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Agronomic Traits and Grain Quality of Upland Rice Cultivated in Southeast Sulawesi, Indonesia

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Abstract. Farms in Southeast Sulawesi Province, Indonesia, historically grow upland rice crops that utilize the slash-and-burn farming system. However, little is known about grain quality and the differences between upland rice varieties in this region. In the present study, growth and grain yield were measured to elucidate the characteristics of traditional upland rice varieties grown by local farmers. Additionally, amylose and protein content were measured to understand their characteristics. In this region, farmers predominantly grew traditional rice varieties, which were deemed as tropical japonica based on the measured agronomic traits. These traditional varieties were highly varied in terms of grain appearance and yield-related factors. Grain yield in the traditional varieties (3.0 t ha^{-1} on average) was inferior to that of Lampung (4.0 t ha^{-1} on average), an improved variety newly introduced from outside the region. In particular, Lampung tended to have a higher spikelet number per m^2 than that of the traditional varieties. The protein and amylose content varied depending on the different varieties. Amylose content of eleven upland rice varieties was determined, with eight varieties characterized as sticky rice, two as non-glutinous varieties, and one as an extremely low amylose variety. These results indicate that this region contains valuable upland rice varieties, and this information is useful for future genetic resource studies.
Key words: Indonesia, Upland rice, Agronomic trait, Protein content, Amylose content

Introduction

Rice growing ecosystems are broadly classified into three types based on soil-water conditions: irrigated lowland, rainfed lowland, and upland; accounting for approximately 75, 19, and 4% of global rice production, respectively[1]. Therefore, the contribution of upland rice to global rice production is not as great as that of lowland rice. However, in Asia, where more than 90% of the world's rice is produced, upland rice remains an important crop for traditional smallholders[1].

In Southeast Sulawesi Province, Indonesia, upland rice has been cultivated by the traditional slash-and-burn system during the rainy season for many years[2, 3, 4, 5]. In this province, the upland rice cultivation area is relatively higher than in other regions and has been estimated at approximately 8,000 ha–10,000 ha (12% of the total rice cultivation area), with annual production estimated between 25,000 t and 32,000 t (8% of the total production)[4, 5]. Therefore, upland rice has played an important role as a staple food item for local people[5]. Farmers in

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this region grow upland rice of traditional varieties mainly for personal consumption[5]. This is because farmers prefer the eating quality of these traditional varieties. If upland rice is sold in the market, its selling price is double that of lowland rice[5]. Recently, some upland rice farmers have shifted from traditional varieties to improved varieties[5, 6]. Therefore, there is a possibility that the improved varieties might replace the traditional varieties in the future.

Traditional varieties have been selected by local people in the past in line with local ecological characteristics; therefore, some traditional varieties possess superior characteristics and can grow under severely stressful environmental conditions, such as drought and aluminum toxicity[7]. Traditional rice varieties in Southeast Asian countries have been recognized as a valuable source of tolerance genes[7]. The traditional rice varieties in Indonesia have been used as breeding materials[8]. It is important to obtain information about traditional upland varieties in this area for studying genetic resources.

In the present study, growth and grain yield were measured to understand the characteristics of traditional rice varieties, with these characteristics compared with an improved rice variety. Additionally, amylose and protein content was measured to understand their abundances because there is currently no information about these factors in this region.

Materials and Methods

Study site

The study sites were located in the southeastern part of Sulawesi Island (Fig. 1). The survey was conducted in farmers' fields on a hillside in Palangga District, South Konawe Regency, Southeast Sulawesi Province, Indonesia, in 2010 and 2012. During the rainy season (late November to late July), the area receives more than 150 mm of rainfall each month. The annual rainfall in this region is approximately 2,000 mm and the average temperature is 24–29 °C[9].

Upland rice was cultivated in the traditional slash-and-burn farming system by Tolakinese farmers during the rainy season. The upland fields were prepared by cutting down the trees in late September, and burning the fields in the end of the dry season (late November)[9]. In the beginning of the rainy season rice seeds were sown directly into the prepared soil in upland field. The upland rice was harvested around May. The plants were grown without the use of fertilizers or pesticides.

Growth and yield surveys

The surveys were conducted twice, in 2010 and 2012, prior to rice harvest. The first survey was performed from

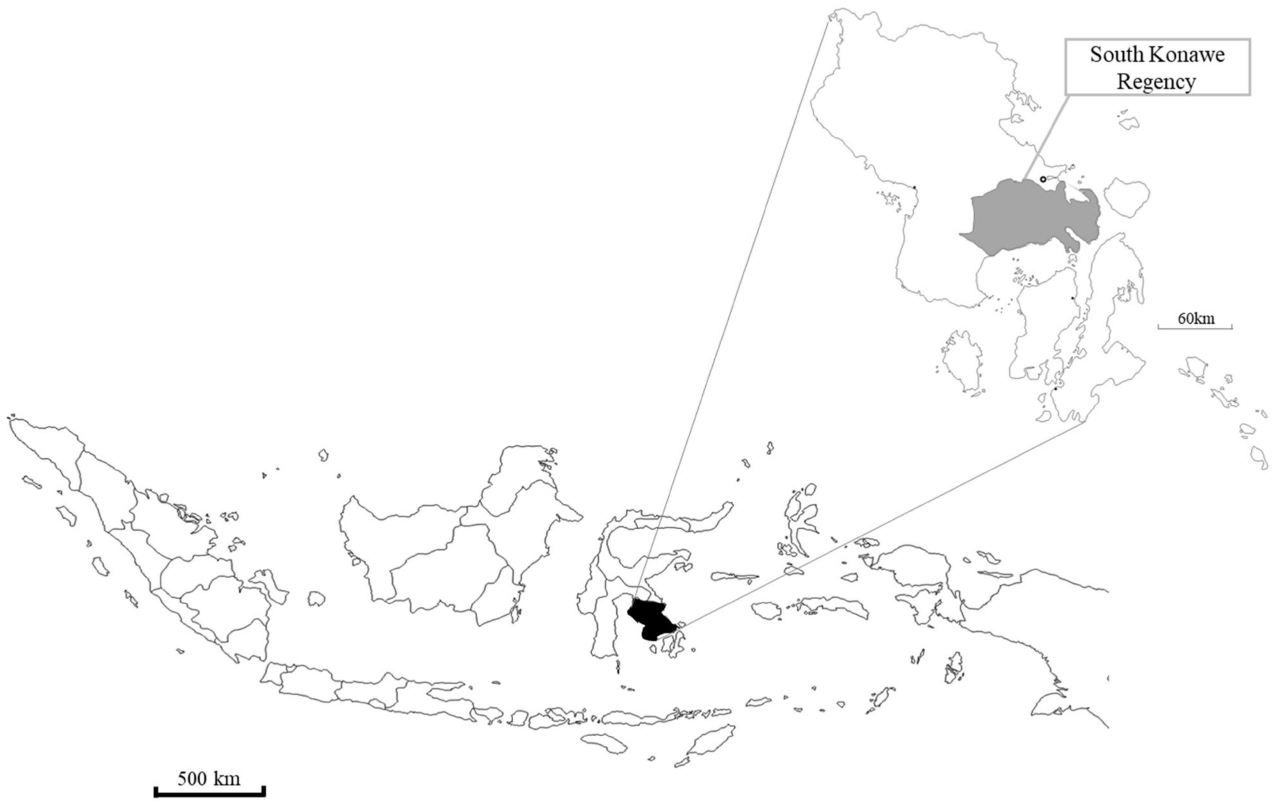

Fig. 1. Map of the study site in Southeast Sulawesi Province, Indonesia.

late April to early May in 2010 in Kiaea and Wawonggura villages. Farmers in Kiaea grew three rice varieties: Dai Hoani, Moku, and Undolia, and farmers in Wawonggura grew one rice variety, Dai Wolio. The second survey was undertaken at three fields in Palangga village from late April to early May in 2012. One farmer grew Uso and two farmers grew Lampung. According to the farmers, Lampung is an improved variety that originated from outside the region in the 2000s, and the other five varieties are considered as traditional varieties. In the 2010 survey, 20 hills per variety were randomly selected to measure plant length, culm length, panicle length, and flag leaf length in the field. In the 2012 survey, these traits were measured for hills sampled from an area of 1 m^2 (approximately 10 hills) with three replications.

During both surveys, to determine the shoot fresh weight and yield components, plant samples were taken from three square plots (1 m × 1 m) per variety. For each square plot, the number of hills per plot and the number of panicles per hill were counted, after which all the hills in the plot were cut at ground level. Panicle morphology was photographed, and we recorded whether grain awns were present based on our observations. To determine the number of spikelets per panicle, percentage of filled grains, and 1000-grain weight, 20 panicles were randomly selected from each plot during the first survey and one representative hill with an average number of panicles per hill was measured during the second survey. After hand-threshing, filled and unfilled grains were separated using fresh water and were counted from each plot. The 1000-grain weight of rice was adjusted to a 14% moisture content. Grain yield was calculated from all yield components.

Amylose and protein content

The brown rice samples were collected from the same growing regions with yield survey areas. Ten upland rice varieties (Biu, Dai Hoani, Dai Wolio, Lampung, Lang Gandobu, Moku, Nggalaru, Undolia, Wolasi, and Wulumata) were collected from the fields around the Palangga District, and one upland variety was collected at a market in Kendari in Southeast Sulawesi Province. However, the variety collected from the market was unknown and the code name “red upland rice” was conferred based on the grain color. For brown rice in these 11 varieties, amylose (Auto-analyzer II, Bran+Luebbe, Germany) and protein content (Infra Alyzer500, Bran+Luebbe , Germany) were measured.

Results

Growth and yield survey

Growth and yield measurements were collected from six rice varieties in our two surveys, have awn (Fig. 2). Grain color was white in six varieties, brown in four varieties, and blackish in one variety (Fig. 3). Plant and culm lengths of the six varieties ranged from 166 to 196 cm and 125 to 154 cm, respectively (Table 1). Plant length of Dai Hoani and Dai Wolio was longer than the other varieties. Panicle length, and flag leaf length ranged from 25.6 to 36.8 cm and from 36.8 to 50.6 cm, respectively.

Hill number per square meter ranged from 9.0 to 12.0 (Table 2). Panicle number per hill and per square meter ranged from 9.6 to 13.1 and from 86 to 136, respectively. Dai Hoani and Moku had lower panicle numbers per hill and per square meter than those of the other varieties. Spikelet number per panicle ranged from 101 to 183, with Dai Wolio and Uso having fewer numbers of spikelets than that of the other varieties. Spikelet number per square meter in the traditional varieties ranged from 13,000 to 17,000, whereas the number in the improved variety (Lampung) was approximately 21,000. The percentage of filled grains ranged from 60.4% to 89.3%. The 1000-grain weight was less than 25.0 g (21.7–23.2 g) in Moku, Uso, and Lampung, whereas it was greater than 25.0 g (27.3–33.2 g) in Dai Hoani, Undolia and Dai Wolio. Brown rice yields from all rice varieties ranged from 203 to 429 g m^{-2}. Lampung showed the highest yield out of the six varieties.

Protein and amylose content in brown rice

The 1000-grain weight ranged from 20.7 to 33.5 g between the 11 rice varieties (Table 3). The protein content in the 11 varieties ranged from 7.8% to 10.7%. Amylose content was 0% in Biu and Dai Wolio, and 5.9% in Wulumata. Amylose content in the other eight varieties ranged from 14.8% to 19.7%.

Discussion

Characteristics of cultivated varieties

In previous studies, more than 20 varieties of traditional upland rice varieties have been examined[3], with one improved rice variety also observed in this region[5, 6]. Similarly, in our survey, farmers grow both traditional and improved rice varieties (Table 1); however, the traditional rice varieties still predominate in the region. The traditional rice varieties were widely different in terms of grain shape, size, and color compared to the improved rice variety (Figs. 2 and 3, Table 3), suggesting that these traditional rice varieties have retained their diversity. This might be because farmers grow several different rice varieties to ensure risk distribution, resulting in the diversity of the varieties being maintained.

Most of the upland rice varieties are classified as tropical japonica, as shown in studies on upland rice in

Fig. 2. Panicles of rice varieties that are used to determine the growth and yield components.
Undolia, Moku, Dai Hoani, and Dai Wolio collected in 2010 (upper left), Uso collected in 2012 (upper right), Lampung-1 collected in 2012 (lower left), and Lampung-2 collected in 2012 (lower right).

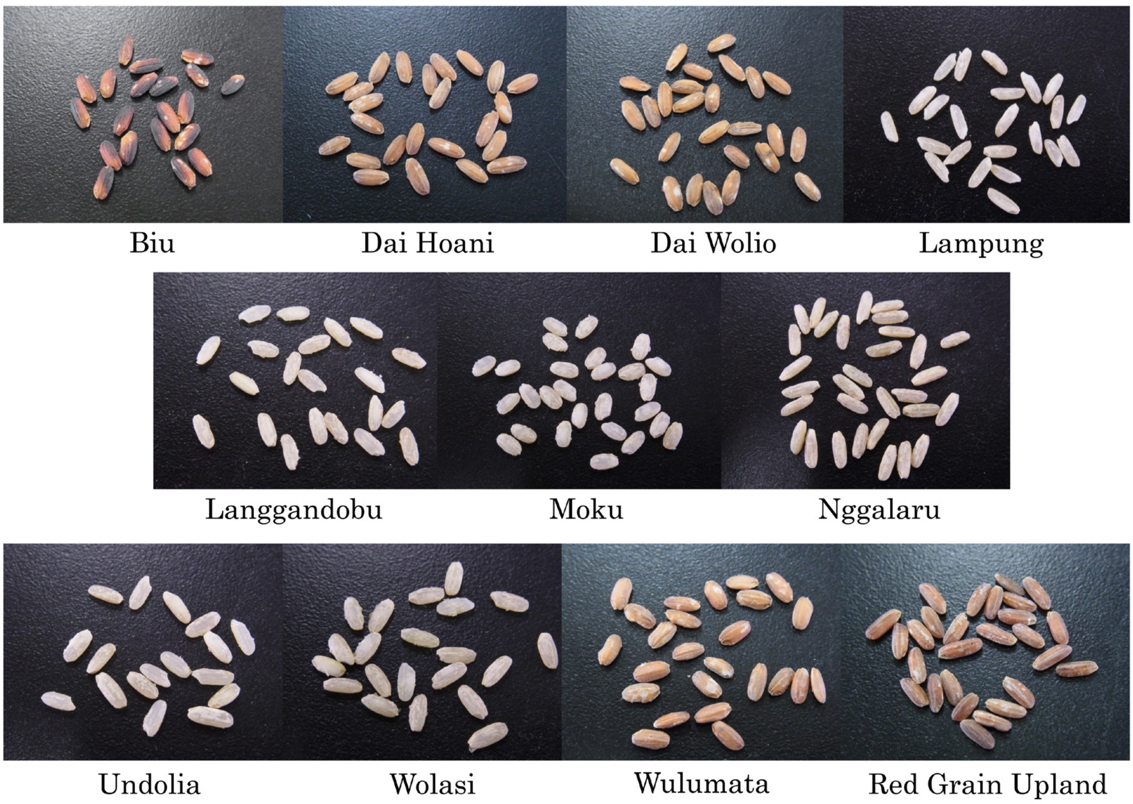

Fig. 3. Grain color and shape variation in rice varieties that are used to determine protein and amylose content in brown rice.

Table 1. Growth characteristics of upland rice varieties in Southeast Sulawesi Province, Indonesia.

Year	Variety	Researched village	Awn	Plant length (cm)	Culm length (cm)	Panicle length (cm)	Flag leaf length (cm)
2010	Dai Hoani	Kiaea	long	196 ± 7	154 ± 8	36.8 ± 1.2	48.1 ± 2.4
	Moku	Kiaea	long	175 ± 6	144 ± 7	28.1 ± 0.6	37.0 ± 2.0
	Undolia	Kiaea	long	174 ± 9	137 ± 11	33.9 ± 1.1	41.8 ± 2.2
	Dai Wolio	Wawouggura	long	184 ± 11	143 ± 6	35.4 ± 1.1	48.1 ± 3.3
2012	Uso	Palangga	long	169 ± 6	133 ± 5	27.6 ± 1.1	36.8 ± 1.7
	Lampung-1	Palangga (Farmer 1)	long	172 ± 2	125 ± 4	27.8 ± 0.2	50.6 ± 2.5
	Lampung-2	Palangga (Farmer 2)	long	166 ± 11	130 ± 8	25.6 ± 0.9	42.1 ± 2.4

Data are mean values with S.D.

Table 2. Yield and yield components of upland rice varieties in Southeast Sulawesi Province, Indonesia.

Year	Variety	No. of hills	Panicle number		Spikelet number		Percentage of filled grain	1000-grain weight	Brown rice yield
		(m^{-2})	(per hill)	(m^{-2})	(per panicle)	(m^{-2})	(%)	(g)	($g\ m^{-2}$)
2010	Dai Hoani	9.0 ± 1.0	9.7 ± 2.0	87 ± 10	174 ± 27	15172 ± 1718	71.2 ± 9.1	33.0 ± 0.7	353 ± 71
	Moku	9.0 ± 0.0	9.6 ± 0.6	86 ± 6	183 ± 12	15797 ± 1752	72.5 ± 6.7	23.2 ± 0.7	267 ± 33
	Undolia	9.3 ± 1.5	12.4 ± 1.2	115 ± 12	150 ± 1	17241 ± 1786	77.9 ± 7.2	27.3 ± 0.7	363 ± 47
	Dai Wolio	12.0 ± 2.6	10.5 ± 2.8	126 ± 15	101 ± 22	12786 ± 3952	77.2 ± 7.0	33.2 ± 0.6	316 ± 71
2012	Uso	10.0 ± 0.8	13.0 ± 1.2	131 ± 22	118 ± 18	15903 ± 5005	60.4 ± 6.7	21.7 ± 0.8	203 ± 48
	Lampung-1	11.3 ± 1.7	10.7 ± 1.1	121 ± 21	175 ± 18	21019 ± 2967	76.5 ± 10.3	23.2 ± 1.3	366 ± 24
	Lampung-2	11.0 ± 2.0	13.1 ± 4.3	136 ± 21	161 ± 42	20914 ± 2233	89.3 ± 2.7	22.9 ± 1.4	429 ± 58

Data are mean values with S.D.

Vietnam and Laos[10, 11]. The morphological traits of tropical japonica varieties include greater than average plant length (120–180 cm), longer leaves, larger but fewer panicles (2–4 panicles per hill), and more (150–300) grains per panicle[12, 13, 14]. The morphological traits of the five traditional upland varieties sampled in our study were similar to those of typical traditional upland rice, except that they had more panicles than typical upland rice (Tables 1 and 2). The higher panicle number may be a unique trait of the upland rice varieties in this region.

Yield levels among collected varieties

In our surveys, the yield of the traditional varieties was 3.0 t ha^{-1} on average, whereas that of the improved variety, Lampung, was 4.0 t ha^{-1}, that is, the traditional varieties had no yield advantage over the improved upland variety (Table 2). Lampung tended to have a higher spikelet number per square meter than that of the traditional varieties. This result supported our previous study, which showed that yield potential might be different between the traditional and improved varieties[5]. The highest yield difference among the traditional varieties was 1.6 t ha^{-1}, with the highest yield in Undolia variety (3.6 t ha^{-1}) and the lowest yield in Uso (2.0 t ha^{-1}); and characteristics of the yield component were different depending on the variety (Table 2). It appears that the selection of rice variety by farmers is more complex than just the yield or morphological traits. These results imply that farmers select rice varieties through comprehensive analysis of the interrelationship among crop traits, environmental factors, social factors, etc. Further studies are needed to understand farmers' strategies for variety management.

Table 3. The 1000-grain weight and amylose and protein content of upland rice varieties in southeast Sulawesi Province, Indonesia.

Variety	1000-grain weight (g)	Protein (%)	Amylose (%)
Biu	25.2	9.8	0.0
Dai Hoani	33.3	10.2	14.8
Dai Wolio	33.5	9.6	0.00
Lampung	23.9	9.3	19.7
Lang Gandobu	20.8	9.6	18.2
Moku	23.4	7.8	19.5
Nggalaru	21.7	7.8	19.3
Undolia	27.6	8.3	19.2
Wolasi	22.2	10.2	18.7
Wulumata	20.7	10.7	5.9
Red Upland Rice	20.7	8.7	18.4

Characteristics of protein and amylose content

Protein content in brown rice is closely related to eating quality[15, 16]. In our study, the protein content varied from 7.8% to 10.7% depending on the rice variety, with an average of 8.7% (Table 3). These values fell within the range (4.3%–18.2%) of the IRRI's World Collection (17,587 cultivars)[16]. Taira and Taira[17] reported that protein content in brown rice was greater in rice grown in uplands compared with rice grown in lowlands. It has also been reported that high N fertilization at heading stage increased protein content in brown rice[17]. In our study, the protein content in brown rice, despite being grown in the upland field, tended to be lower than the average of the IRRI's World Collection (9.5%)[16]. This may be because in this region rice was cultivated without fertilization.

Damardjati and Oka[18] have reported that a major factor in determining eating quality is the amylose content, but consumer preferences differed widely in the Indonesian region. According to Gomez (1979) [16], amylose content in rice was classified as waxy (0%–2% in brown rice, 0%–2% in milled rice), very low (0%–9% in brown rice, 2%–9% in milled rice), low (10%–19% in brown rice, 9%–20% in milled rice), intermediate (20%–24% in brown rice, 20%–25% in milled rice), and high (> 25% in brown rice, > 25% in milled rice). In our studies, amylose content of non-glutinous rice was 14.8%–19.7% in brown rice, which was estimated at 15.8%–22.5% in milled rice, based on a previous study that compared the amylose content of brown and milled rice[19]. Damardjati and Oka[18] collected rice samples from three large regions (Jakarta, South Sulawesi, and North Sumatra) in Indonesia and reported that the amylose content of 469 samples of milled rice ranged from 17.2% to 27.3% (low to high). They reported that most people in Sumatera and Sulawesi preferred the less sticky rice, whereas people in Java preferred sticky rice. A similar low to intermediate amylose content (10%–25%) was found in our study, which was conducted in Southeast Sulawesi. Additionally, it has been reported that most traditional upland varieties were placed in the intermediate category for amylose content[20]. Therefore, farmers in this region may prefer normal amylose content rice varieties rather than high amylose content rice varieties.

Besides non-glutinous rice, two glutinous rice were found with amylose content of 0% (Table 3). However, the ratio of glutinous rice varieties was less than 20% of the collected samples. Similarly, Pasolon and Borromeu[3] reported that glutinous rice occupied 15% of the collected upland rice in the same region. Thus, non-glutinous rice predominates in this region. Glutinous rice is generally cooked by steaming and is mainly eaten during festivals or gatherings[9]. Farmers might have consciously cultivated the sticky rice varieties in certain ratios. Wulumata had less than 10% amylose content (Table 3). This rice is categorized as having a very low amylose content. Similar to our results, very low amylose content rice was found from landraces in mountainous areas in Southeast Asia[21, 22]. In Japan, rice with low amylose content is becoming increasingly popular because it is being developed as one of the new types of rice by breeding to expand rice demand[23]. Thus, this type of unique characteristic might be important from the point of view of genetic resources.

Conclusion

Upland rice grown by farmers in the Southeast Sulawesi Province was highly diverse in terms of grain appearance and yield-related factors. Almost all studied rice varieties were traditional varieties categorized as tropical japonica rice. Although, amylose and protein content differed depending on the rice variety, there were no high values of protein and amylose content in non-glutinous rice from our surveys. However, we observed a rice variety (Wulumata) with extremely low amylose content, which is a unique characteristic. Our results show that this region has valuable upland rice varieties, and these characteristics are important when considering these varieties for their genetic resources. Eating quality was only partially researched in the present study; therefore, future research should be undertaken to study a wider range of eating qualities.

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