut, South Kalimantan	Landrace
Siam Kuning	04	Banjar, South Kalimantan	Landrace
Siam Perak	05	Banjar, South Kalimantan	Landrace
Siam Arjuna	06	Banjar, South Kalimantan	Landrace
Banih Kuning	07	Banjar, South Kalimantan	Landrace
Siam Unus	08	Banjar, South Kalimantan	Landrace
Siam Adil	09	Banjar, South Kalimantan	Landrace
Ganal Perak	10	Banjar, South Kalimantan	Landrace
Pandak Putih	11	Banjar, South Kalimantan	Landrace
Siam Rukut	12	Barito Kuala, South Kalimantan	Landrace
Siam Saba	13	Banjar, South Kalimantan	Landrace
Unus Mayang	14	Banjar, South Kalimantan	Landrace
Karang Dukuh	15	Barito Kuala, South Kalimantan	Landrace
Siam Mutiara	16	Barito Kuala, South Kalimantan	Landrace
Unus Mutiara	17	Tanah Laut, South Kalimantan	Landrace
Siam Putih	18	Banjar, South Kalimantan	Landrace
Ciherang	19	Banjar, South Kalimantan	Improved
Lakatan Wangi	20	Banjar, South Kalimantan	Landrace
Lakatan Pacar	21	Banjar, South Kalimantan	Landrace
Siam Tanggung	22	Banjar, South Kalimantan	Landrace
Unus Putih	23	Tanah Laut, South Kalimantan	Landrace
Siam Orok	24	Banjar, South Kalimantan	Landrace
Siam Babirik	25	Tanah Laut, South Kalimantan	Landrace
Siam Adus	26	Banjar, South Kalimantan	Landrace
Sardani*	27	Sumatera Island	Landrace

Note: * An outgroup.

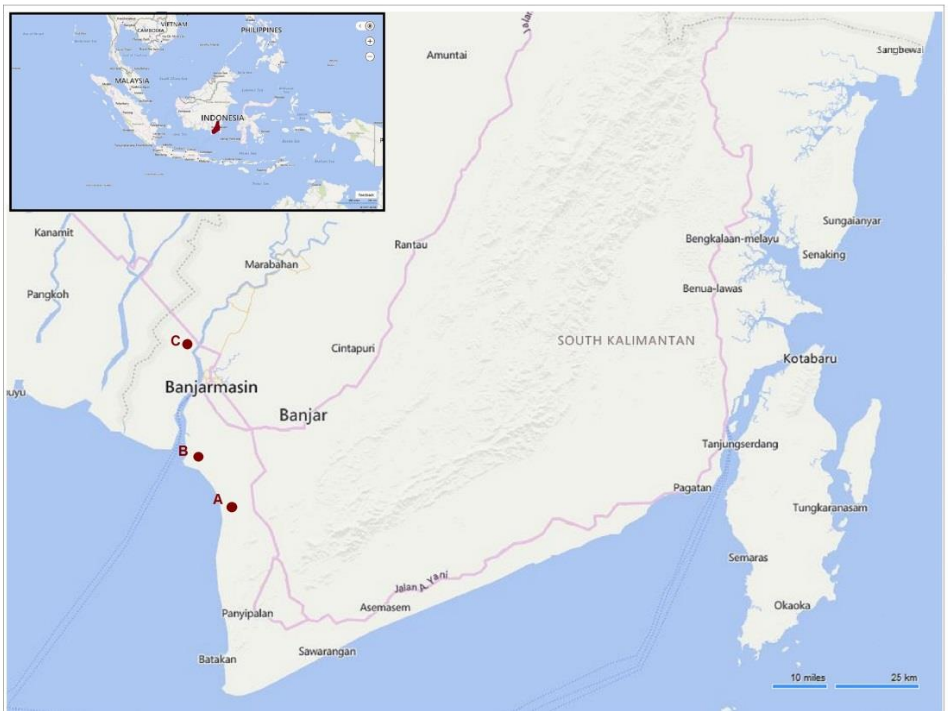

Fig 1. A map Indonesia showing the collecting sites of the tidal swamp rice germplasm in the South Kalimantan Province, Indonesia. Red point indicated three locations of sampling areas, i.e. the regency of Tanah Laut (A), Banjar (B), and Barito Kuala (C). The name of cultivars of each sampling location listed in Table 1.

Table 2. Shannon's diversity indices of the tidal swamp rice germplasm based on the qualitative traits.

Characters	Num. Spec.	H' Index
Coleoptile anthocyanin coloration (CAC)	1	0.10[a]
Leaf blade anthocyanin coloration (LBAC)	1	0.10[a]
Endosperm type (ET)	2	0.13[a]
Auricle shape (AS)	8	0.13[a]
Culm habit (CH)	12	0.26[a]
Anther color (AC)	1	0.28[a]
Basal leaf sheath color (BLSC)	1	0.29[a]
Distribution of anthocyanin coloration of leaf blade (DACLB)	1	0.29[a]
Panicle exsertion (PE)	15	0.48[a]
Attitude of panicle branches (APB)	12	0.67[b]
Stigma color (SC)	1	0.70[b]
Flag leaf attitude (FLA)	16	0.72[b]
Awn distribution (AD)	1	0.85[c]
Secondary branches of panicle (SBP)	16	0.93[c]
Average		0.42

Note : [a] Low; [b] Medium; [c] High.

Table 3. Shannon's diversity indices of the tidal swamp rice germplasm based on the quantitative traits.

Characters	Average	STDEV	Lowest Value	Cultivar	Highest Value	Cultivar	Num. Spec	H' Index
100-grain weight (g)	22.15	4.24	15.00	(Siam Mutiara, Unus Mutiara)	30.00	(Ganal Perak, Ciherang)	18	0.14[a]
Panicle length (cm)	26.30	6.16	18.00	(Siam Adus)	40.00	(Banih Kuning)	6	0.20[a]
Leaf blade length (cm)	52.07	9.89	23.00	(Siam Pandak)	67.00	(Siam Orok, Siam Mutiara)	20	0.24[a]
Flag leaf width (cm)	1.36	0.38	0.60	(Unus Mutiara)	2.00	(Banih Kuning, Sardani*)	8	0.26[a]
Leaf blade width (cm)	1.11	0.42	0.40	(Siam Tanggung, Unus Putih)	2.00	(Sardani*)	12	0.26[a]
Culm diameter (mm)	3.77	2.59	1.00	(Siam Kuning)	14.60	(Lakatan Wangi)	5	0.33[a]
Grain length (mm)	6.47	8.10	5.20	(Pandak Putih)	6.56	(Unus Mutiara)	20	0.34[a]
Grain width (cm)	1.81	2.68	1.20	(Siam Saba, Siam Mutiara)	2.02	(Siam Unus)	7	0.34[a]
Number of productive tiller (unit)	14.81	6.97	6.00	(Siam Rukut, Siam Halus)	30.00	(Karang Dukuh)	19	0.36[a]
Flag leaf length (cm)	38.65	15.57	21.00	(Siam Unus, Siam Rukut)	77.00	(Siam Putih)	10	0.44[a]
Auricle length (cm)	2.06	0.64	1.10	(Siam Kuning, Siam Orok)	3.30	(Siam Mutiara)	7	0.49[a]
Plant age (days)	166.81	40.53	92.00	(Ciherang)	271.00	(Unus Mutiara)	7	0.53[b]
Grain ratio	3.66	0.72	2.81	(Siam Unus)	5.31	(Siam Saba)	14	0.61[b]
Number of tiller (unit)	18.44	15.50	6.00	(Siam Rukut, Siam Halus)	77.00	(Karang Dukuh)	7	0.68[b]
Plant height (cm)	86.67	16.54	55.00	(Siam Unus)	120.00	(Lakatan Pacar)	11	0.70[b]
						Average		0.39

Note: * An outgroup; [a] Low; [b] Medium.

Fig 2. Phenotypic diversity of the tidal swamp rice shown in morphological grain traits. Circle indicate an outgroup cultivar of *Sardani*. Details of cultivar's name listed in Table 1. Bar = 10 mm.

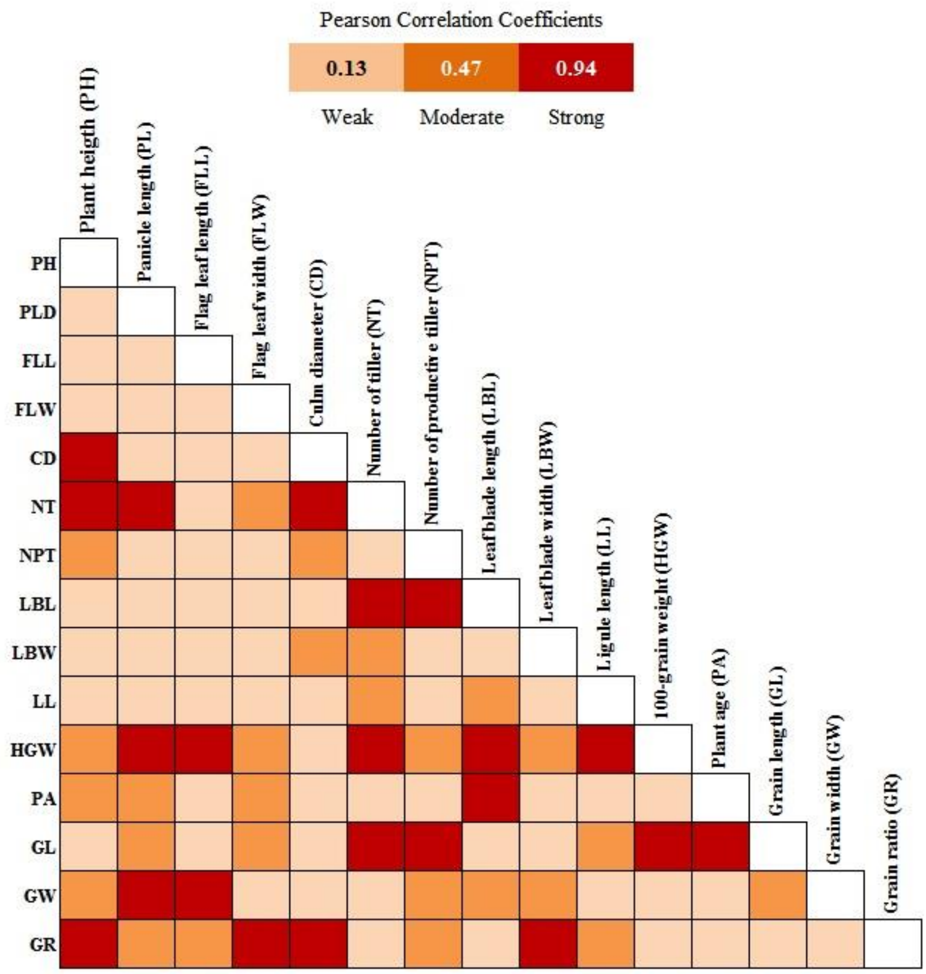

Fig 3. Pearson's correlation coefficients of the quantitative traits of the tidal swamp rice cultivars. Different color indicate the categories of correlation levels: Light orange = weak; Orange = intermediate; Dark red = strong.

Table 4. PCA score of qualitative and quantitative traits of the tidal swamp rice germplasm.

Descriptors	Components				
	PC1	PC2	PC3	PC4	PC5
Qualitative traits					
Coleoptile anthocyanin coloration (CAC)	0.34[a]	-0.12	-0.12	-0.64	-0.86
Basal leaf sheath color (BLSC)	0.34[a]	-0.12	-0.12	-0.64	-0.86
Leaf blade anthocyanin coloration (LBAC)	0.34[a]	-0.12	-0.12	-0.64	-0.86
Distribution of anthocyanin coloration of leaf blade (DACLB)	0.34[a]	-0.12	-0.12	-0.64	-0.86
Culm habit (CH)	0.80	0.38[a]	0.14	-0.57	0.87
Flag leaf attitude (FLA)	0.35	0.73	0.24[a]	-0.46[a]	0.20
Stigma color (SC)	0.34[a]	-0.12	-0.12	-0.64	-0.86
Anther color (AC)	0.34[a]	-0.12	-0.12	-0.64	-0.86
Awn distribution (AD)	-0.68	0.29[a]	0.16	-0.23	-0.18
Attitude of panicle branches (APB)	0.84	0.12	-0.61	-0.17	-0.23
Secondary branches of panicle (SBP)	0.11	-0.15	-0.44	0.21[a]	0.29[a]
Panicle exsertion (PE)	0.65	0.20[a]	0.51	0.26	0.11
Endosperm type (ET)	0.34	-0.13	0.21[a]	0.34	-0.35[a]
Auricle shape (AS)	-0.34	0.36	0.35[a]	-0.21[a]	-0.29[a]
Quantitative traits					
Plant height (PH)	0.11	-0.27	0.21[a]	0.66[a]	0.34[a]
Number of productive tiller (NPT)	0.20	-0.29[a]	0.20	-0.20	0.16
Culm diameter (CD)	0.17	-0.90	-0.40	0.29[a]	-0.18
Leaf blade length (LBL)	0.61	-0.11	0.23[a]	0.39[a]	0.13
Leaf blade width (LBW)	0.24[a]	-0.17	0.25[a]	0.64	0.88
Panicle length (PL)	0.16	-0.50	0.35[a]	0.84	0.16
Flag leaf length (FLL)	0.12	0.29[a]	0.11	0.20	-0.81
Flag leaf width (FLW)	0.12	-0.92	0.32[a]	0.22	-0.18
Auricle length (AL)	0.16	0.48	0.38[a]	0.38	-0.20
Number of tiller (NT)	-0.17	-0.35[a]	0.19	-0.21[a]	0.11
100-grain weight (HGW)	0.70	-0.28[a]	0.16	-0.20	0.12
Grain length (GL)	0.23[a]	0.14	-0.15	0.17	0.30[a]
Grain width (GW)	0.11	-0.28[a]	-0.97	0.33	-0.17
Grain ratio (GR)	0.11	0.22[a]	0.89	-0.10	0.44[a]
Plant age (PA)	-0.18	-0.31[a]	0.81	0.29[a]	-0.51
Eigenvalue	7.82	3.35	2.93	2.36	1.81
Percentage (%)	26.95	11.56	10.11	8.14	6.23
Cumulative percentage (%)	26.95	38.51	48.62	56.76	62.99

Note : [a] Contributed to diversity indices.

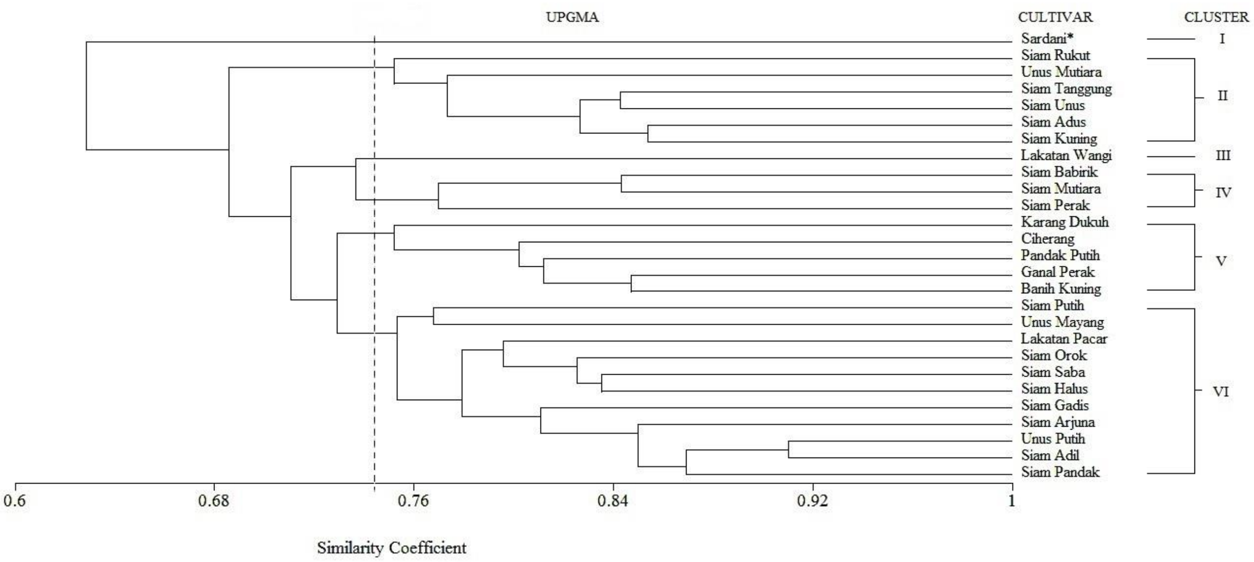

Fig 4. Dendrogram of phenetic relationship of the tidal swamp rice cultivars based on UPGMA analysis. Note: * An outgroup.

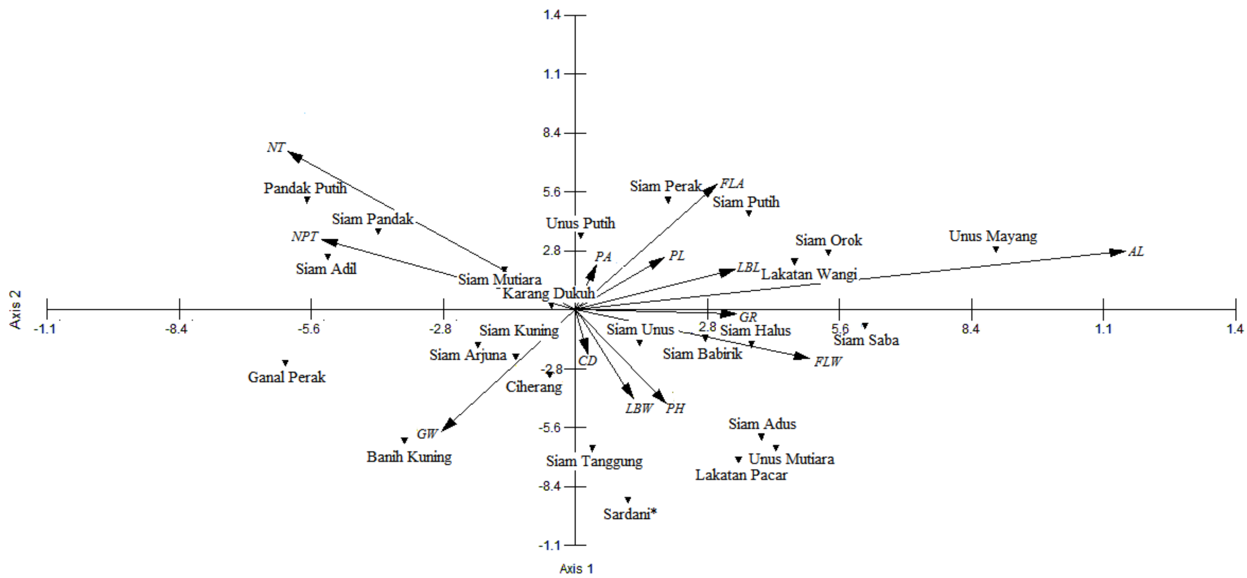

Fig 5. Clustering of the tidal swamp rice cultivars based on PCA analysis. This germplasm was clustered based on the different of phenotypic traits, indicated by the upper case abbreviation in front of vector. Note: * An outgroup, CD = culm diameter, PH = plant height, NPT= number of productive tiller, FLA = flag leaf attitude, PA = plant age.

swamp rice germplasm is exhibiting a unique relationship based on this trait (Figure 4). For instance, *Siam Adil* is closely related to *Unus Putih*, while *Siam Perak* is very distantly with *Siam Rukut*. Based on this relationship, *Sardani* (an outgroup) is very close to *Lakatan Pacar*, but most distant relation with *Siam Perak*. However, *Ciherang* (an improved cultivar) is very closely related to *Banih Kuning* but far related to *Siam Perak*. Hence, *Siam Perak* can be used as a parent's candidate in the developing new rice cultivars, particularly for the tidal swamp areas.

In plant breeding or developing new rice cultivar, individuals with distant relationship may be crosses to produce offspring with a high genetic diversity (Acquaah, 2007). Conversely, crossing individuals with a close relationship may narrow the genetic variability of their offspring (Acquaah, 2007), known as inbreeding (Frankham et al., 2002). It is, therefore, can lead a decreased yields and increased susceptibility to the pests and diseases (Charlesworth, 2003). Thus, a germplasm with a high genetic variability and a far genetic relationship is very useful in the future rice breeding program (Anumalla et al., 2015).

Cluster analysis (Figure 4) shows the germplasm divided into six main groups, where *Sardani* (an outgroup) separated alone with other cultivars at a similarity coefficient of 62%. According to Chaveerach et al. (2008) separation occurs in a similarity coefficient of 65%; the cultivars may be grouped into a genus level or will lead to speciation. However, it requires further validation, particularly by the molecular markers. Because the separation is due to mutation events in the *Sardani* genome or merely a phenotypic plasticity (Fusco and Minelli, 2010).

The result of PCA (Figure 5) shows a different feature of the tidal swamp rice cultivars clustering. Based on this figure, this germplasm clustered into four main groups, along with several traits. The first group consisted of eight cultivars (*Siam Pandak*, *Ciherang*, *Banih Kuning*, *Siam Babirik*, *Siam Arjuna*, *Ganal Perak*, *Pandak Putih*, and *Siam Gadis*) were influenced by the grain weight and the plant height. Based on the traits of the flag leaf attitude, the number of productive tillers, and the length of panicle, the second group generated, consists of *Siam Adil*, *Siam Mutiara*, *Lakatan Pacar*, *Karang Dukuh*, and *Sardani* cultivars. The third group, composed by *Siam Perak*, *Siam Orok*, *Siam Adus*, and *Siam Saba*, as well as *Unus Putih* and *Unus Mayang* strongly influenced by the grain ratio and the plant age. The last group (*Siam Kuning*, *Siam Halus*, *Siam Rukut*, *Siam Putih*, *Siam Tanggung*, *Lakatan Wangi*, and *Unus Mutiara*) strongly affected by the culm diameter.

This clustering indicates that this germplasm has a relatively high genetic diversity. Similar to our results reported by Tripathi et al., (2013) when studied the local aromatic rice of *Jhinuwa* from Pokhara, Nepal. Working with some Indonesian rice cultivar, Kristamtini et al., (2012) reported that germplasm only forms five groups. A different result show by Tandekar and Koshta (2014) when studied 100 cultivars of the local Indian rice, and clustered germplasm into six major groups.

Materials and Methods

Germplasm characterization

A total of 27 cultivars of the tidal swamp rice (Table 1), comprises 26 were collected randomly from 3 sites of the South Kalimantan Province, Indonesia (Figure 1) and one as comparison from the Sumatera Island, Indonesia, was used in this study. An outgroup cultivar, namely *Sardani*, was obtained from the Indonesian Swampland Agriculture Research Institute (BALITTRA), Indonesia. All samples were planted and maintained in a greenhouse of Faculty of Biology, Universitas Gadjah Mada, Indonesia by three replicates, for nine months from January to September 2015. This germplasm was characterized by the Rice Descriptors (Biodiversity Internatinal, 2007), where 14 qualitative and 15 quantitative characters were observed (Table 4).

Data analysis

Data analysis was started with scoring and standardized the morphological dataset obtained. Shannon-Weaver diversity index (H') was used to determine the phenotypic diversity of this germplasm (Help et al., 1998). Diversity indices were calculated based on phenotypic frequency using standardized Shannon-Weaver Diversity index formula:

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

where, *p*i is the frequency proportion of the descriptor state, and *N* is the number of states observed. An arbitrary scale of diversity indices adapted from Rabara et al. (2014) 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). Correlations among morphological traits analyzed utilizing PROC CORR procedure in SAS ver. 9.3 (SAS Institute, 1998). The level of correlation referred to Taylor's (1990) criteria: weak (r = 0.35), moderate (r = 0.36–0.67) and strong (r = 0.68–1.00). Multivariate statistical analyses of characterization data was conducted using principal component (PCA) and cluster (CA) analyses. PCA was employed to recognize the distinctive morphological traits that contributed to the most variance in the measured variables. In PCA, the raw data standardized, and the distance matrix using the variance-covariance coefficients computed. The Proportion of a variance criterion was used to identify the different principal components that contributed to the total variance in the dataset (Rabara et al., 2014). PCA and CA were done using MVSP ver. 3.1 software (Kovach, 2007). The distance matrix was generated using the Euclidean Distance Coefficients and used as input for clustering using the unweighted pair group of arithmetic means (UPGMA) method.

Conclusion

Tidal swamp rice germplasm shows a unique diversity in phenotypic traits. While this diversity was a relatively low, the secondary branch of panicle show the highest diversity of qualitative traits, with an index value of 0.93. Similarly, the plant height was the highest for quantitative traits (0.70). The correlation analysis confirmed that plant height, strongly correlated to the culm diameter, the number of tillers, and the grain ratio. The PCA indicated that several independent traits, such as the coleoptile anthocyanin coloration, basal leaf sheath color, and grain length, have positively contributed to the diversity, accounting 62.99%. Based on this analysis, the tidal swamp rice were clustered into four groups. According to UPGMA, this germplasm separated into six main groups, where *Sardani* (an outgroup) was very closely related to *Lakatan Pacar* and most distantly to *Siam Perak*. This information would be useful for the future rice breeding program, particularly in developing new rice cultivars in the tidal swamp areas.

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