Grain diversity and cultivation of Indonesian swamp rice germplasm: building the foundation for an ex-situ conservation programme

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SUMMARY

Tropical swamps are ecosystems with high genetic resources amongst plants, animals and microbes that are also in some demand as agricultural land. Traditional rice cultivars, known as swamp rice, are very interesting in this context, mainly because of their high adaptability to extreme local conditions such as waterlogging, low pH, heavy metal poisoning and salinity. We have collected 107 accessions of swamp rice from seven Indonesian provinces across the two large islands of Sumatra and Kalimantan. In this study we aimed to determine the range of grain trait diversity amongst this swamp rice germplasm, and to cultivate the different forms under managed conditions at the Research Station of the Indonesian Swamp Agricultural Reseach Institute (ISARI) in South Kalimantan. The germplasm was classified into six categories on the basis of grain shape, i.e., very long-slender, very long-intermediate, long-slender, long-intermediate, medium-slender and medium-intermediate. The very long-slender class, identified as the *indica* subspecies, was dominant (71 %). The germplasm was planted successfully and grew well, with most plants >100 cm tall but showing height differences between different accessions. The accession *Ketan* from Lampung was tallest and *Betek* from South Sumatra was shortest. Our study provides an initial foundation for a future ex-situ conservation effort for swamp rice in Indonesia.

KEY WORDS: genetic diversity, landrace, *Oryza sativa*, peatswamp

INTRODUCTION

The principal distinguishing characteristic of tropical swamp ecosystems is the seasonally recurrent shallow waterlogging that leads to swampy areas being known as saturated land (Kennish 2016, Trettin *et al*. 2019). These swamps are also notable for hosting high numbers of endemic species of flora, fauna and microbes (Mitsch 2013, Giesen *et al.* 2018, Harrison *et al*. 2020) and performing numerous beneficial ecosystem functions. In general, they act as giant reservoirs that store floodwater and maintain surface water flow during dry periods, whilst filtering or purifying the water and thus improving water quality (Harrison *et al*. 2020). Furthermore, swamps provide opportunities for economic benefits to, for example, the industrial, agricultural and tourism sectors (Page *et al*. 2012, Harrison *et al*. 2020).

Although swampland is regarded as marginal land for agriculture, it is currently used extensively for this purpose in efforts to feed the world's rapidly growing human population (Sulaiman *et al*. 2019, Qurani & Lakitan 2021). For example, in Asia, over 200 million ha of swampland are utilised for agricultural purposes (Wang 2020), including 20.7 million ha of tidal and 13.3 million ha of inland swamps in Indonesia (Gunawan *et al*. 2012, Mursyidin *et al*. 2019, Qurani & Lakitan 2021). These areas are mostly located on the large islands of Sumatra and Kalimantan (Gunawan *et al*. 2012, Sulakhudin & Hatta 2018).

The traditional rice cultivar known as swamp rice is very interesting in the context of the inherent value of natural swamps combined with the need to utilise them for agriculture. Swamp rice germplasm has developed over a long period under the intensively interacting influences of local environmental adaptation and the selection of desirable traits by farmers (Sanghera *et al*. 2013, Mursyidin *et al*. 2017). Consequently, swamp rice exhibits some agronomic traits that might be beneficially utilised in conservation and breeding programs aiming to improve crop yield stability, stress tolerance, adaptability to local conditions, etc. (Azeez *et al*. 2018, Mursyidin *et al*. 2019); for example, tolerance to acidity, salinity and metal contamination (Rao *et al*. 2018, Mursyidin *et al*. 2021).

Subspecies of Indonesian swamp rice are phenotypically distinguished on the basis of grain shape. Historically, the *indica* subspecies moved from Sumatra to Kalimantan (Borneo) about 300 years ago (Kiple & Ornelas 2000). On the other hand, *javanica* rice comes from Java Island, and continues to change genetically through domestication. Hence, it seems that the islands of Sumatra and Kalimantan provide an important route for the domestication and distribution of traditional rice accessions worldwide (Mursyidin *et al*. 2017). According to Calingacion *et al*. (2014), grain shape is also fundamental to developing new rice cultivars for swamp areas within Indonesia because local farmers and consumers have strong preferences with regard to this trait. For example, most farmers in South Kalimantan Province cultivate and consume medium-sized rice grain, e.g. the so-called *Siam* group.

With the increasing adoption of high-yielding 'green revolution' cultivars, the traditional swamp rice germplasm has begun to disappear (Nourollah 2016). Consequently, urgent action to preserve and conserve this germplasm is now needed. In general, the main goal of conservation is to ensure the sustainability of species, habitats and biological communities, including interactions amongst species or between species and their environments (Offord 2016, Malhotra *et al*. 2018). According to Offord (2016), there are three possible conservation strategies, namely ex-situ, in-situ, and on-farm. Ex-situ conservation involves collecting samples from the place of origin and storing them somewhere. For example, the International Rice Research Institute (IRRI) has established a gene bank for rice, by collecting and storing dried rice seeds in preservation tanks at a temperature of -20 ºC (Jackson 2016). While this kind of conservation has certain limitations, it is relatively safe and cost efficient when implemented for some plant species (Galetti 2018, Malhotra *et al*. 2018).

For Indonesia, we have collected more than one hundred accessions of swamp rice (*Oryza sativa* L.) from different parts of the country (Mursyidin *et al*. 2017). The objective of this study was to characterise this germplasm morphologically on the basis of grain shape (diversity) and cultivate it under managed conditions at a location distant from its origin. Thus, we aimed to establish an initial foundation for a future ex-situ conservation effort for swamp rice in Indonesia.

METHODS

This study encompassed 107 accessions of swamp rice collected from tidal and inland swamps across seven regions (provinces) of Indonesia (Figure 1). Table A1 in the Appendix catalogues the complete collection of swamp rice accessions, including their origins and growing habitats. This seed was planted, cultivated and harvested in May–October 2020 at the

Figure 1. Map of Indonesia, showing the seven regions (provinces) where the 107 swamp rice accessions employed in this study were collected. Detailed information about the accessions (names, habitats) is listed in Table A1 in the Appendix.

research station of the Indonesian Swampland Agriculture Research Institute (ISARI) in Tanjung Harapan Village (Alalak District, Barito Kuala Regency, South Kalimantan Province; Figure 2). The land to be planted was prepared using a hoe and hand tractor to loosen the soil, then flooded with water twice a month to prevent weeds from growing. Seeds were sown in a moist (but not saturated) seedbed using the 'tugal' method, which involves making holes ± 5 cm deep using a galam (*Melaleuca leucadendron*, a typical plant of swamps) stick with a pointed tip. The rice grain (20–25 seeds per accession) was placed into the seedbed holes, then the seedbed was covered with soil plus a layer of reed leaves to deter predators, especially birds, and kept moist by regular watering. After sprouting, the seedlings were transplanted to the edge of the planting site using a hoe and cleaver; then, when they were about four weeks old, they were planted out in a pattern of two rows, 2.5 m long, for each cultivar (see Figure 5 later). The plants were maintained by fertilising with urea (90 kg ha^{-1}) and the NPK fertiliser 'PHONSKA' (150 kg ha^{-1}) one week after planting out, and weeding (removing weeds growing around each plant) four weeks after fertiliser application. The rice field was protected from rats and birds by plastic fences and para-nets. After harvesting, the grain of each rice accession was measured and determined using the Khan *et al*. (2009) criteria (Table 2), then classified as subspecies *indica*, *javanica* or *japonica* (Zhang *et al*. 2011). Plant height was also measured, as an additional rice descriptor (Tran *et al*. 2012).

Figure 2. Map showing the location of the ex-situ conservation site for Indonesian swamp rice germplasm at the ISARI Research Station (red circle; 3º 10′ 15.77″ S, 114º 36′ 12.34″ E).

Table 2. Morphological classification of rice grain into four categories based on its relative length (L) and width (W). Source: Khan *et al*. (2009).

Grain size	Length (mm)	Grain shape	Grain ratio (L/W)
very long	>7.50	slender	>3.00
long	6.61–7.50	intermediate	2.10–3.00
medium	5.50–6.60	bold	1.10–2.00
short	≤ 5.50	round	<1.00

RESULTS

Grain diversity

Based on initial observation, our accessions of Indonesian swamp rice were classified into the *indica* and *javanica* subspecies plus an intermediate form. We further classified the latter into three categories, i.e., close to one of the subspecies *indica*, *javanica* or *japonica* (Figure 3). Interestingly, our morphological observations identified five accessions of *indica* with an awn on the grain tip (E in Figure 3). Further analysis revealed that the germplasm encompassed six shape classes, i.e., very long-slender, very long-intermediate, long-slender, long-intermediate, medium-slender, and medium-intermediate (Table A2). Figure 4A shows this grouping more clearly, and that the very long-slender *indica* subspecies was dominant (71 %). Within the intermediate form, the category 'close to *japonica*' was more frequent (68 %) than the two others (Figure 4B).

Rice cultivation

Generally, the Indonesian swamp rice germplasm was planted successfully and grew well, although some plants did not grow optimally (Figure 5). Figure 6 shows the variation in plant height. The plants grown from most of the swamp rice accessions reached >100 cm in height, the tallest being *Ketan* (from Lampung) and the shortest *Betek* (from South Sumatra).

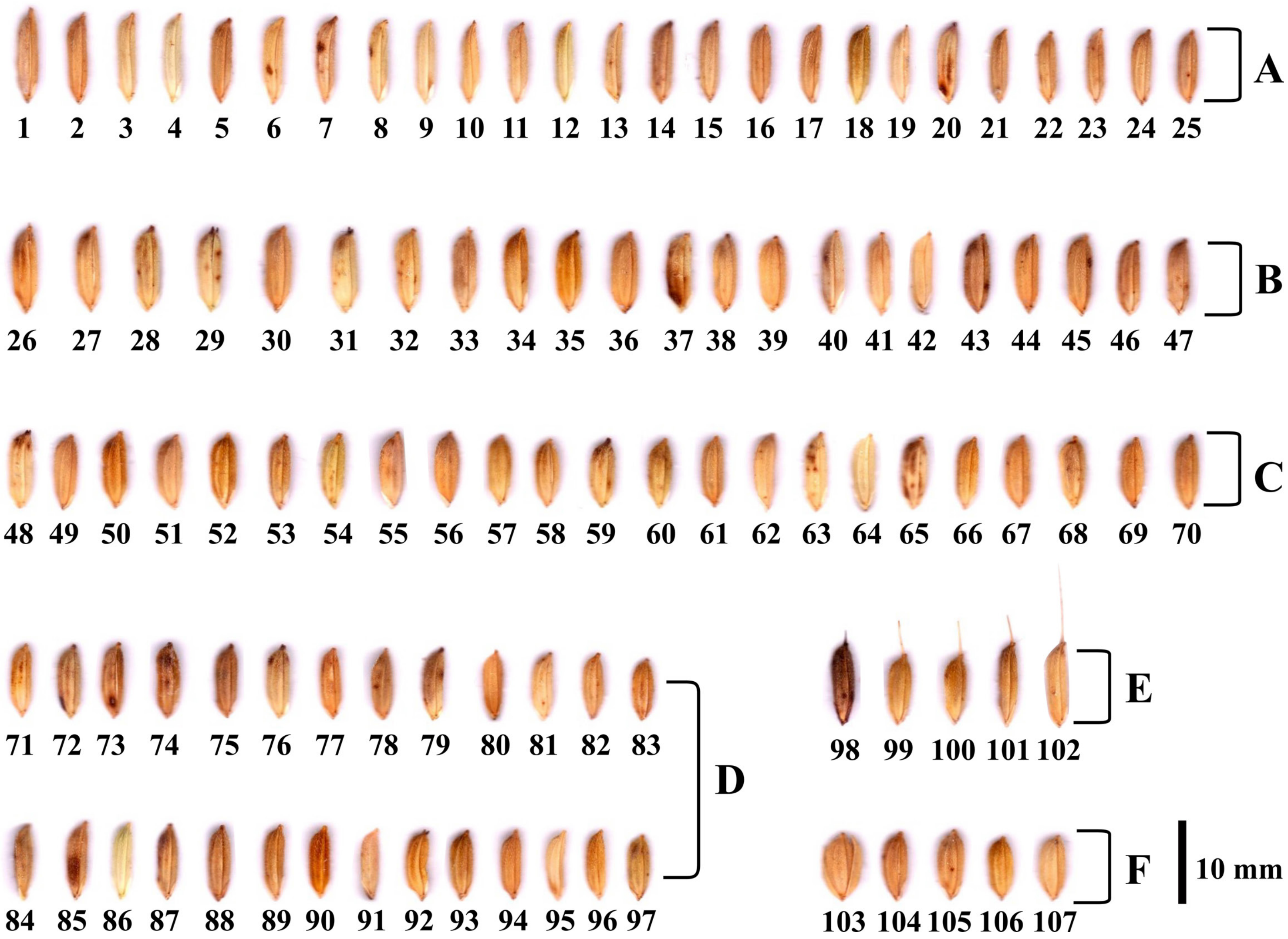

Figure 3. Grain diversity of Indonesian swamp rice germplasm, showing differences among accessions. The labels A–F indicates the subspecies: A = *indica*; B = *javanica*; C = close to *javanica*; D = close to *indica*; E = *indica* with awn on grain tip; F = close to *japonica*. The name of each accession is provided in Table A1.

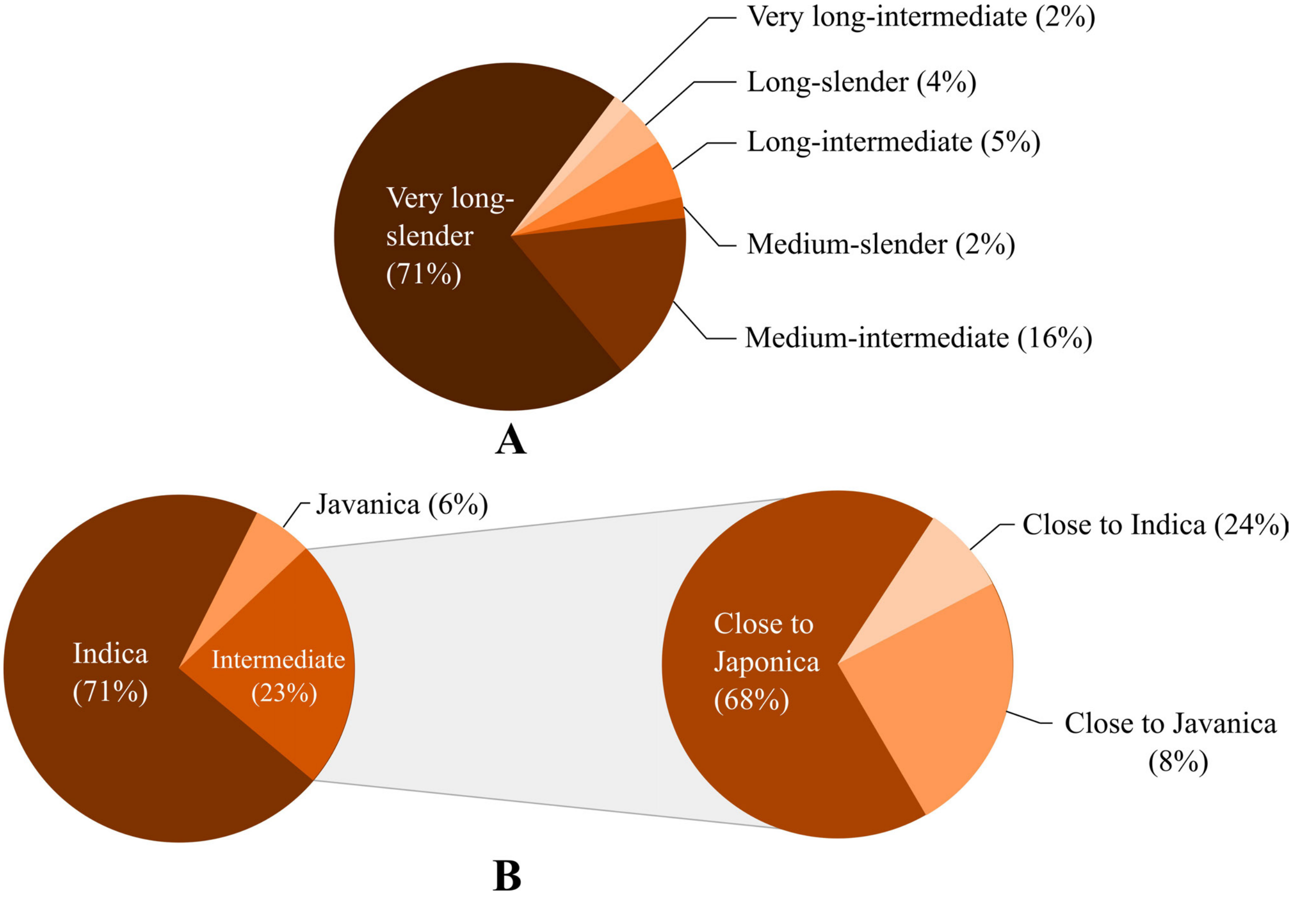

Figure 4. Percentage of Indonesian swamp rice germplasm accessions based on grain shape (A) and sub-species (B).

DISCUSSION

Grain diversity

On the basis of grain shape, Indonesian swamp rice shows distinctive characteristics (Figure 3, Table A2) and is dominated by the *indica* subspecies (Figure 4). Genetically, the shape of the rice grain is determined by several traits, e.g., weight, length, width and thickness (Zheng *et al*. 2015). At molecular level, several genes (QTL), such as *Dwarf1* (*D1*), *GS3* and *GW2*, control this trait (Fu *et al*. 2015, Zhou *et al*. 2015). Zhou *et al*. (2015) reported that *GS3* affects the grain length and weight, whereas *GW2* is related to grain width and weight.

Regardless of the characteristics of the grain studied, information on genetic diversity is essential for plant genetic conservation, preventing the genetic erosion of breeding populations, and selecting superior parents for plant breeding (Wu *et al*. 2021). In other words, studies of genetic diversity facilitate an understanding of the relationships between accessions and help towards identifying redundancies or admixtures in the germplasm (Delfini *et al*. 2021). Generally, genetic diversity is indispensable to the formation of an initial population for natural selection, the evolutionary direction and future adaptive changes (Govindaraj *et al*. 2015, Lloyd *et al*. 2016). In conservation efforts, an understanding of genetic diversity is essential for maximising the effectiveness and efficiency of the programme.

Rice cultivation

Although all of the swamp rice accessions that we planted can grow, their growth is not optimal. The main obstacle is soil agrophysical differences between their original habitats and the ISARI research station, which has a potentially sour sulfate soil with Type B water overflow (by large tides only; Vepraskas & Craft 2016). According to Vepraskas & Craft (2016), this soil type is characterised by a pyrite content of >2 %, unoxidised, and located at a depth of <50 cm from the soil surface.

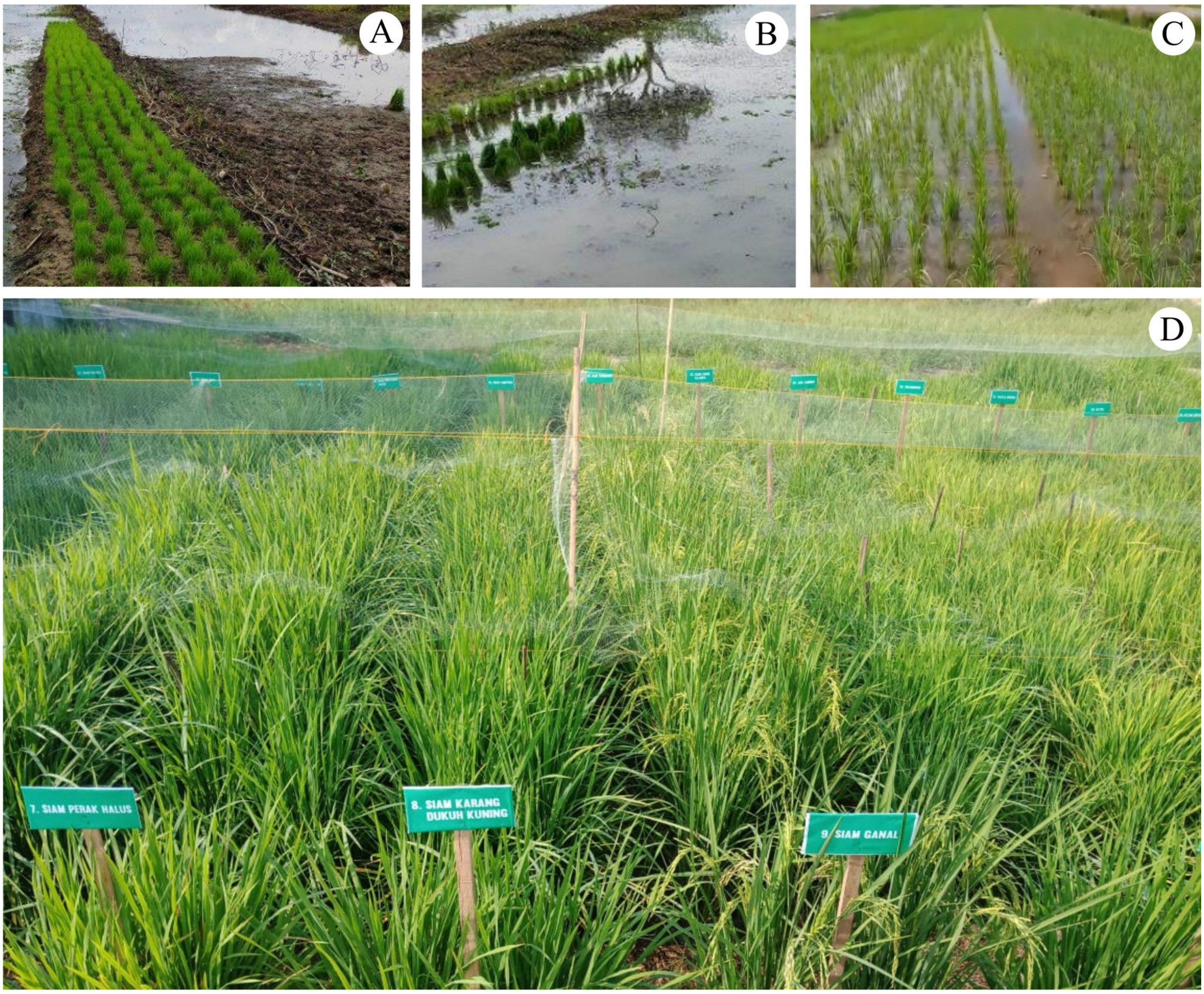

Figure 5. Cultivation of Indonesian swamp rice germplasm at the ISARI Research Station in South Kalimantan. A: seedlings grown from seeds planted in slightly dry soil on the edge of a swamp rice field; B: seedlings after translocation to the planting site; C: four-week old rice seedlings after planting out; D: flowering plants protected from birds by para-net installation.

Table A1 shows that the swamp rice was collected two different types of land, namely tidal swamps and inland swamps. According to Craft (2016) and Kennish (2016), there are significant differences between these two habitats. The tidal ecosystem is naturally characterised by soils that are water-saturated or shallowly stagnant year-round or for several months per year. The dominant soil formation process is gleization which is characterised by a grey-bluish reduced soil horizon and the formation of a peat layer on the surface. In contrast, the inland swamp is located near the middle of the catchment, upstream of any tidal influence but subject to periodic flooding of the river during the rainy season. This land is gradually inundated by stagnant water which subsequently recedes with the change from rainy season to the dry season of the following year (Craft 2016, Kennish 2016).

According to Michael (2020), problems in acid sulfate soils are due to the presence of a pyrite (FeS_2) layer that undergoes oxidation and causes soil acidification. In very acidic conditions (pH < 4), the solubility of aluminum increases drastically and can poison the plants (Khairullah 2020). Poisoning usually occurs in dry soil or during a prolonged drought (Shamshuddin *et al*. 2013). Conversely, when the soil is flooded, the increase in pH can lead to the reduction of ferric iron to ferrous. This phenomenon occurs mainly in actual acid sulfate soils (when pyrite has oxidised) that are re-inundated by rain or tidal water (Khairullah *et al*. 2021, Shamshuddin *et al*. 2013). Ferrous iron

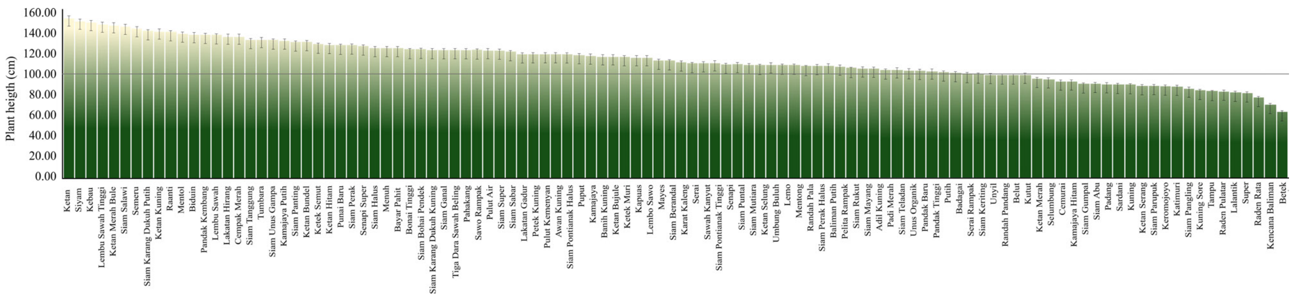

Figure 6. Plant height variation (cm) of Indonesian swamp rice germplasm growing at the ISARI Research Station, South Kalimantan, Indonesia.

concentrations of 300–400 ppm are highly poisonous to rice plants and cause low nutrient availability (Craft 2016, Panhwar *et al*. 2016).

In the inland swamps, the main problem is the fluctuations of inundation between rainy and dry seasons (Mehner & Tockner 2022). Consequently, most farmers have difficulty predicting the degree of waterlogging, especially when planting and when the plants are entering the vegetative growth phase. So far, farmers have adapted their agronomic methods by delaying planting and by translocating seedlings more than once (Paiman *et al*. 2020). In addition to the problem of waterlogging, the land conditions of inland swamps are very acidic, causing high availability of Al and Fe (Maruapey *et al*. 2020). On the other hand, the availability of plant macronutrients such as nitrogen, phosphorus and potassium is reduced (Maruapey *et al*. 2020). In the context of agronomy, efforts to increase crop productivity include improving fertilisation methods in terms of dosage, timing and method of administration (Mehner & Tockner 2022).

So how does the rice plant grow in swamp locations? Physiologically, its success is probably due to the mechanism of lengthening the stems and storing energy during submergence, which is an adaptation of rice plants to swampland conditions (Setter *et al*. 1997). Local adaptations of rice to heavy metal poisoning, especially by Fe, include avoidance mechanisms and tissue tolerance. Asch *et al*. (2005) explain that the avoidance mechanism may be related to the ability of rice to oxidise Fe^{2+} to Fe^{3+} on the root surface, resulting in the formation of harmless iron plaques. As a result of this mechanism, there are also differences in the distribution of Fe in roots, stems and leaves that enable the rice plant to grow in swamplands (Sahrawat 2000, Audebert 2006).

The measurements of plant height show that most of our rice accessions grow to heights of more than 100 cm (Figure 6), which makes the germplasm suitable for use as a parent or for further development in waterlogged swamp habitats. According to Wu *et al*. (2011), plant height must be correlated with the size (diameter) of the stem to minimise lodging. In breeding programmes, lodging is a limiting factor on potential yields because it can reduce the canopy for photosynthesis, increase respiration and susceptibility to disease, and limit the translocation of nutrients and carbon to the grain (Wu *et al*. 2011). Ünan *et al*. (2013) report that lodging is correlated with plant height. At molecular level, the plant height variations are controlled by a gene regulator, i.e., *rice plasticity 1* (*RPL1*), located on chromosome 6 (Nayar 2014).

Regardless of the land conditions, several pests and diseases also present obstacles to the growth of swamp rice at the ISARI site. The most troublesome are white rice stem borers, brown and green leafhoppers, and ear bugs (*Leptocorisa oratorius*, Hemiptera) including blast and tungro. According to Susanti *et al*. (2016), these pests and diseases are common in most Indonesian swamp rice farms. To eliminate or reduce such problems they suggest the use of natural reagents and predators, as well as some safe chemicals; for example, spiders (Arachnida), extracts of ‘purun’ or water chestnut (*Eleocharis dulcis*), silicates from rice husk ash, and potassium, as well as sex pheromones (Susanti *et al*. 2016).

Future programmes

Since this is the first step towards ex-situ conservation, some follow-up activities are urgent. For example, the conservation effort should be supported by creating a database or core collections (Kumar *et al*. 2020). This would reduce conservation costs, increase management efficiency, and continue to support the utilisation of genetic diversity through the precise and rapid identification of sources of genetic diversity for specific trait improvement programmes (Kumar *et al*. 2020, Tanaka *et al*. 2021). According to Liu *et al*. (2015), the development of core collections is an efficient approach to exploring, characterising and utilising the genetic diversity of large populations. This activity also has strategic value because it can facilitate exploration of the germplasm resource for new genes (Tanaka *et al*. 2021).

Conceptually, the core collection is a set of accessions with maximum genetic diversity and minimum repetition, including existing ecologically and genetically different ones (Kumar *et al*. 2020, Vilayheuang *et al*. 2020). In other words, a core collection is composed of a small percentage of representative genotypes drawn from most of the genetic diversity of the entire population (Tanaka *et al*. 2021). The size of core collections varies between 5 % and 30 % of the overall population (Liu *et al*. 2015). However, the core collection should be reviewed regularly (Kumar *et al*. 2020).

Characterisation of the germplasm collection must also be done systematically and periodically (Kumar *et al*. 2020), using both morphological (phenotypic) and molecular markers; e.g., SNPs that are faster, more accurate, and stable against environmental influences (Mursyidin *et al*. 2018). According to Liu *et al*. (2015), analysing differences in genetic diversity between core collections and the entire population is essential to testing the effectiveness of such activities. In other words, characterisation is carried out to avoid duplication, contamination, mixing or mislabelling of germplasm collections and to monitor the viability of these genetic resources for the future (Ahmed & Iftekharuddaula 2017, Vilayheuang *et al*. 2020).

Finally, to maintain the viability of germplasm and to determine when germination tests should be made, cold storage of the seed and plant rejuvenation are also needed (Maxted *et al*. 2020).

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AUTHOR CONTRIBUTIONS

DHM initiated the study, carried out the data analyses, created most of the Figures and Tables, and wrote the first draft of the manuscript. IK designed the field experiment and documentation. MS did the fieldwork and morphological observations. All authors contributed to interpretation of the results and to writing the final manuscript.

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Appendix

Table A1. List of Indonesian swamp rice accessions used in the study, including their origins and natural habitats.

Province of origin	Name of accession	Code	Habitat
Jambi	*Mentol*	72	Tidal swamp
	Mentong	36	Tidal swamp
	Menuh	103	Tidal swamp
	Sawah Kanyut	73	Tidal swamp
South Sumatra	*Belut*	78	Tidal swamp
	Betek	33	Tidal swamp
	Bonai Tinggi	74	Tidal swamp
	Cempak Merah	60	Tidal swamp
	Cemurai	75	Tidal swamp
	Mayes	59	Inland swamp
	Padang	55	Inland swamp
	Sawo Rampak	77	Inland swamp
	Pelita Rampak	16	Inland swamp
	Sardani	56	Tidal swamp
	Serai Rampak	105	Inland swamp
Lampung	*Awan Kuning*	76	Tidal swamp
	Kamajaya	80	Tidal swamp
	Karat Kaleng	5	Tidal swamp
	Katimuri	58	Tidal swamp
	Kebau	70	Tidal swamp
	Kencana Baliman	61	Tidal swamp
	Keromojoyo	71	Tidal swamp
	Ketan Bujule	79	Tidal swamp
	Ketek Muri	107	Tidal swamp
	Ketek Semut	99	Tidal swamp
	Kuning Sore	38	Tidal swamp
	Kutut	25	Tidal swamp
	Lembo Sawo	2	Tidal swamp
	Lembu Sawah	54	Tidal swamp
	Lembu Sawah Tinggi	34	Tidal swamp
	Petek Kuning	3	Tidal swamp
	Punai Baru	66	Tidal swamp
	Senapi	52	Tidal swamp
	Senapi Super	98	Tidal swamp
	Tampu	53	Tidal swamp
	Tumbara	24	Tidal swamp
West Kalimantan	*Randah Pala*	37	Tidal swamp
	Selumbung	65	Tidal swamp
	Umbung Buluh	19	Tidal swamp
Central Kalimantan	*Padi Merah*	18	Tidal swamp
	Pahakang	17	Tidal swamp
	Pulut Air	13	Tidal swamp
	Pulut Kemenyan	31	Tidal swamp
	Raanti	62	Tidal swamp
	Raden Pulatar	97	Tidal swamp
	Kapuas	104	Tidal swamp

Province of origin	Name of accession	Code	Habitat
	Adil Kuning	100	Tidal swamp
	Badagai	101	Tidal swamp
	Baliman Putih	21	Tidal swamp
	Banih Kuning	39	Tidal swamp
	Bayar Pahit	87	Tidal swamp
	Biduin	69	Tidal swamp
	Ketan	83	Tidal swamp
	Ketan Bundel	92	Tidal swamp
	Ketan Hitam	11	Tidal swamp
	Ketan Kuning	14	Tidal swamp
	Ketan Merah	29	Tidal swamp
	Ketan Merah Bule	50	Tidal swamp
	Ketan Selung	28	Tidal swamp
	Ketan Serang	44	Tidal swamp
	Kuning	81	Tidal swamp
	Lakatan Gadur	12	Tidal swamp
	Lakatan Hirang	15	Tidal swamp
	Lalantik	32	Tidal swamp
	Lemo	67	Tidal swamp
	Pandak Baru	48	Tidal swamp
	Pandak Kembang	85	Tidal swamp
	Pandak Tinggi	7	Tidal swamp
	Puput	106	Tidal swamp
	Putih	96	Tidal swamp
	Randah Pandang	41	Tidal swamp
	Raden Rata	40	Tidal swamp
South Kalimantan	*Siam Adus/Abu*	94	Tidal swamp
	Siam Berandal	63	Tidal swamp
	Siam Ganal	1	Tidal swamp
	Siam Gumpal	93	Tidal swamp
	Siam Halus	9	Tidal swamp
	Siam Karang Dukuh Kuning	64	Tidal swamp
	Siam Karang Dukuh Putih	8	Tidal swamp
	Siam Kretik/Keriting	46	Tidal swamp
	Siam Mayang	47	Tidal swamp
	Siam Mutiara	26	Tidal swamp
	Siam Pangling	95	Tidal swamp
	Siam Panting	23	Tidal swamp
	Siam Parupuk	35	Tidal swamp
	Siam Perak	102	Tidal swamp
	Siam Perak Halus	4	Tidal swamp
	Siam Pontianak Halus	22	Tidal swamp
	Siam Pontianak Tinggi	42	Tidal swamp
	Siam Puntal	88	Tidal swamp
	Siam Rukut	10	Tidal swamp
	Siam Sabar	27	Tidal swamp
	Siam Salawi	90	Tidal swamp
	Siam Super	91	Tidal swamp
	Siam Tanggung	86	Tidal swamp
	Siam Teladan	89	Tidal swamp
	Siam Unus Gampa	43	Tidal swamp
	Super	49	Tidal swamp

Province of origin	Name of accession	Code	Habitat
South Kalimantan	*Unus Organik*	57	Tidal swamp
	Unyil	6	Tidal swamp
East Kalimantan	*Kamajaya Hitam*	45	Tidal swamp
	Kamajaya Putih	51	Tidal swamp
	Semeru	84	Tidal swamp
	Serai	82	Tidal swamp
	Siam Bohai Pendek	68	Tidal swamp
	Siyam	30	Tidal swamp
	Tiga Dara Sawah Beling	20	Tidal swamp

Table A2. Characteristics of Indonesian swamp rice germplasm based on the grain length, width, and ratio, including grain type and subspecies.

Name of accession	Code	Province of origin	Grain length (mm)	Grain width (mm)	Grain ratio (length/width)	Grain type	Subspecies
Petek Kuning	3	Lampung	9.43 ± 0.31	1.80 ± 0.10	5.24	very long-slender	*indica*
Siam Halus	9	South Kalimantan	9.37 ± 0.23	1.83 ± 0.06	5.11	very long-slender	*indica*
Lakatan Hirang	15	South Kalimantan	9.30 ± 0.17	2.53 ± 0.06	3.67	very long-slender	*indica*
Siam Berandal	63	South Kalimantan	9.20 ± 0.61	1.93 ± 0.23	4.76	very long-slender	*indica*
Siam Perak	102	South Kalimantan	9.20 ± 0.30	2.43 ± 0.15	3.78	very long-slender	*indica*
Banih Kuning	39	South Kalimantan	9.13 ± 0.47	2.50 ± 0.26	3.65	very long-slender	*indica*
Pulut Kemenyan	31	Central Kalimantan	9.07 ± 0.55	2.83 ± 0.06	3.20	very long-slender	*indica*
Sawah Kanyut	73	Jambi	9.07 ± 0.40	2.23 ± 0.25	4.06	very long-slender	*indica*
Pahakang	17	Central Kalimantan	9.00 ± 0.53	2.10 ± 0.20	4.29	very long-slender	*indica*
Super	49	South Kalimantan	9.00 ± 0.20	2.67 ± 0.15	3.38	very long-slender	*indica*
Siam Ganal	1	South Kalimantan	8.97 ± 0.75	2.20 ± 0.20	4.08	very long-slender	*indica*
Mentong	36	Jambi	8.97 ± 0.38	2.50 ± 0.26	3.59	very long-slender	*indica*
Siam Salawi	90	South Kalimantan	8.93 ± 0.31	2.47 ± 0.12	3.62	very long-slender	*indica*
Pulut Air	13	Central Kalimantan	8.93 ± 0.15	1.70 ± 0.10	5.25	very long-slender	*indica*
Ketan	83	Lampung	8.90 ± 0.61	2.33 ± 0.23	3.81	very long-slender	*indica*
Siam Sabar	27	South Kalimantan	8.90 ± 0.26	1.83 ± 0.06	4.85	very long-slender	*indica*
Ketan Merah Bule	50	South Kalimantan	8.90 ± 0.17	2.23 ± 0.15	3.99	very long-slender	*indica*
Senapi Super	98	Lampung	8.87 ± 0.60	2.43 ± 0.06	3.65	very long-slender	*indica*
Siam Puntal	88	South Kalimantan	8.87 ± 0.49	1.87 ± 0.06	4.75	very long-slender	*indica*
Ketan Bujule	79	South Kalimantan	8.87 ± 0.29	2.47 ± 0.12	3.60	very long-slender	*indica*
Lembu Sawah	54	Lampung	8.83 ± 0.76	2.37 ± 0.12	3.73	very long-slender	*indica*
Kamajaya	80	Lampung	8.83 ± 0.12	2.50 ± 0.26	3.53	very long-slender	*indica*
Kapuas	104	Central Kalimantan	8.80 ± 0.92	2.37 ± 0.15	3.72	very long-slender	*indica*
Pandak Tinggi	7	South Kalimantan	8.80 ± 0.26	1.83 ± 0.15	4.80	very long-slender	*indica*
Pandak Baru	48	South Kalimantan	8.77 ± 0.29	2.33 ± 0.12	3.76	very long-slender	*indica*
Siam Perak Halus	4	South Kalimantan	8.73 ± 0.06	1.97 ± 0.12	4.44	very long-slender	*indica*
Semeru	84	East Kalimantan	8.70 ± 0.85	2.30 ± 0.26	3.78	very long-slender	*indica*
Kuning	81	South Kalimantan	8.67 ± 0.60	2.47 ± 0.31	3.51	very long-slender	*indica*
Raanti	62	Central Kalimantan	8.67 ± 0.51	2.37 ± 0.12	3.66	very long-slender	*indica*
Kutut	25	Lampung	8.67 ± 0.31	1.93 ± 0.06	4.48	very long-slender	*indica*
Randah Pala	37	West Kalimantan	8.63 ± 0.91	2.43 ± 0.40	3.55	very long-slender	*indica*
Siam Pangling	95	South Kalimantan	8.60 ± 0.46	2.03 ± 0.12	4.23	very long-slender	*indica*
Ketan Hitam	11	South Kalimantan	8.60 ± 0.40	2.20 ± 0.20	3.91	very long-slender	*indica*
Ketan Kuning	14	South Kalimantan	8.57 ± 0.64	2.47 ± 0.21	3.47	very long-slender	*indica*
Unus Organik	57	South Kalimantan	8.50 ± 0.50	1.90 ± 0.00	4.47	very long-slender	*indica*

Name of accession	Code	Province of origin	Grain length (mm)	Grain width (mm)	Grain ratio (length/width)	Grain type	Subspecies
Pelita Rampak	16	South Sumatera	8.47 ± 0.38	2.37 ± 0.06	3.58	very long-slender	*indica*
Siam Parupuk	35	South Kalimantan	8.43 ± 0.31	2.33 ± 0.06	3.61	very long-slender	*indica*
Lalantik	32	South Kalimantan	8.40 ± 1.08	2.23 ± 0.12	3.76	very long-slender	*indica*
Umbung Buluh	19	West Kalimantan	8.40 ± 0.17	2.20 ± 0.17	3.82	very long-slender	*indica*
Siam Mayang	47	South Kalimantan	8.37 ± 0.25	1.93 ± 0.06	4.33	very long-slender	*indica*
Badagai	101	South Kalimantan	8.33 ± 0.64	1.97 ± 0.12	4.24	very long-slender	*indica*
Adil Kuning	100	South Kalimantan	8.33 ± 0.21	1.90 ± 0.00	4.38	very long-slender	*indica*
Siam Unus Gampa	43	South Kalimantan	8.27 ± 0.93	2.27 ± 0.12	3.65	very long-slender	*indica*
Siam Panting	23	South Kalimantan	8.27 ± 0.40	1.80 ± 0.00	4.59	very long-slender	*indica*
Raden Rata	40	South Kalimantan	8.27 ± 0.15	2.23 ± 0.06	3.70	very long-slender	*indica*
Randah Pandang	41	South Kalimantan	8.23 ± 0.86	2.60 ± 0.26	3.17	very long-slender	*indica*
Kuning Sore	38	Lampung	8.20 ± 0.30	2.20 ± 0.17	3.73	very long-slender	*indica*
Kencana Baliman	61	Lampung	8.20 ± 0.10	2.53 ± 0.06	3.24	very long-slender	*indica*
Siyam	30	East Kalimantan	8.20 ± 0.10	2.70 ± 0.10	3.04	very long-slender	*indica*
Siam Kretik/Keriting	46	South Kalimantan	8.17 ± 0.78	2.37 ± 0.12	3.45	very long-slender	*indica*
Siam Mutiara	26	South Kalimantan	8.17 ± 0.64	2.33 ± 0.21	3.50	very long-slender	*indica*
Siam Pontianak Tinggi	42	South Kalimantan	8.17 ± 0.45	2.00 ± 0.10	4.09	very long-slender	*indica*
Siam Tanggung	86	South Kalimantan	8.17 ± 0.35	1.97 ± 0.12	4.15	very long-slender	*indica*
Pandak Kembang	85	South Kalimantan	8.17 ± 0.06	2.00 ± 0.10	4.09	very long-slender	*indica*
Katimuri	58	Lampung	8.13 ± 0.64	2.47 ± 0.15	3.30	very long-slender	*indica*
Siam Teladan	89	South Kalimantan	8.13 ± 0.21	1.97 ± 0.15	4.13	very long-slender	*indica*
Ketan Bundel	92	South Kalimantan	8.10 ± 0.30	2.27 ± 0.06	3.57	very long-slender	*indica*
Lakatan Gadur	12	South Kalimantan	8.07 ± 0.35	2.00 ± 0.10	4.04	very long-slender	*indica*
Biduin	69	South Kalimantan	8.07 ± 0.32	2.37 ± 0.06	3.41	very long-slender	*indica*
Tiga Dara Sawah Beling	20	East Kalimantan	8.07 ± 0.27	2.23 ± 0.12	3.61	very long-slender	*indica*
Bayar Pahit	87	South Kalimantan	8.03 ± 0.45	2.33 ± 0.15	3.44	very long-slender	*indica*
Tampu	53	Lampung	8.03 ± 0.15	2.60 ± 0.10	3.09	very long-slender	*indica*
Siam Rukut	10	South Kalimantan	8.00 ± 0.79	2.43 ± 0.12	3.29	very long-slender	*indica*
Padi Merah	18	Central Kalimantan	8.00 ± 0.10	2.20 ± 0.10	3.64	very long-slender	*indica*
Belut	78	South Sumatera	7.97 ± 0.32	2.37 ± 0.21	3.37	very long-slender	*indica*
Siam Karang Dukuh Kuning	64	South Kalimantan	7.97 ± 0.32	2.30 ± 0.17	3.47	very long-slender	*indica*
Cempak Merah	60	South Sumatera	7.93 ± 0.55	2.47 ± 0.06	3.21	very long-slender	*indica*
Punai Baru	66	Lampung	7.90 ± 0.20	2.37 ± 0.06	3.34	very long-slender	*indica*
Siam Bohai Pendek	68	East Kalimantan	7.90 ± 0.17	2.77 ± 0.23	2.86	very long-intermediate	close to *indica*
Ketan Selung	28	South Kalimantan	7.87 ± 0.49	2.43 ± 0.12	3.23	very long-slender	*indica*
Ketek Muri	107	Lampung	7.87 ± 0.40	2.40 ± 0.20	3.28	very long-slender	*indica*

Name of accession	Code	Province of origin	Grain length (mm)	Grain width (mm)	Grain ratio (length/width)	Grain type	Subspecies
Siam Super	91	South Kalimantan	7.83 ± 0.42	2.20 ± 0.36	3.56	very long-slender	*indica*
Kamajaya Hitam	45	East Kalimantan	7.80 ± 0.30	2.53 ± 0.12	3.08	very long-slender	*indica*
Lembu Sawah Tinggi	34	Lampung	7.73 ± 0.25	2.37 ± 0.12	3.27	very long-slender	*indica*
Awan Kuning	76	Lampung	7.73 ± 0.21	2.43 ± 0.06	3.18	very long-slender	*indica*
Baliman Putih	21	South Kalimantan	7.70 ± 0.20	2.20 ± 0.17	3.50	very long-slender	*indica*
Siam Karang Dukuh Putih	8	South Kalimantan	7.67 ± 0.06	2.10 ± 0.10	3.65	very long-slender	*indica*
Mentol	72	Jambi	7.63 ± 0.38	2.60 ± 0.36	2.93	very long-slender	*indica*
Sawo Rampak	77	South Sumatera	7.53 ± 0.38	2.33 ± 0.06	3.23	very long-slender	*indica*
Betek	33	South Sumatera	7.50 ± 0.20	2.37 ± 0.12	3.17	long-slender	close to *indica*
Serai	82	East Kalimantan	7.50 ± 0.10	2.13 ± 0.06	3.52	long-slender	close to *indica*
Lemo	67	South Kalimantan	7.30 ± 0.30	2.13 ± 0.06	3.42	long-slender	close to *indica*
Siam Pontianak Halus	22	South Kalimantan	7.10 ± 0.36	1.90 ± 0.26	3.74	long-slender	close to *indica*
Tumbara	24	Lampung	6.97 ± 0.61	2.33 ± 0.06	2.99	long-intermediate	*javanica*
Lembo Sawo	2	Lampung	6.80 ± 0.17	2.40 ± 0.20	2.83	long-intermediate	*javanica*
Siam Adus/Abu	94	South Kalimantan	6.77 ± 0.25	2.33 ± 0.12	2.90	long-intermediate	*javanica*
Ketan Merah	29	South Kalimantan	6.73 ± 0.35	2.37 ± 0.06	2.84	long-intermediate	*javanica*
Mayes	59	South Sumatera	6.70 ± 0.36	2.50 ± 0.10	2.68	long-intermediate	*javanica*
Kebau	70	Lampung	6.67 ± 0.23	2.47 ± 0.12	2.70	long-intermediate	*javanica*
Menuh	103	Jambi	6.60 ± 0.20	3.00 ± 0.10	2.20	medium-intermediate	close to *Japonica*
Kamajaya Putih	51	East Kalimantan	6.57 ± 0.21	2.60 ± 0.17	2.53	medium-intermediate	close to *Japonica*
Senapi	52	Lampung	6.53 ± 0.31	2.57 ± 0.12	2.54	medium- intermediate	close to *Japonica*
Serai Rampak	105	South Sumatera	6.50 ± 0.30	2.63 ± 0.21	2.47	medium-intermediate	close to *Japonica*
Padang	55	South Sumatera	6.50 ± 0.17	2.37 ± 0.15	2.75	medium-intermediate	close to *Japonica*
Siam Gumpal	93	South Kalimantan	6.47 ± 0.25	2.53 ± 0.06	2.55	medium-intermediate	close to *Japonica*
Sardani	56	South Sumatera	6.45 ± 0.35	2.57 ± 0.15	2.51	medium-intermediate	close to *Japonica*
Raden Pulatar	97	Central Kalimantan	6.43 ± 0.15	2.23 ± 0.21	2.88	medium-intermediate	close to *Japonica*
Unyil	6	South Kalimantan	6.40 ± 0.30	2.23 ± 0.42	2.87	medium-intermediate	close to *Japonica*
Puput	106	South Kalimantan	6.37 ± 0.32	2.23 ± 0.06	2.85	medium-intermediate	close to *Japonica*
Selumbung	65	West Kalimantan	6.37 ± 0.31	2.00 ± 0.10	3.19	medium-slender	close to *Indica*
Karat Kaleng	5	Lampung	6.37 ± 0.29	2.20 ± 0.17	2.90	medium-intermediate	close to *Japonica*
Cemurai	75	South Sumatera	6.33 ± 0.49	2.33 ± 0.21	2.71	medium-intermediate	close to *Japonica*
Bonai Tinggi	74	South Sumatera	6.30 ± 0.17	2.33 ± 0.23	2.70	medium-intermediate	close to *Japonica*
Ketek Semut	99	Lampung	6.00 ± 0.30	2.27 ± 0.06	2.65	medium-intermediate	close to *Japonica*
Putih	96	South Kalimantan	6.00 ± 0.26	2.13 ± 0.06	2.81	medium- intermediate	close to *Japonica*
Keromojoyo	71	Lampung	5.90 ± 0.26	2.27 ± 0.15	2.60	medium-intermediate	close to *Japonica*
Ketan Serang	44	South Kalimantan	5.77 ± 0.31	2.43 ± 0.06	2.37	medium-slender	close to *Javanica*