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A Systematic Review of Weedy Rice in Southeast Asia: Variants, Morphology, Yield, Management, and Potential Value to Food and Health Security

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Abstract The widespread adoption of direct-seeded rice (DSR) systems due to water and labor scarcity has intensified weedy rice infestations in Southeast Asia. A systematic review using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses, or PRISMA, was conducted to determine the variants, morphological variability, yield, and management of weedy rice in consideration of its status as an agricultural weed. The potential benefits of weedy rice to food and health security in the region were also explored by reviewing its ethnobotanical applications, along with wild and traditional rice varieties. A total of 74 studies were included and grouped into five research priority areas, namely weedy rice variants (12 studies), morphology (14 studies), yield (3 studies), management (51 studies), and weedy rice/wild rice/traditional rice varieties with food and medicinal uses (10 studies), with some studies overlapping among the areas. It was found that weedy rice populations in Southeast Asia are morphologically diverse and can be grouped into distinct morphotypes/biotypes. Key morphological traits such as panicle type, awn presence, grain and pericarp coloration, and plant height are often used to differentiate weedy rice variants in the field. This morphological variability may exist between and among weedy rice populations across Southeast Asian countries. However, more weedy rice surveys are needed to sufficiently cover the extent of morphological variability, as well as the spread and severity of infestation, in the major rice-producing countries of the region. In terms of competitive ability, the morphological variability of weedy rice may enhance its competitiveness in the field and help evade management. While cultural and chemical control methods are effective, an integrated approach for controlling weedy rice is still preferred and recommended. There was evidence for the use of weedy rice as food and medicine in Southeast Asia; however, current ethnobotanical investigations primarily focus on traditional rice varieties. Hence, the available data on the ethnobotanical uses of weedy rice is minimal, underscoring the need for further investigation to comprehensively capture its culinary and medicinal significance in the region.

Keywords Weedy Rice, Systematic Review,

Southeast Asia, Morphological Variability, Integrated Weedy Rice management, Ethnobotany

1. Introduction

Weedy rice infestation is a recurring and growing problem for rice farmers worldwide because it can generate substantial yield and economic losses in the absence of appropriate control measures [1,2,3]. It is estimated that a global reduction of 1.9 M mt (0.5%) in long-grain rice output could result from simultaneous weedy rice infestation in leading rice-producing countries, including China, India, and Vietnam [4]. In Southeast Asia, the transition from puddled transplanted rice (PTR) to direct-seeded rice (DSR) due to water and labor scarcity is challenged by the increase in weedy rice infestation because of the loss of traditional practices that would suppress weed growth through early flooding and seedling size advantage [1,5]. The ability of weedy rice to thrive in a broad range of agro-environmental conditions and compete with cultivated rice for the same resources [6,7,8] makes it a significant constraint to sustainable rice production and a threat to food security [4].

However, weedy rice possesses favorable biological characteristics that may elevate its status from a problematic weed to a valuable one. Taller plant height, compact canopy structure, high tillering ability, seed shattering, and seed dormancy are some of the traits that contribute to the establishment of weedy rice across different environmental conditions, including temperature variations, unstable water supply, soil salinity, drought, and CO_2 increase [9]. The high tolerance to stress of weedy rice makes it an ideal candidate for screening specific genes that could improve stress tolerance in cultivated varieties [2]. In addition, weedy rice could potentially be used to breed commercial rice cultivars with better nutritional qualities [2]. Wang et al. [10] found that weedy rice had higher quantities of anthocyanin, beneficial trace elements, free amino acids, and unsaturated fatty acids than cultivated rice, which makes it valuable for the development of rice cultivars with better nutritional content. These characteristics of weedy rice may be beneficial to the future of rice breeding, production, and consumption.

The current systematic review discusses the status of weedy rice as a weed in Southeast Asia (SEA) in terms of what is currently known about its variants, morphology, yield, and management. Due to evidence of the potential values of weedy rice to rice breeding and consumption, an additional review was done to determine its ethnobotanical uses as food and medicine in the local communities of Southeast Asia. The investigation of its ethnobotanical significance may support its potential role in the food and health security of the local communities, as well as promote its conservation and sustainable utilization.

2. Materials and Methods

The methodological approach that was used to conduct the systematic review was the Preferred Reporting Items for Systematic Reviews and Meta-Analyses, or PRISMA [11,12]. The literature search was done on Google Scholar, Wiley Online Library, Science Direct, and the Weed Science journal. A summary of the information sources and search strategies is presented in Table 2. Zotero, a reference management software, was used to store and organize the search results. Duplications from the records were detected and removed using the Deduplicator tool in the IEBH SR-accelerator (https://sr-accelerator.com).

The screening and selection of articles were done with Rayyan's help. Rayyan is an AI-powered research tool that can conduct systematic literature reviews with speed and efficiency [13]. Articles were screened based on the title and abstract of the paper. Once it passed the screening, the full texts of the articles were retrieved and carefully assessed for eligibility based on pre-defined criteria (Table 1). The data extracted from the included studies were recorded in MS Excel sheets. The main research priority areas were weedy rice variants, weedy rice morphology, weedy rice yield, weedy rice management, and ethnobotanical knowledge of the consumption and medicinal uses of weedy rice. Wild rice and traditional rice varieties were also included in the query because these rice species show promising potential as natural medicinal and nutritional sources [14,15]. A flow diagram of the study selection process is presented in Figure 1.

Table 1. Eligibility criteria for the papers that were included in the systematic review

Inclusion criteria	
1.	A study of weedy rice in any of the regions in Southeast Asia
2.	Published from 1988 to 2023 (for literature searches on weedy rice morphology, yield, and management)
3.	An empirical study – theses/dissertations, conference proceedings, case studies, or peer-reviewed and/or published in a journal
4.	The full text is accessible and written in English
5.	The study must satisfy at least one of the following:
●	A comparative morphological study between weedy rice and commercial rice varieties (in a typical garden experiment), reports of new weedy rice variants with morphological descriptions, or growth and development studies of weedy rice
●	Reports the yield of weedy rice in terms of the following yield component characteristics: number of panicles per plant, grains per panicle, 1000-grain weight
●	A survey on the weedy rice management practices of farmers or experimental studies on conventional or potential weedy rice control methods
●	Includes an ethnobotanical survey of weedy rice/wild rice/traditional rice varieties used as medicine or food by local communities in Southeast Asia
Exclusion criteria	
1.	Duplicated articles
2.	Articles published before 1988 (for literature searches on weedy rice morphology, yield, and management)
3.	Articles that studied weedy rice/wild rice/traditional rice in regions outside of Southeast Asia
4.	Literature types other than an empirical study (e.g. review, books, book chapters, newsletters, commentaries)
5.	Studies that are not related to weedy rice or any weed problem in rice production in general
6.	Articles that focused on rice weeds or pests that are not weedy rice
7.	Articles not written in the English language
8.	Full-text is not accessible/available

Table 2. The list of databases and corresponding search strings used in the literature search

Database	Weedy rice morphology, yield, and management			Weedy rice/wild rice/traditional rice as food and medicine		
	Search string	**Applied Filters**	**Date searched**	**Search string**	**Applied Filters**	**Date searched**
Google Scholar	(“weedy rice” OR “Oryza spp.”) AND (Philippines OR Malaysia OR Thailand OR Vietnam OR Laos OR Cambodia OR Myanmar OR Singapore OR Brunei OR Indonesia OR "Timor-Leste")	Only English pages were searched	December 15, 2023	("weedy rice" OR "wild rice" OR "traditional rice") AND (ethnobot* OR ethnomed* OR medic* OR food) AND (Philippines OR Malaysia OR Thailand OR Vietnam OR Laos OR Cambodia OR Myanmar OR Singapore OR Brunei OR Indonesia OR "Timor-Leste")	Only English pages were searched	March 20-21, 2024
Wiley Online Library	(“weedy rice” OR “Oryza spp.”) AND (Philippines OR Malaysia OR Thailand OR Vietnam OR Laos OR Cambodia OR Myanmar OR Singapore OR Brunei OR Indonesia OR "Timor-Leste")	Year of publication: 1988-2023, Publication type: “Journals”	December 17, 2023	("weedy rice" OR "wild rice" OR "traditional rice") AND (ethnobot* OR ethnomed* OR medic* OR food) AND (Philippines OR Malaysia OR Thailand OR Vietnam OR Laos OR Cambodia OR Myanmar OR Singapore OR Brunei OR Indonesia OR "Timor-Leste")	Publication type: “Journals”, Access type: Open Access Content	March 25, 2024
Science Direct*	(“weedy rice” OR “Oryza spp.”) AND (Philippines OR Malaysia OR Thailand OR Vietnam OR Laos) (“weedy rice” OR “Oryza spp.”) AND (Cambodia OR Myanmar OR Singapore OR Brunei OR Indonesia OR "Timor-Leste")	Year of publication: 1988-2023, Title, abstract, and Author-specified keywords segments only	December 17, 2023	rice AND (ethnobotanical OR ethnomedicinal OR medicine OR food) AND (Philippines OR Malaysia OR Thailand OR Vietnam) rice AND (ethnobotanical OR ethnomedicinal OR medicine OR food) AND (Laos OR Cambodia OR Myanmar OR Singapore) rice AND (ethnobotanical OR ethnomedicinal OR medicine OR food) AND (Brunei OR Indonesia OR "Timor-Leste")	Title, Abstract, and Author-specified Keywords segments only, Access type: Open access & Open archive	March 25, 2024
Weed Science journal	(“weedy rice” OR “Oryza spp.”) AND “Southeast Asia”	Year of publication: 1988-2023	December 17, 2023	-	-	-

*Science Direct was searched more than once because it only allows a maximum of 8 Boolean connectors per field

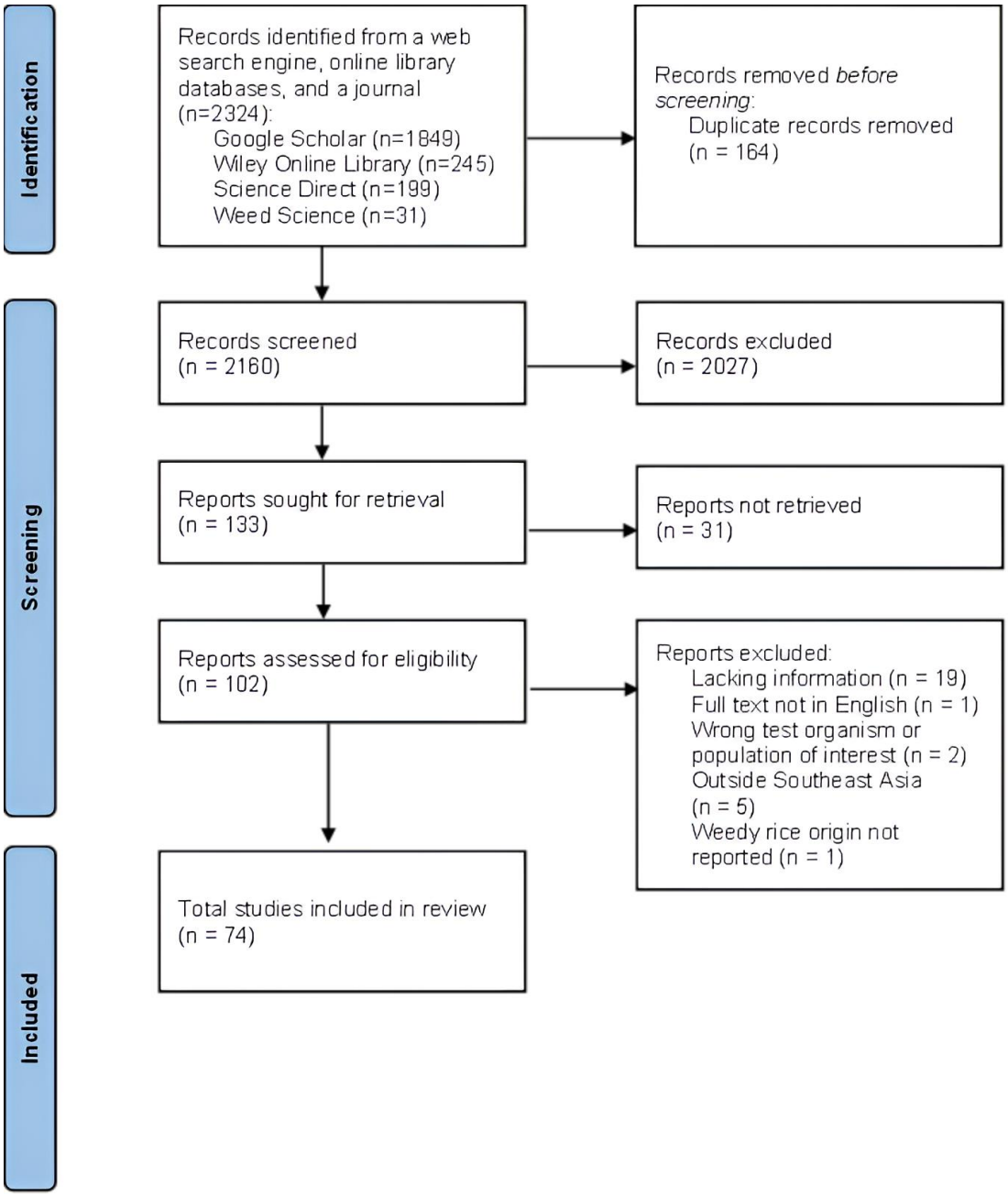

Figure 1. The PRISMA flow diagram of the study selection process

3. Results and Discussion

A total of 74 studies were included in the systematic review. These studies were categorized based on the main research priority areas: (1) weedy rice variants, (2) morphology, (3) yield, (4) management, and (5) weedy rice/wild rice/traditional rice varieties with food and medicinal uses. Table 3 shows the number of studies for the first four research priority areas which constitutes a total of 64 studies. Fourteen (14) studies were used to extract data about weedy rice morphology, while fifty (50) studies were about different management strategies for weedy rice. Of the 14 morphological studies, only three studies from the Philippines reported weedy rice yield in terms of the number of panicles per plant, number of grains per panicle, and 1000-grain weight. One study about weedy rice management was counted twice, both in the Philippines and Vietnam, because it used weedy rice collected from these two countries. Data about weedy rice morphotypes/biotypes were searched from the 14 morphological studies. Twelve (12) out of the fourteen (14) studies reported that they grouped weedy rice into morphotypes/biotypes based on key morphological characteristics. A majority (~64.06%) of the weedy rice morphological and management studies were from Malaysia.

Table 3. The number of weedy rice studies from five major rice-producing countries in Southeast Asia

Country	Included studies per country	Percentage distribution (%)	Distribution of studies across research areas			
			Studies on Morphology (n=14)*			Management Strategies (n=50)
			Morphological Characters (n=14)	Variants (n=12)	Yield Characteristics (n=3)	
Cambodia	3	4.69	0	0	0	3
Malaysia	41	64.06	10	9	0	31
Thailand	8	10.94	1	0	0	7
Philippines	6	9.38	3	3	3	3
Vietnam	5	9.38	0	0	0	5
Philippines and Vietnam	1	1.56	0	0	0	1
Total studies included	64	100.0	14	12	3	50

*Data on weedy rice "variants" and "yield characteristics" were extracted from 12 out of 14 and 3 out of 14 morphological studies, respectively.

Meanwhile, Cambodia (~4.69%) and Vietnam (~9.38%) had the least number of studies, with no weedy rice morphological study recorded from both countries, following the eligibility criteria of the systematic review. Only the weedy rice morphological studies from the Philippines consistently reported both yield and morphotypes/biotypes in the same studies. Overall, more studies about weedy rice management (78.13%) than morphology (21.88%) were included.

Variants of Weedy Rice in Southeast Asia

The morphological characters used for grouping weedy rice varieties were mainly qualitative, often describing observable plant parts such as the grain, awn, and pericarp (Table 4). Previous studies have indicated that the primary morphological characteristics helpful in differentiating weedy rice and cultivated rice are often vegetative (e.g., culm, plant height, tillering ability) or reproductive (e.g., panicle type, awn presence, grain and pericarp coloration) structures [9]. Qualitative descriptors for weedy rice are helpful for quick identification [16]. For instance, awns are often absent or shorter in traditional landraces and cultivars, while many weedy rice populations have awned grains, especially those found growing along with the wild rice

Oryza rufipogon [17]; hence, many researchers include awn presence to identify and group weedy rice populations during field observations. Similarly, plant height is also a suitable separator between weedy rice and cultivated rice because weedy rice morphotypes/biotypes were frequently much taller than commercial rice varieties in the field [18,19].

Preferably, qualitative characters with higher variability between weedy rice populations are used to group weedy rice into distinct morphotypes or biotypes. For example, in the study of Ishak *et al.* [20], pericarp coloration was chosen over hull coloration because it is more variable, ranging between red, brown, and white pericarps. These differences in trait variability may be one of the reasons why key morphological characters used for grouping weedy rice populations often vary between studies, even if they are from the same country or region. Nonetheless, despite the usefulness of qualitative characters, weedy rice morphotypes/biotypes can be better differentiated by studying all morphological characters, both quantitative and qualitative [21].

Table 4. Weedy rice variants from Malaysia and the Philippines

Origin	Morphotype/ biotype nomenclature	Key traits used for grouping	Reference
Malaysia	Acc 1 – Acc 16	Panicle type Pericarp color Awn existence Seed length Grain shattering percentage	[22]
	RNA; red pericarp-awnless BNA; brown pericarp-awned WNA; white pericarp-awnless RA; red pericarp-awned BA; brown pericarp-awned WA; white pericarp- awned	Pericarp color Awn presence	[20]
	PWR01 – PWR14	Panicle type Plant height Awn color Apiculus color Lemma and palea color	[21]
	SWR01 – SWR12 (SWR; Selangor weedy rice)	Plant height Lemma and palea color Awn color Apiculus color Panicle type	[23]
	SH; straw hull awnless mSH; intermediate straw hull awnless BR; brown hull awnless BH; black hull awnless SHA; straw hull awned mSHA; intermediate straw hull awned BRA; brown hull awned BHA; black hull awned	Hull color Awn presence	[16]
	Variant 1 Variant 2 Variant 3	Panicle type Awn presence Grain pigmentation	[24]
	WR01 WR02 WR03 WR04	Panicle type Plant height Awn color Lemma and palea color Grain shape (length-width ratio)	[25]
	V1 V2 V3 V4	Panicle type Awn presence Awn color Panicle threshability Spikelet fertility	[26]
	PB1 – PB9 PP1 – PP9 SGN1 – SGN9 SGA1 – SGA9	Plant erectness Culm height Days until maturity Panicle type	[17]

Table 4 continued

Philippines	WR-NE1	Grain color	[18]
	WR-NE2	Awn color	
	WR-NE3	Pericarp color	
	WR-NE4	Purple-colored stem	
	WR-NE5		
	WR-Cot1 – WR-Cot1	Grain color/length/width/discoloration	[27]
	WR-SuK1 – Wr-SuK5	Awn presence	
	WR-Min1 – WR-Min35	Awn length	
		Panicle type	
	WR-ILO1	Grain color	[19]
	WR-ILO2	Awn presence	
	WR-ILO3	Pericarp color	
	WR-ILO4		
	WR-ILO5		
	WR-ILO6		
	WR-ILO7		
	WR-ILO8		

The Variability of Morphological Traits of Weedy Rice Populations in Southeast Asia

Weedy rice populations in Southeast Asia are morphologically diverse (Table 5). The most defining feature of weedy rice is its red pericarp, which gives it the common name "red rice" in some regions [4,28]. However, there are also weedy rice biotypes that do not have the red pericarp. In the Philippines, for example, brown, light brown, white, whitish, yellowish green, black, and light gold pericarps exist [18,27]. Similarly, weedy rice in Malaysia has brown, light brown, and white pericarps [20,22]. Thus, the term weedy rice is more appropriate [29]. Other qualitative traits that showed variation between weedy rice populations from different countries include the plant type, apiculus color, awn presence, awn color, grain color, and the presence of a purple-colored stem (Table 5).

Weedy rice populations also showed variation in quantitative traits, including panicle shattering, seed germination, plant height, tiller number, grain size, and yield (Table 6). These characteristics are essential to the competitiveness of weedy rice populations in the field. Panicle shattering aids in dispersal and soil seed bank establishment, which increases their survival and prevalence in agricultural landscapes [30]. Plant height is also an important agronomic trait. Because the competitive ability of rice is strongly linked to characteristics related to light interception [31], taller weedy rice can capture light better than cultivated rice [32]. Meanwhile, a higher tillering ability can increase the survival of the plant as it occupies more space in the field [33] and has a greater density [34]. Studies that explore the relationship between weed morphology and its competitive ability may provide valuable information for the development of action thresholds and site-specific management [3].

Table 5. Variability of qualitative morphological characters between weedy rice populations from Southeast Asia

CHARACTERS	COUNTRY		
	Malaysia (n*=10)	**Philippines (n=3)**	**Thailand(n=1)**
PLANT TYPE	Erect, intermediate, open		Erect, spreading
LEAF			
Leaf blade color			Green
Leaf sheath color			Green, green with purple at the margin
Leaf blade pubescence	Pubescent or intermediate glabrous		
Flag leaf attitude		Erect, semi-erect, horizontal, descending	
CULM			
Internode color			Green
Auricle color			Colorless, light purple
Ligule shape			2-cleft
Ligule color			Colorless, light purple
PANICLE			
Panicle type	Open, intermediate, compact/close		Open
Panicle: attitude of branches	Erect, semi-erect, spreading, horizontal		
Panicle threshability	Easy, loose		
SPIKELET			
Apiculus color	Straw, brown, red		Colorless, red
Spikelet fertility	Fertile, highly sterile, partly sterile		
Awn presence	Awned, awnless		Awned, awnless
Awn color	Awnless, straw	Awnless, deep purple, golden yellow, straw, yellow, straw with purple pigmented tip	
Lemma and palea color	Straw, brown, brown (tawny), reddish, white, brown furrows		
Grain shape	Slender, medium		
Grain color		Straw, straw with purple tip, yellow, golden yellow, light yellow, yellow with purple tip, whitish, blackish brown, light brown, brown (tawny), brown (tawny) with purple tip, light gold with purple tip	Straw, dark gray
FLOWER			
Stigma color			Colorless, purple
Pericarp color	Red, brown, light brown, white	Red, brown, light brown, white, whitish, yellowish green, black, light gold	Red, white
Anther size			Medium
Purple-colored stem^		Present, absent	
REFERENCE	[16,17,20,21,22,23,24,25,26,35]	[18,19,27]	[36]

Blank cells indicate that the character was not reported.
*n=number of included studies
^Unique to Philippine weedy rice populations

Table 6. Variability of quantitative morphological characters between weedy rice populations from Southeast Asia

Trait	Trait variability in weedy rice	
	Malaysia	**Philippines**
Panicle shattering	Moderate, moderately high, high	No shattering to high, early shattering
Germination	Slower than or comparable to commercial rice varieties	Typically faster than commercial rice varieties, although some varieties are slower
Plant height	Typically taller than commercial rice varieties	
Tiller number	Lower tillering activity than commercial rice varieties:	
	Commercial rice had an average of 12.22 ±0.68 tillers, while the highest average tiller number among six weedy rice variants was only 7.55 ±0.57 tillers [20]	The average tiller number of cultivated rice was 14 tillers, while weedy rice produced 9 tillers on average[18]
Grain size	The grain length-width ratio is lower than in commercial rice varieties	
Yield components		
Number of panicles per plant	-	6.0 – 23.7 panicles*
Grains per panicle	-	60.7 – 164.95 grains**
1000-grain weight	-	17.1 – 24.9 g*

Sources: [17,18,19,20,21,23,25,26,27]
*range recorded from 13 weedy rice variants from Nueva Ecija and Iloilo, Philippines [18,19]
**range recorded from 27 weedy rice variants from Nueva Ecija, Iloilo, and Central Mindanao, Philippines [18,19,27]

Weedy Rice Management in Southeast Asia

The majority of the weedy rice research in Southeast Asia included in the review focused on the management of weedy rice. Table 7 presents the summary of the control strategies recorded from the included studies. Preventive methods, especially using of uncontaminated planting material, are crucial to prevent the spread and establishment of weedy rice [1]. Clean rice seeds can be achieved by on-farm seed cleaning techniques, commercial cleaning, or by purchasing certified seeds from authorized sources [37,38]. Cultural control methods, such as repeated tillage [37,39], water seeding and transplanting [39,40,41,42], early flooding [43,44], and manual weeding [37], are also routinely practiced to minimize weedy rice infestations.

Early flooding, in particular, has been shown to suppress the emergence and growth of weedy rice. Hamid et al. [43] found that weedy rice germination was significantly decreased by flooding at a depth of 10.0 cm at 0 days after seeding (DAS), while moist and saturated soils at 80% and 100% water holding capacity, respectively, favor seed germination. Similarly, Yusoff et al. [44] found that flooding at a depth of 10.0 cm at 0 DAS can decrease weedy rice germination, and root and shoot growth. In DSR systems, however, the application of early flooding may be limited by the sensitivity of rice cultivars to anaerobic conditions at early growth stages, possibly leading to poor crop establishment and lower yields [5]. To address this problem, anaerobic-tolerant cultivars having better crop establishment and higher grain yields under flooded soil conditions may be sown [5]. Anaerobic-tolerant cultivars can endure flooded conditions due to their coleoptiles developing faster and longer, facilitating their emergence above the soil surface where oxygen (O_2) is accessible [45]. However, additional research is necessary to improve the combined use of anaerobic-tolerant cultivars and flooding (timing, depth, and duration) to manage weedy rice without compromising grain yields.

A more recent strategy using the Clearfield® rice technology (CRT) made it possible to control weedy rice selectively [46,47]. However, the lack of knowledge among farmers regarding its implementation [48], the high cost, and the emergence of Imidazolinone (IMI)-resistant weedy rice [49] are significant constraints to its adoption and sustainability. The CRT package could only remain sustainable with proper application; hence, monitoring and educational programs about the technology among farmers should be intensified [50]. More importantly, it is of vital importance to strictly follow the stewardship guidelines of the CRT package, including (1) planting Clearfield® rice for two consecutive planting seasons only, (2) using certified Clearfield® rice seeds from authorized agencies, and (3) using registered IMI herbicides at the recommended rate and timing of application [51].

The use of herbicides has become more widespread and frequent in major rice-producing regions in Southeast Asia. Listed in Table 8 are the synthetic herbicides recorded in the current review, along with their recommended doses and timing of application based on field experiments. One study by Chhun et al. [37] reported that despite multiple information sources on proper herbicide use, there was still a knowledge gap on the proper doses and timing of

application.

Emerging plant-based herbicides were also included in the review due to the growing interest in more sustainable and eco-friendly herbicide options (Table 9). It appears that most studies on potential plant-based herbicides measure inhibitory activities in terms of their effect on the germination and seedling growth of weedy rice. This choice of tested indices may reflect the need to control weedy rice at its early stage of growth and development when the root system is most vulnerable to control by allelochemicals [52].

Nonetheless, there appears to be a lack of field experiments in the included studies which may limit their application in actual rice field conditions, especially with regards to the recommended application rates, timing of application, and selectivity to weedy rice. Because the majority of the included studies conducted laboratory bioassays, the timing of application of the plant extracts immediately followed the sowing of weedy rice seeds on Petri dishes lined with filter paper (Table 9). Consequently, the phytotoxic effects of the plant species at different growth stages of weedy rice were not explored. Moreover, several tested plants, such as *Parthenium hysterophorus* L., *Cleome rutidosperma* DC., *Borreria alata* (Aubl.) DC., *Tinospora tuberculata* (or *Tinospora crispa*), and *Piper betle* L., exhibited phytotoxic effects on cultivated rice, especially at increasing concentrations [52,53,54,55,56], thereby further limiting their application.

Meanwhile, one study by Aslani et al. [57] revealed that pre-emergence application of leaf powder and leaf extract, as well as a foliar spray of leaf extract, of *T. crispa* did not inhibit the growth and grain yield of transplanted rice under glasshouse conditions. In fact, the highest doses (leaf powder: 4 t ha^{-1}, leaf extract: 4 L ha^{-1}) of pre-emergence application promoted the grain yield of transplanted rice compared to the control [57]. The study of Aslani et al. [57] demonstrated that allelopathic plants may have the potential to inhibit weed germination and growth, while also increasing the growth and yield of cultivated rice.

The lack of field studies on potential plant sources of herbicides underscores the need for further research to validate the phytotoxic effects of the tested plant species under actual agronomic conditions in both transplanted and direct-seeded rice systems. Doing so would provide more appropriate recommendations to farmers, especially on the timing and rate of application. Furthermore, it is recommended that the level and extent of phytotoxicity to cultivated rice be included in similar studies in the future, in order to maximize the allelopathic potential of the plant without compromising rice yield and quality.

Table 7. Weedy rice control strategies and methods recorded in Southeast Asia

Control strategy	Control method	Reference
Preventive	Use of clean seeds:	
	• Winnowing, floatation, winnowing+floatation	[37,38,58]
	• Commercial cleaning services	
	• Industry-certified seeds	[59,60,61,62]
	Use of high-quality rice cultivars	[63]
	Field surveillance	[39]
	Rice straw burning	[39]
	Removal of panicles at harvest	[64,65,66]
Cultural	Multiple tillage	[37,39]
	Stale seedbed technique	[64,67]
	Water seeding and transplanting	[39,40,41,42]
	Early flooding (preferably at a depth of 10.0 cm)	[43,44]
	Use of anaerobic-tolerant cultivars	[45,68]
	Manual weeding	[37]
Chemical	Synthetic herbicides	See Table 8
	Plant-based herbicides	See Table 9
Biotechnology	Clearfield® rice technology (CRT)	[42,48,49,50]
Integrated Weedy Rice Management (IWRM)	Multiple control strategies used	[38,69]

Table 8. Commercial herbicides that can be used to control weedy rice in Southeast Asia

Herbicide	Recommended application rate/concentration	Timing of application	Type of study	Effect on Cultivated Rice	Reference
Malaysia					
Premix of 70% imazapic and 30% imazapyr	150 g ai ha^{-1} (similar to the stewardship guidelines of Clearfield® rice technology)	Preemergence at the 0 to 1-leaf stage	Field experiment (under wet-seeded rice conditions)	Selectively control weedy rice; Clearfield® rice are IMI-resistant	[70]
Thailand					
Flufenacet 60% WP* + oxadiargyl 40% SC	0.113 kg ai ha^{-1} + 0.125 kg ai ha^{-1}	2 DBS^ + 9 DAS	Field experiment (under wet-seeded rice conditions)	Moderately toxic to cultivated rice due to higher than normal rates of application	[71]
Dimethanamid 90% EC + oxadiargyl 40% SC	0.28 kg ai ha^{-1} + 0.125 kg ai ha^{-1}	2 DBS + 9 DAS			
Dimethanamid 90% EC + (profoxydim 10% EC + quinclorac 25% SC)	0.28 kg ai ha^{-1} + (0.02 + 0.09 kg ai ha^{-1})	2 DBS + (7 DAS)			
Glufosinate-ammonium	15-30 g ai L^{-1}	At anthesis or 3 days after anthesis	Field experiment	Toxic to rice; some panicles grew abnormally	[72]
MSMA	72 g ai L^{-1}			Not toxic but less efficient than glufosinate-ammonium	
Quizalofop-p-ethyl	7.5 g ai L^{-1}				
Vietnam					
Pretilachlor 300 g l^{-1} + fenclorim (safener) 100 g l^{-1}	900 g ai ha^{-1}	1st application: 1 DAS, 2nd application: 18-20 DAS, 3rd application: 38-40 DAS	Field experiment (under wet-seeded rice conditions)	No phytotoxic effects were observed due to the safener	[73]
Cambodia					
2-,4-D; Bispyribac-sodium; Pyribenzoxim; Quinclorac + pyrazosulfuron + fenoxaprop; Propanil + clomazone; Bensulfuron + quinclorac	The application rate varied among farmers, but most of them used higher doses than recommended	Post-emergence	Survey of farmers	Not included in the survey	[37]

*SC=suspension concentrate, WP=wettable powder, EC=emulsifiable concentrate, G=granule

^ DBS=days before sowing, DAS=days after sowing

Table 9. Potential plant sources for plant-based herbicides for weedy rice

Study location and plant species used	Source of herbicidal effects	Timing of application	Type of study	Phytotoxic effects		Reference
				On weedy rice	On cultivated rice	
Malaysia						
Parthenium hysterophorus L., *Cleome rutidosperma* DC., and *Borreria alata* (Aubl.) DC.	Plant extract	Pre-germinated weedy rice seeds at 0 days after sowing on filter paper	Laboratory experiment, Glasshouse experiment	Suppressive effects on germination and seedling growth (radicle length and hypocotyl length)	Survival rate, hypocotyl, and radicle length was reduced	[53,54]
Leucaena leucocephala (Lam.) de Wit	Leaf volatile compounds	0 days after sowing the seeds on filter paper	Laboratory experiment		Inhibited radicle growth	[74]
	Foliage leachate	0 days after sowing the seeds on the gelatinized agar		Inhibitory effects on radicle growth	10 mg of total dry leaves weight promoted radicle growth	
	Root exudates	0 days after sowing the seeds on the gelatinized agar			Radicle growth was inhibited, although less sensitive than the weedy rice	
Cuscuta campestris Yuncker	Plant extract	0 days after sowing the seeds on filter paper	Laboratory experiment	Germination and growth inhibition	Not tested	[75]
Tinospora tuberculata (or *Tinospora crispa*)	Leaves and stem extracts	0 days after sowing the seeds on filter paper	Laboratory experiment	Reduction in the percentage of seed germination and seedling growth	Reduction in the percentage of seed germination and seedling growth	[55,56]
		At the three-leaf stage of weedy rice	Hydroponic culture	Reduction in root and shoot growth, dry weight, photosynthetic pigments, chlorophyll content, and transpiration volume	Reduction in root and shoot growth, dry weight, photosynthetic pigments, chlorophyll content, and transpiration volume	[76]
	Leaf powder, leaves extract (direct application)	Pre-emergence	Glasshouse experiment	Inhibitory effects on growth (in terms of germination, biomass, and plant height)	No inhibitory effects on growth and development, even promoting grain yield	[57]
	Leaves extract (applied by foliar spray)	Post-emergence (2-week old weedy rice)	Glasshouse experiment			

Table 9 continued

Turnera subulata Sm.	Leaf volatile compounds	0 days after sowing the seeds on filter paper	Laboratory experiment	Growth inhibition	Not tested	[77]
	Foliage leachate	0 days after sowing the seeds on the agar medium				
	Leaves extract	0 days after sowing pre-germinated seeds on filter paper			Not tested	[78]
Mucuna cochinchinensis (Wight) Burck	Leaves, seeds, and root extracts	0 days after sowing the seeds in petri dishes	Laboratory experiment	Inhibition of seed germination and seedling growth	Not tested	[79]
Thailand						
Piper betle L.	Leaves extract	0 days after sowing the seeds in germination paper	Laboratory experiment	Inhibition of seed germination and seedling growth	Reduction in seed germination and seedling growth	[45]
Leptochloa chinensis	Stem extract	0 days after sowing the seeds in filter paper	Laboratory experiment	Inhibition of seed germination and seedling growth (in terms of shoot length, root length, seedling fresh and dry weights)	Not tested	[80]
Alstonia scholaris	Leaves extract	0 days after sowing the seeds in filter paper	Laboratory experiment	Inhibition of seed germination and seedling growth (in terms of shoot length, root length, seedling fresh and dry weights)	Not tested	[81]

No single control method can effectively and sustainably manage the weedy rice problem [39]. Therefore, an integrated approach consisting of conventional and modern technologies is recommended to efficiently and sustainably control weedy rice. In the Philippines, on-farm trials of the IWRM strategy showed that the application of IWRM practices decreased weedy rice contamination in farmer-kept seeds, reduced weedy rice plants at harvest, and increased rice yields [69]. The IWRM strategy used by Martin & Tanzo [69] included the following practices:

- Land preparation
  - Single pass plowing
  - Harrowing three times at an interval of 5 to 7 days
  - Leveling the rice field one day before seeding
- Use of certified seeds
- Drum seeding at a rate of 80 kg ha^{-1}
- Application of preemergence herbicides (Pretilachlor + Fenchlorim) at a rate of 300 g ai/ha, 1 to 3 days after seeding
- Maintaining irrigation water at a depth of 3 to 5 cm, starting at 8 to 10 days after seeding
- Hand-roguing of weedy rice when it is visible at the reproductive stage of the cultivated rice
- Cleaning of thresher and dryer

In Northwest Cambodia, the IWM strategy proposed by Martin et al. [38] showed similarities to that of Martin & Tanzo [69]. Martin et al. [38] also recommended the use of a drum seeder at a seeding rate of 80 kg ha^{-1}. The combination of drum seeding at 80 kg ha^{-1}, reduced inversion tillage, the stale seedbed technique, the use of clean seeds, and the application of pre- and post-emergence herbicides was suggested by Martin et al. [38]. This combination of methods could improve current IWRM strategies and potentially reduce the seeding rate further (i.e., below the recommended 80 kg ha^{-1} by drum or drill seeding).

It is important to remember that an IWRM strategy is not merely a combination of different strategies applied at varying stages of crop growth and development. For example, Chi et al. [66] reported that rice farmers in the Mekong Delta practiced a combination of weedy rice control methods, including burning the field, using a rotavator, maintaining water on the field, buying pure seeds, cutting or pulling weedy rice, and allowing ducks to eat seeds left on the soil. However, they determined that these control methods are not applied in an integrated manner and that farmers lack information about IWRM. According to Ziska et al. [82], an integrated weed management (IWM) strategy includes monitoring, determining action thresholds, and deciding on management tools after assessing the threat. Management decisions should be made in consideration of the efficacy of the methods, possible costs, and potential harm to the environment [82]. More importantly, the control strategies must be assessed after every application to determine efficacy and identify methods that need to be improved or modified for succeeding management decisions.

Weedy Rice/Wild Rice/Traditional Rice Varieties Used as Medicine and/or Consumed as Food by Local Communities in Southeast Asia

A total of 10 studies were included after the final screening of weedy rice/wild rice/traditional rice varieties with food and medicinal uses. The data from the ten studies were recorded from four countries in Southeast Asia, namely the Philippines, Indonesia, Malaysia, and Myanmar. A total of 179 rice varieties were found in the current review (Supplementary Table 1); however, the data reported here is limited to the rice varieties that were provided with detailed information about their preparation and uses by the original authors (Table 10 and 11). Only two weedy rice variants were reported to have ethnobotanical uses: one as food [83] and the other as medicine [84]. No record of wild rice consumption or medicinal uses was found. The only record of weedy rice consumption was reported from the Sasak community in Mandalika, Lombok Island [83]. The Sasak people called it *pare bea*, which was described as red rice [83]. However, information about its preparation was not provided; hence, it was not included in Table 11.

Ethnobotanical knowledge plays an integral role in the realization of the United Nations' sustainable development goals (SDGs) under the 2030 Agenda for Sustainable Development. The SDGs are related to common global issues, including poverty, hunger, the nutritional and health status of the people, sustainable agriculture, affordable healthcare facilities and services, and climate change [89]. Ethnomedicinal knowledge of plants provides rural and upland communities with easily accessible remedies for various diseases and disorders. In the North West Province of South Africa, for example, rural communities continue to rely on their indigenous knowledge of lands to meet primary healthcare needs, particularly for treating childhood diseases such as gastrointestinal diseases, urinary, genital diseases, skin-related diseases, and respiratory diseases [90]. Likewise, the present review recorded studies that reported traditional rice varieties and one weedy rice with ethnomedicinal value to local communities in Southeast Asia. The traditional rice varieties with medicinal applications that were reported in the review were documented by Cabanting and Perez [85] from the Philippines. They were the first to document traditional rice landraces that were used to prevent and treat human and animal ailments in selected local communities of the country. Because rice landraces and cultivars are abundant in the Philippines, Cabanting and Perez [85] urged fellow researchers to conduct more ethnobotanical investigations about the medicinal, culinary, and cultural importance of traditional rice.

Table 10. The traditional rice varieties and weedy rice that were provided with information about their medicinal applications

Local name	Plant part used	Mode of preparation	Administration	Application/Effects/Uses	Reference
Gapon Gapon	Grains	Cooked rice/Rice porridge	Oral	Measles, fatigue, constipation, stomach ache caused by gas/bloating, influenza, and fever	[85]
	Grains	Decoction	Oral	Stomach ache caused by gas/bloating	
	Rice straw	Ash	Topical	Muscle aches	
Bihod	Grains	Cooked rice/Rice porridge	Oral	Prevents relapse of ailment and helps lessen fatigue, muscle aches, and constipation.	
Tang co	Grains	Rice porridge	Oral	Prevents relapse of ailment	
Pilit Tapul	Grains	Cooked rice/Rice porridge	Oral	Prevents relapse of ailment, relieves constipation, and treats skin disease in carabao	
Dinorado	Grains	Cooked rice	Oral	To release the underlying cause of fever (in both children and adults) and help lessen fatigue.	
	Roots, Rice straw	Decoction	Oral	Stomach ache caused by gas/bloating	
Bulawan	Grains	Cooked rice	Oral	Prevents relapse of ailment and lessens fatigue	
Hinumay	Grains	Cooked rice	Oral	Prevents relapse of ailment and lessens fatigue	
Kutibos	Grains	Cooked rice	Oral	To release the underlying cause of fever (in both children and adults)	
Makaitot	Grains	Cooked rice	Oral	Increases sexual desire or treats sexual dysfunction	
Bagtok	Grains	Cooked rice	Oral	Ailments from supernatural causes, especially those involving high fevers	
Salog	Grains	Roasted	Oral	Influenza	
Tres Marias	Grains	Cooked rice	Oral	Increases sexual desire or treats sexual dysfunction	
Dalino	Grains	Wash water	Topical	Clears pimples on the face	
	Grains	Decoction	Oral	Prevents relapse of various ailments	
	Grains and non-rice materials	Decoction	Oral	Postpartum recovery	
	Roots	Decoction	Oral	Release latent ailments with unidentified causes	
Kinilala	Grains	Wash water	Oral	Urinary tract infection (UTI), unusual yellowing of urine, and different ailments caused by special incantations (“bulong”) and hexes/evil eye (“kulam”)	
Inowak	Grains	Wash water	Topical	Clears pimples on the face	
	Grains, Roots	Wash water and decoction	Oral	Hematemesis	
Karikit	Grains	Rice porridge	Oral	Prevents relapse of ailments	
	Roots	Decoction	Oral	Beriberi or manas (inflammation)	
Pindinga/Kandinga	Grains	Rice porridge	Oral	Postpartum recovery	
	Grains and roots	Rice porridge	Oral	Prevents relapse of various ailments	

Table 10 continued

Maragaya white variant	Grains and non-rice materials	Paste mixed with non-rice herbs or materials	Topical	Measles, typhoid fever, cough	
	Grains	Infusion	Oral	Measles, fever, headache, stomach ache caused by gas/bloating, stomach ache from indigestion, fatigue, and cough	
	Grains	Rice porridge	Oral	Measles and fever	
	Grains	Dry pulverized	Topical	Headache, stomach ache caused by gas/bloating, and stomach ache from indigestion	
	Grains	Dry pulverized	Oral	Muscle aches	
	Grains	Wash water	Oral	Common cold	
	Grains, Roots	Rice porridge	Oral	Measles	
		Ash	Topical		
	Roots, Rice straw	Infusion	Oral	Common cold and cough	
Maragaya purple variant	Grains	Not provided	Not provided	Different ailments caused by special incantations (“bulong”) and hexes/evil eye (“kulam”)	
	Grains	Infusion	Oral	Measles, fever, headache, stomach ache caused by gas/bloating, stomach ache from indigestion, fatigue, and cough	
	Grains	Dry pulverized	Topical	Headache, stomach ache caused by gas/bloating, and stomach ache from indigestion	
	Grains	Wash water	Oral	Common cold	
Weedy rice, Ketan gajih	Grains	Not provided	Not provided	Stomach diseases in babies, high fever, restlessness, appetite enhancer, and for removal of intestinal worms	[84]

Table 11. The traditional rice varieties that were provided with information about their preparation and consumption as food

Traditional rice name	Features	Preparation/Uses	References
Bisol	Glutinous rice	An ingredient in biko (a sticky rice dessert made with brown sugar and coconut milk) or rice cakes served by the Tboli tribe during their celebrations	[86]
Nao Tha Yung	Glutinous	Can be boiled or steamed/used in brewing alcohol/used to make cake	[87]
Kanoa Kanwen Swen Poh	Aromatic and waxy	Mixed with other rice to add flavor	
Kanoa Lun Rau	Glutinous	Best for alcohol brewing/can be boiled, cooked, or made into a paste	
Kaeha – Apo Tha	Variety with the hardest texture	Blended with soft rice varieties	
Ti Kha Tha	Soft texture, semi-glutinous	Blended with hard rice varieties	
Khauk Chan	Soft texture, semi-glutinous	Blended with hard rice varieties	
Ywet Thay Ka Lay	Not provided	Cooked and sometimes blended with other rice varieties	
Rice or Padi (local variety name was not provided)	White or black grains, glutinous or non-glutinous	Can be steamed or fried/cooked in banana leaves or bamboo (“buluh”) stalks/main ingredient in “tuak”, a traditional rice wine	[88]

Meanwhile, local food plants are relevant to the issue of food security by increasing the food supply, diversifying the diet, reducing malnutrition, and even acting as important genetic resources for the improvement of domesticated plant species whose wild relatives are the indigenous food plants [91]. The availability of wild edible plants, for instance, can help mitigate food shortages and offer nutritional supplements to impoverished communities located in rural and mountainous areas [92]. Similarly, rice landraces cultivated by subsistence farming are important food sources for upland communities whose long-term survival heavily relies on the maintenance of traditional farming systems [86]. In addition, household incomes can also be derived from the application of ethnobotanical knowledge. Zapico et al. [86] reported that some rice landraces grown by Sarangani farmers were both used for family consumption and as a source of income when there is a surplus of harvests. Moreover, the introduction and promotion of traditional farming to niche markets can transform it into a more profitable venture for the benefit of upland communities [86].

Ethnobotanical studies are also important to the conservation of biodiversity. The findings of such studies may serve as bases for the development of sustainable consumption-production models that can be adopted in decision and policy-making for the responsible use and effective management of traditionally valuable plants [91]. The traditional and weedy rice varieties that were reported in the current review as medicinal and nutritional sources of rural and upland communities in Indonesia [84], Philippines [85,86], Myanmar [87], and Malaysia [88] demonstrate their significance to local healthcare and sustenance and, thus, necessitate increased awareness among local communities to promote the conservation and sustainable use of these plants. Although weedy rice is undesirable in rice cultivation, their controlled cultivation as a source of food and medicine by locals may prove beneficial to the local communities in the long run. Moreover, as ethnobotanical studies on weedy rice in Southeast Asia are very limited, more research endeavors must be done to document other weedy rice varieties that are used as medicine and food.

4. Conclusions

The current systematic review provided extensive information on the status of weedy rice in major rice-producing countries in Southeast Asia. The determination of the morphological variability of weedy rice may aid in the identification and classification of populations, supply useful traits for distinguishing the weed from cultivated varieties, provide insights on their adaptive potential across varying environments, help identify desirable traits for crop breeding and crop improvement programs, and provide useful information for site-specific management strategies. The review of weedy rice management studies, on the other hand, helps promote cost-efficient and sustainable farm practices that reduce weedy rice infestations while increasing agricultural productivity. Finally, the review of ethnobotanical investigations provided valuable information on the medicinal and culinary uses of weedy rice and traditional rice varieties that could establish their roles in community healthcare, diversify local diets, support knowledge preservation initiatives, and promote the sustainable utilization of these important local plant resources.

Supplementary Table

Supplementary Table 1. List and descriptions of weedy/traditional rice varieties used as either medicine or food by different local communities in Southeast Asia

Country, study sites, and respondents	Name of rice variety	Classification (weedy/ traditional)	Description/ Features	Use/application (consumption/ medicine)	Reference
Philippines					
Farmers, housekeepers, local government workers, and community traders in select barangays of Palawan, Zamboanga del Norte, Zamboanga del Sur, and North Cotabato	Gapon Gapon	Traditional		Medicine	[85]
	Bihod	Traditional		Medicine	
	Tang co	Traditional		Medicine	
	Pilit Tapul	Traditional		Medicine	
	Dinorado	Traditional		Medicine	
	Bulawan	Traditional		Medicine	
	Hinumay	Traditional		Medicine	

Supplementary Table 1 continued

	Kutibos	Traditional		Medicine	
	Makaitot	Traditional		Medicine	
	Bagtok	traditional		Medicine	
	Salog	Traditional		Medicine	
	Tres Marias	Traditional		Medicine	
	Dalino	Traditional		Medicine	
	Kinilala	Traditional		Medicine	
	Inowak	Traditional		Medicine	
	Karikit	Traditional		Medicine	
	Pindinga/Kandinga	Traditional		Medicine	
	Maragaya (White variant)	Traditional		Medicine	
	Maragaya (Purple variant)	Traditional		Medicine	
Farmers, village officials, and tribal elders from 14 upland villages in Sarangani Province	Mitaw	Traditional	Big grains	Consumption	[86]
	Hinumay	Traditional	Aromatic, highly shattering	Consumption	
	Dinorado Puti	Traditional	Aromatic	Consumption	
	Pilit Puti	Traditional	Glutinous, very viable, vigorous	Consumption	
	Dihilan	Traditional		Consumption	
	Kambing	Traditional	Good quality seeds	Consumption	
	Kalumfang	Traditional	Aromatic, tasty	Consumption	
	Walokangoy	Traditional		Consumption	
	Mlal	Traditional	Aromatic	Consumption	
	Lumabet	Traditional	Small grains	Consumption	
	Fandabulaw	Traditional	Pale white grains, high-yielding		
	Malgas	Traditional	Small grains		
	Lumamon	Traditional	Large panicles, tasty, aromatic	Consumption	
	Sugen	Traditional	Large panicles, high-yielding	Consumption	
	Mlikat Fitam	Traditional	Glutinous	Consumption	
	Muslim	Traditional	Aromatic	Consumption	
	Dinorado Pula	Traditional	Red rice	Consumption	
	Kanone	Traditional	Palatable, low-yielding	Consumption	
	Abtu Kulang	Traditional	High volume expansion (“rises when cooked”	Consumption	
	Larangan	Traditional	Tasty or aromatic	Consumption	
	Bulawan	Traditional	Very aromatic	Consumption	
	Fitam kwat	Traditional	High-yielding, very tall	Consumption	
	Buling	Traditional	Very small grains	Consumption	
	Sumalong	Traditional	Low tillering	Consumption	
	Salmaka	Traditional	Attractive to birds	Consumption	
	Morado	Traditional	Pale red grains	Consumption	
	Blitan	Traditional		Consumption	
	Mlikat tari	Traditional	Glutinous	Consumption	

Supplementary Table 1 continued

Mlato	Traditional		Consumption
Mlikat Tapol	Traditional	Glutinous or robust	Consumption
Bagio	Traditional		Consumption
Byaan	Traditional	Palatable, drought-tolerant	Consumption
Palawan	Traditional	Palatable	Consumption
Manol	Traditional	Easy to pound	Consumption
Mlikat Kulo	Traditional	Glutinous	Consumption
T'kudang	Traditional		Consumption
Twel	Traditional	Golden brown grain	Consumption
Klanon	Traditional	Pale yellow grain	Consumption
Lanao	Traditional	High tillering	Consumption
Almawan	Traditional		Consumption
Katiil	Traditional	Palatable	Consumption
Uyayang	Traditional	Grown in hardpan soil, aromatic, tasty	Consumption
Saibon	Traditional	Highly shattering	Consumption
Lakag	Traditional		Consumption
Manisi	Traditional		Consumption
Lambak	Traditional		Consumption
Blogo	Traditional		Consumption
Migsayap	Traditional	Palatable	Consumption
Tabaw	Traditional	Very long awns, not attractive to birds	Consumption
Pilit Gumatos	Traditional	Glutinous	Consumption
Langisi	Traditional		Consumption
Kubo	Traditional		Consumption
Tamaing	Traditional		Consumption
Kulay	Traditional		Consumption
Kabaho	Traditional	Grain shaped like a hunting knife	Consumption
Kasagpi	Traditional	Leftover rice is not good for eating, hard to thresh	Consumption
Tulon	Traditional		Consumption
Balabak	Traditional	Glutinous	Consumption
Slot	Traditional	Looks similar to pig feces	Consumption
Lagani	Traditional		Consumption
Mayaman	Traditional	White, tasty, aromatic	Consumption
Lapinig	Traditional	Drought-tolerant, tasty, aromatic	Consumption
Fantilanen	Traditional	Easy lodging, aromatic, high-yielding	Consumption
Liwanan	Traditional		Consumption
Pilit Subo	Traditional		Consumption
Minala	Traditional		Consumption
Salakat	Traditional	Glutinous, very sticky	Consumption
Lakado	Traditional		Consumption

Supplementary Table 1 continued

Farmers from 16 upland villages in Sarangani province	Malgas	Traditional		Consumption	[93]
	Muslim	Traditional		Consumption	
	Lagfisan	Traditional		Consumption	
	Mlal	Traditional		Consumption	
	Mlikat Blawen	Traditional		Consumption	
	Moradu	Traditional		Consumption	
	M'likat Siawen	Traditional		Consumption	
	Samfang	Traditional		Consumption	
	M'likat Tapol	Traditional	Brown hull	Consumption	
	Paiawan	Traditional		Consumption	
	Fantilanen	Traditional		Consumption	
	M'likat Tapol	Traditional	Straw-colored hull	Consumption	
Indonesia					
Traditional healers, vocational school teachers and lecturers; study sites were undisclosed	*Ketan gajih*	Weedy		Medicine	[84]
Upland Baduy population in West Java	pare ketan areuy	Traditional	Glutinous	Consumption	[94]
	pare ketan	Traditional	Glutinous	Consumption	
	pare (ketan) bodas	Traditional	Glutinous	Consumption	
	pare ketan bulu kuda	Traditional	Glutinous	Consumption	
	pare ketan gadog	Traditional	Glutinous	Consumption	
	pare ketan hideung	Traditional	Glutinous	Consumption	
	pare ketan kasumba	Traditional	Glutinous	Consumption	
	pare ketan keuyeup	Traditional	Glutinous	Consumption	
	pare ketan kidang	Traditional	Glutinous	Consumption	
	pare ketan jalupang	Traditional	Glutinous	Consumption	
	pare ketan langgasari	Traditional	Glutinous	Consumption	
	pare kertan meloy	Traditional	Glutinous	Consumption	
	pare ketan Nangka	Traditional	Glutinous	Consumption	
	pare ketan putri	Traditional	Glutinous	Consumption	
	pare ketan ruyung	Traditional	Glutinous	Consumption	
	pare ketan siang	Traditional	Glutinous	Consumption	

Supplementary Table 1 continued

Traditional leaders and members of the Sasak community in Mandalika, Lombok Island, West Nusa Tenggara	pare bulu	Traditional	Tasty	Consumption	[83]
	pare bea	Weedy	Red rice	Consumption	
Malaysia					
Inhabitants of the Rumah Emmanuel longhouse located along the Kanowit river banks in Nanga Lipus	Padi or rice (no specific variety name was provided)	Traditional	White or black grains, glutinous or non-glutinous	Consumption	[88]
Myanmar					
Farmers and local people of select districts in Northern Kachin state and Southern Chin state	mayan	Traditional	Glutinous	Consumption	[95]
	am “am hen”	Traditional		Consumption	
	am “am kholon”"	Traditional		Consumption	
	mam “ga wa mam”	Traditional		Consumption	
	mam “ta nai mam”	Traditional	Soft rice	Consumption	
	mam “n bo mam”	Traditional	Glutinous, white rice	Consumption	
	mam “n bo jang”	Traditional	Glutinous, blackish purple rice	Consumption	
	vm [am] “vm se [am se]”	Traditional	White, soft rice	Consumption	
	“e dn [e pu]”	Traditional	Red, hard rice	Consumption	
	“z si si [ze si si]”	Traditional	Not sticky	Consumption	
	sen pa	Traditional		Consumption	
	sen thar	Traditional		Consumption	
	pi nal	Traditional		Consumption	
	cang swat	Traditional		Consumption	
	pi nal mi buet	Traditional	Slightly aromatic	Consumption	
	tham hrim	Traditional	Favorable quality for eating	Consumption	
	cang swat	Traditional		Consumption	
	paw	Traditional	Long culm	Consumption	
	di kul	Traditional	Sticky rice, black awn, black pericarp	Consumption	
	ka thlang	Traditional	Sticky rice, black awn	Consumption	
	ca mum	Traditional	Sticky rice, black hull, black awn, white pericarp	Consumption	
	mizu ca sawk	Traditional	Sticky rice, reddish brown hull	Consumption	
	ma du cang	Traditional	Not sticky, high-yielding, favorable quality for eating	Consumption	
	nga cheik	Traditional	Glutinous	Consumption	
	kauk nhyin	Traditional		Consumption	
	ney pyi hnwe	Traditional	Aromatic	Consumption	

Supplementary Table 1 continued

Farmers and local people of select districts in Chin state	“madu”	Traditional	Short awn, non-waxy	Consumption	[96]
	“mizora tok sho”	Traditional	Upland rice, waxy	Consumption	
	“sam mho”	Traditional	Slightly red rice, waxy	Consumption	
	“dek ki”	Traditional	Violet, waxy rice	Consumption	
	“lisong”	Traditional		Consumption	
	cc ta, “madu”	Traditional		Consumption	
	“madu”	Traditional		Consumption	
	“sa sha”	Traditional		Consumption	
	“ba ta ma nung”	Traditional		Consumption	
	“cca ne”	Traditional	Waxy	Consumption	
	ca teng	Traditional		Consumption	
	“japani”	Traditional		Consumption	
	fa cang, “japani”	Traditional		Consumption	
Farmers and local people of select districts in Northern Sagaing region and Shan state	Ga Le Zha Fha	Traditional		Consumption	[87]
	A Zha	Traditional		Consumption	
	Ga Lwer	Traditional	Glutinous	Consumption	
	La Ya	Traditional		Consumption	
	Zi Tsa	Traditional	Glutinous	Consumption	
	Ko Poh Tha	Traditional		Consumption	
	Ye Lum Tha	Traditional		Consumption	
	Ta Ka Pi	Traditional	Semi-waxy rice	Consumption	
	Nao Tha Yung	Traditional	Glutinous	Consumption	
	Ra Cha Tha	Traditional		Consumption	
	Ten Nee Tha	Traditional	High-yielding, hard texture, good flavor	Consumption	
	Kanoa Kanwen Swen Poh	Traditional	Aromatic and waxy	Consumption	
	Ten Nee Tha Kare Poh	Traditional	Semi-waxy	Consumption	
	Kanoa Lun Rau	Traditional	Glutinous	Consumption	
	Kaeha – Apo Tha	Traditional	Variety with the hardest texture	Consumption	
	Ti Kha Tha	Traditional	Soft texture, semi-glutinous	Consumption	
	Khauk Chan	Traditional	Soft texture, semi-glutinous	Consumption	
	Ara Tha	Traditional	Red rice	Consumption	
	Chang Pel	Traditional		Consumption	
	Ywet Thay Ka Lay	Traditional		Consumption	
	Man Khan Phauk	Traditional		Consumption	

Empty cells indicate that the information was not provided in the study.

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