

Key agronomic traits for variety selection by farmers in upland rice systems of Lao

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Abstract

In the mountainous areas of Lao P.D.R, where upland rice production under shifting cultivation has been a major system for rice security, farmers have grown diverse varieties according to their indigenous knowledge. However, the policy for forest conservation and the shift to a market economy since the 1990s has dramatically changed the nature of shifting cultivation, which potentially affects the farmers' selection of varieties of upland rice. To identify the key agronomic traits for variety selection by upland rice farmers, we conducted a germplasm collection and an interview survey of rice characteristics and cultivation frequency in a total of 26 villages in the Luang Prabang, Vientiane and Sekong Provinces during the period from 2014 to 2015. Characteristics, such as plant height, tiller number, soil adaptability, and maturity, were recorded as categorical parameters with two to five classes; grain shape (length and width) and grain weight were measured as continuous parameters.

We collected 244 accessions from 26 villages. The number of accessions per village was highest in Luang Prabang Province, which proportionately has the largest area of shifting cultivation in Lao. For each characteristic evaluated with the interview survey, a Pearson's chi-square test was performed to compare the frequency distribution between the primary genotype group ($n=27$), which were the genotypes with the highest cultivation frequency in each village, and the total population ($n = 244$). The results showed a significant difference in two characteristics: environmental adaptability and maturity. The frequency distribution of environmental adaptability to poor, moderate and good environments was 29%, 55% and 24% for the total population but 15%, 22% and 63% for the primary genotype group. The frequency distribution of maturity for early, middle and late maturity was 19%, 30% and 51% for the total population but 7%, 11% and 82% for the primary genotype group. These results indicate that upland rice farmers in Lao tend to prefer varieties with late maturity that are adapted to good environments.

Introduction

The Lao P.D.R. (hereafter, Lao) is a landlocked country in Southeast Asia and has the second highest annual rice consumption per capita in the world (approximately 170 kg per capita,

GRiSP, 2013). Traditionally, shifting cultivation has been one of the dominant rice ecosystems in Lao due to the geographic characteristics of the country; mountainous terrain occupies 70% of the total land area. Particularly in the northern region, upland rice production has been a key practice for food security for the resource-poor farmer with 60% of rice producers engaged in shifting cultivation (Steering Committee for the Agricultural Census 2012).

Lao is the one of the countries with the largest genetic diversity of rice (Rao et al. 2002). Due to the erratic rainfall and lack of fertilizer input, the yield is generally low, approximately 1.7 t ha⁻¹ (Committee for Planning and Investment 2006; Ministry of Planning and Investment 2013). To achieve stable rice production under such poor conditions, upland rice farmers utilize their genetic resources according to the local indigenous knowledge, which is based on their long-term experience. In addition, the cultivation of multiple varieties in a single field, which is practiced for convenient management, accelerates natural interbreeding on farms and consequently promotes genetic diversification in upland rice (Rao et al. 2006). There has been growing concern regarding rice diversity conservation in Lao; germplasm surveys have been widely conducted across Lao since the 1990s (Sato 1991; Roder et al. 1996; Rao et al. 2002; Kuroda et al. 2006).

Changes in socioeconomic conditions during the past decade have greatly influenced shifting cultivation in Lao. To control shifting cultivation and conserve forest area, the land allocation policy, which sets a clear boundary for the agricultural zone and the conservation forest zone within a territory of each village, was implemented in 1996. This led to a decrease in arable land and resulted in a shortened fallow period with a reduction from 40 years in 1950 to 2–3 years in 2000 in some areas (Roder 2001; Linquist et al. 2007). Shortened fallow periods caused soil degradation and decreased yield leading to a rice shortage at the household level (Ducourtieux and Castella 2006; Saito et al. 2006a). However, in 2000's, market economy has rapidly extended even into the rural area and diversified the livelihood of local farmers, resulting in the increasing opportunities for cash crop production and for off-farm works. Such changes also have led the local farmers to secure rice sufficiency at household level not by self-production, but by purchase at market. Overall, the demand on shifting cultivation for rice sufficiency has decreased. At the national level, there has been a gradual decrease in the area involved in shifting cultivation (Hunri et al. 2013).

Understandably, these socioeconomic changes have influenced the farmers' selection of varieties. After implementation of the land allocation policy, farmers initiatively adopted varieties with early maturity and adaptability to poor soil conditions; early maturity made it possible to harvest during the period when rice is least available and poor soil adaptability contributed to stable rice production under the conditions created by short fallow periods (Songyikhangsuthor et al. 2002; Saito et al. 2006a, b). During this period, the participatory variety selection program selected promising traditional varieties with the desirable traits of early maturity and yield superiority under poor soil conditions (Linquist et al. 2006). However, it is unclear how the current diversification of livelihood and the trend towards decreasing shifting cultivation influence the farmers' selection of rice varieties.

The objective of this study is to investigate the key traits for farmers' selection of varieties

for upland rice production in shifting cultivation ecosystems in Lao. We conducted a survey in 26 villages of three provinces: Luang Prabang (north), Vientiane (central) and Sekong (south). In this survey, we collected information on agronomic traits such as maturity, plant height, lodging resistance, etc., for each variety and identified the primary genotypes that were cultivated most frequently for each village. From the morphological data, we identified which agronomic traits were the key parameters for the selection of these primary genotypes.

Materials and Methods

Study area

We conducted the survey in 26 villages of three provinces: Luang Prabang (north), Vientiane (central) and Sekong (south) (Table 1). The survey villages were located on the main road with good accessibility. Thus, their location has the socioeconomic background such that local livelihoods are easily influenced by the market economy and forest conservation policy.

All the villages surveyed in this study were engaged in the agronomic activity of upland rice production, however, the ethnic backgrounds differed among the regions (Table 1). Officially, Lao is composed of 49 ethnic groups that are geographically categorized into three groups of Lowland Lao, Midland Lao and Highland Lao (State Planning Committee 1997). Generally, Lowland Lao is engaged in lowland rice production, whereas Midland and Highland Lao are engaged in upland rice production. In Lao, the staple food is glutinous rice; the exception is the Hmong group, a major ethnic group of Highland Lao who eat non-glutinous rice as a staple food (Roder 1996).

Germplasm collection

The germplasm survey was conducted during the dry season from December 2014 to March 2015. In each village, we collected all the upland rice varieties and interviewed farmers regarding the agronomic traits and cultivation frequency for all of the collected varieties. In this survey, we collected a total of 244 varieties from 26 villages. With regard to ethnic groups, Midland Lao comprises the Khum in the Luang Prabang and Vientiane Provinces, whereas Sekong Province comprises the Katou in the Galun district and the Kriang in the Dak Chun district. Lowland Lao and Highland Lao include the Lao Loum and Hmong, respectively.

Table 1. Village list for rice genotype collection.

District Name	Village Name	Number of households ¹⁾				% of upland farmers	Num of genotypes	
		Lowland Lao	Midland Lao	Highland Lao	Total		Glutinous	Non-glutinous
Lurang Prabang (Northern Lao)								
Xiengngeun	Kiew mai lo	2	59	4	65	100	12	3
	Phonexay	26	81	0	107	60	13	1
	Kiew Ya	0	100	26	126	100	18	4
Phonexay	Houay King	0	130	96	226	100	15	3
	Houa Meuang	0	87	0	87	100	17	2
	Tha pho	42	113	0	155	60	15	1
Pakou	Latthahae	116	0	0	116	50	8	2
	Houay lo	43	139	33	215	75	11	5
	Houay kang	0	70	0	70	70	9	2
Vientiane (Central Lao)								
Meun	Namphuoun	100	400	10	510	30	11	3
	Namphone	12	1	505	518	40	3	3
	Phonseng	126	0	308	434	40	2	3
Met	Houay pa mak	2	182	0	184	80	9	0
	Nadi	132	19	0	151	10	1	0
	Seesaath nua	50	11	0	61	50	8	1
Vanvieng	Na do kun	0	53	0	53	40	11	1
	Na mou nua	3	0	176	179	20	4	3
	Nan part	35	30	0	65	40	5	0
Fuang	Keo kun	43	64	0	107	30	3	0
	Nameuang	38	105	0	143	65	18	4
Sekong (Southern Lao)								
Galun	Chun	0	33	0	33	100	5	1
	Chok	0	45	0	45	95	5	1
	Sonkong	0	69	0	69	90	5	0
Dak Chun	Dak doun	0	43	0	43	95	4	2
	Cha lun	0	114	0	114	80	3	4
	Dao doun	0	14	0	14	100	4	2
(Average)								
Luang Prabang		25	87	18	129.7	79.4	13.1	2.6
Vientiane		49	79	91	218.6	40.5	6.8	1.6
Sekong		0	53	0	190	42	6	3

Interview survey and grain shape measurement

In the interview survey, agronomic traits were collected as categorical parameters with two to five classes: 1) endosperm type (non-glutinous, glutinous), 2) maturity (very early, early, moderate, late, very late), 3) plant height (short, moderate, long), 4) tiller number (small, moderate, many), 5) lodging (non-resistant, moderate, resistant), 6) soil adaptability (poor soil, moderate soil, good soil), 7) aroma (non-aromatic, moderate, strong), and 8) grain color (white, colored (black or red)). We also identified the varieties with the highest cultivation frequency in each village. In total, 27 varieties were identified from 26 villages because two varieties were selected in one of these villages. These 27 varieties were categorized as the primary genotype group.

For all the collected varieties, grain shape and grain weight were measured at the Rice Research Center, Vientiane, Lao. For grain weight determination, the total weight and moisture

content of 500 grains were measured twice and then averaged with a moisture correction of 14%. For the grain shape measurement, we estimated the parameters of grain width and grain length using the image analysis software “SmartGrain” developed by Tanabana et al. (2012); 70 to 100 grains were scanned at a resolution of 400 dpi. Based on the morphological data, we categorized each variety as one of three subspecies (tropical japonica, indica or temperate japonica) using the categorization method proposed by Matsuo (1952).

Statistical analysis

To identify the key agronomic traits of the farmers’ selection of varieties, we compared the frequency distribution between the primary genotype group ($n = 27$) and the total population ($n = 244$) for each trait. When the primary genotype group exhibited a different frequency distribution of, for example, trait “A” in comparison with that of the total population, the primary genotypes were interpreted as intentionally selected from the perspective of trait “A”, indicating that trait “A” is a key trait in the farmers’ selection of variety. Based on this concept, we used Pearson’s chi square test to compare the frequency distribution between the two groups using JMP 10.1 software (SAS, Inc., Tokyo).

Results and Discussion

As Table 1 shows, the availability of upland rice varieties was very different among the regions. The number of varieties was highest in Luang Prabang (15.7 varieties per village), where upland rice is still cultivated widely, followed by Vientiane (8.5 varieties per village) and Sekong (6.0 varieties per village). Generally, the number of glutinous varieties was much greater than the number of non-glutinous varieties of rice; although the non-glutinous varieties were popular in particular locations, in the highland Lao population, which consumes non-glutinous rice as a staple food (Namphone village, etc.), or villages located near the Vietnam border such as villages in the Dak Chun district, which sell non-glutinous rice to Vietnam, non-glutinous varieties were in the majority. Even in Vientiane Province, the villages with large populations in midland Lao, particularly the Khum tribe, also exhibited a larger number of varieties. These results indicate that genotype availability could be affected by both regional factors and ethnic factors.

Each variety was categorized as one of three subspecies using the categorization method of Matsuo (1952) (Fig. 1). The majority of varieties were categorized as tropical japonica, whereas indica ($n = 22$) and temperate japonica ($n = 1$) were in the minority. This result was consistent with the results of previous studies (Sato 1996, Roder et al. 1996), which reported that upland rice in Lao is mainly composed of the tropical japonica type, suggesting that the ecotype may be similar among the three regions.

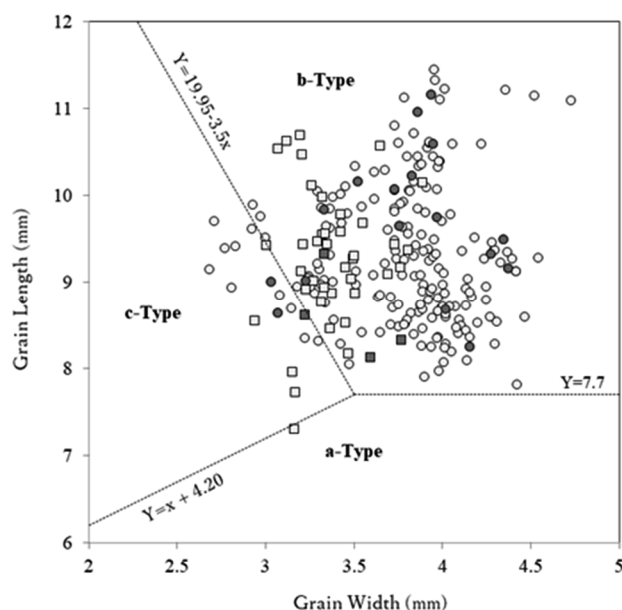


Fig. 1. Grain shape of glutinous and non-glutinous genotypes. Each accession was categorized as one of three types using the method developed by Matsuo (1952): a-type (temperate japonica), b-type (tropical japonica) and c-type (indica). The circle and square symbols represent the glutinous and non-glutinous genotypes, respectively. The closed symbols are the primary genotypes in each village (Asai et al. 2016).

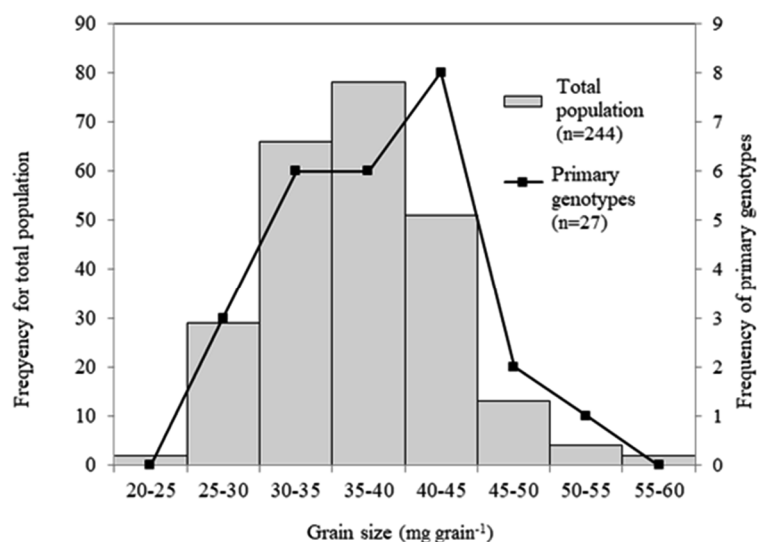


Fig. 2. Frequency distribution of grain size for the total population and primary genotypes. Pearson's chi-squared test indicated that the frequency distributions were not significantly different between the two groups (Asai et al. 2016).

The genotypic variation in grain weight was very large, ranging from 22 mg to 58 mg (Fig. 2). A statistical comparison of grain shape between glutinous and non-glutinous varieties showed that glutinous rice has a greater grain width (3.8 mm vs 3.4 mm) but no difference in grain length,

and thus glutinous rice has a higher grain weight. With regard to the ecotype, there were no significant differences in grain weight and grain shape (length and width) among three regions.

The frequency distributions for each parameter are presented in Table 2. With the exception of the parameters of endosperm and grain color, these categorical parameters should be carefully interpreted. Because the categorization was conducted within each village, the criteria may differ among the villages. This implies that the variation within a single category might be high. Rao et al. (2006) noted a similar issue in that the varieties categorized as early maturity exhibited variation in the number of days to harvesting (from 90 days to 120 days). To determine the reliability of the dataset, we focused on the relationship between plant height and lodging resistance. It is well known that plant height is a key parameter determining lodging resistance (Jones et al. 1997). Thus, we evaluated whether this relationship was observable within our dataset. The results clearly showed that the proportion of lodging-resistant varieties was higher in the short plant height group than in the high plant height group, as the hypothesis predicts (Fig. 3), indicating that our dataset might be not sufficiently robust to precisely identify the phenotypes of each individual variety, but it could be applied to identify the overall trends for each parameter.

Table 2. Frequency distribution of each characteristic for the total population and the primary genotypes based on Pearson's chi-squared test.

Interview topic	Answer	Total population (n=244)		Primary genotypes (n=27)		Probability ratio (Pearson's chi-squared test)
		Frequency (accessions)	Ratio (%)	Frequency (accessions)	Ratio (%)	
Endspem type	Non-glutinous	48	19.7	5	18.5	0.96 ns
	Glutinous	196	80.3	22	81.5	
Maturity	Very Early	5	2.0	0	0.0	<0.05
	Early	42	17.3	2	7.4	
	Moderate	72	29.6	3	11.1	
	Late	98	40.3	15	55.6	
	Very Late	26	10.7	7	25.9	
Plant height	Short	29	11.9	3	11.1	0.66 ns
	Moderate	92	37.7	8	29.6	
	Long	123	50.4	16	59.2	
Tiller number	Small	8	3.2	1	3.7	0.25 ns
	Moderate	148	60.7	12	44.4	
	Many	88	36.1	14	51.8	
Lodging	Non-resistant	51	20.9	7	25.9	0.77 ns
	Moderate	134	54.9	13	48.1	
	Resistant	59	24.2	7	25.9	
Environment adaptability	Poor environment	68	27.9	4	14.8	<0.01
	Moderate environment	107	43.9	6	22.2	
	Good environment	69	28.2	17	63.0	
Aroma	Non-aromatic	29	11.8	1	3.8	0.34 ns
	Moderate	177	72.2	23	85.2	
	Strong	39	15.9	3	11.5	
Grain color	White	192	78.3	24	88.9	0.38 ns
	Black or Red	53	21.6	3	11.1	

*ns, not significant.

The results from the Pearson's chi-square test indicated a significant difference in the frequency distribution between the primary genotype group and total population for environment adaptability ($p < 0.01$) and maturity ($P < 0.05$). For environment adaptability, the proportion of "poor environment", "moderate environment" and "good environment" was 28%, 44% and 28% for the total population, respectively, but 15%, 22% and 63% for the primary genotype group, respectively. For maturity, the proportion of "very early and early", "moderate" and "very late and late" was 19%, 30% and 51% for the total population, respectively, but 7%, 11% and 82% for the primary genotype group, respectively. These results indicated that the primary genotype group has the traits of late maturity and adaptability to good soil. This result is consistent with a case study in Vientiane (Asai et al. 2017) that reported that in Nameuang village, where shifting cultivation was widely practiced, 78% of the total seed sown was categorized as the late maturity type and 70% of the total seed sown was adapted to good soil. These findings suggest that late

maturity and adaptability to good soil play a key role in upland rice production in Lao.

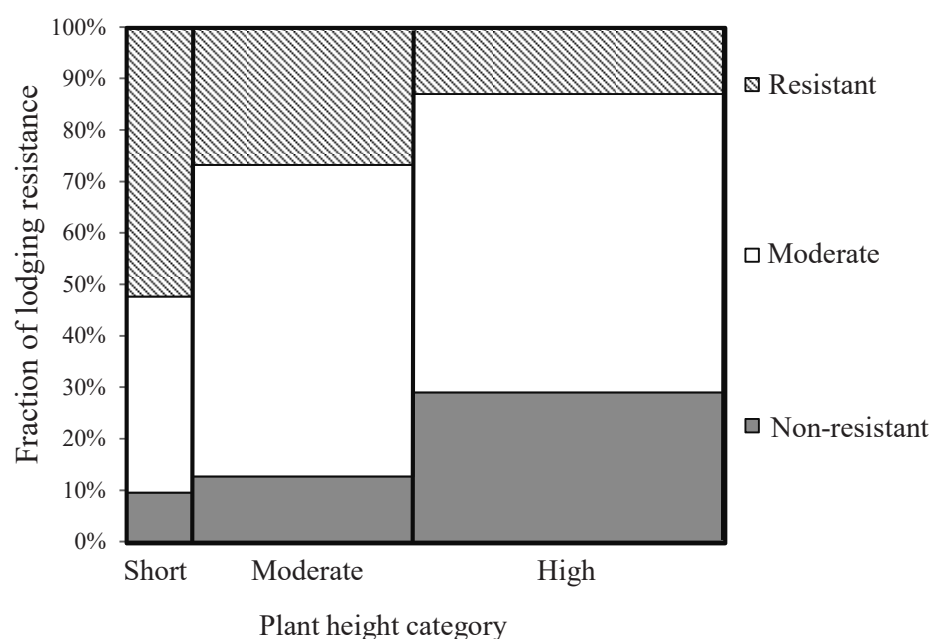


Fig. 3. Relationship between lodging resistance and plant height (Asai et al. 2016).

This trend in the farmers' selection of varieties should be interpreted in context of the socioeconomic situation, particularly the land allocation policy of the 1990s and the subsequent expansion of the market economy in the 2000s. When the land application policy was put into effect, farmers actively adopted varieties with adaptability to poor soil and early maturity to overcome the soil degradation and to shorten the period of rice insufficiency (Songyikhangthour et al. 2002; Saito et al. 2006b). However, our results demonstrate that the trend in farmer variety selection shifted from early maturity and adaptability to poor soil in the 1990s to late maturity and adaptability to good soil in the present. The background for this shift is that the demand for early maturity and adaptability to poor soil has decreased, in part because land use intensity has decreased due to the declining trend in shifting cultivation and in part because the approaches to rice security have been diversified, even in rural areas, due to the expansion of the cash crop market and labor employment opportunities (Nakatsuji 2013). Upland farmers in Lao generally recognize that some of the cash crops such as sesame and Job's tears are more adaptable to poor soil environments than upland rice (Nakatsuji 2004; Saito et al. 2006b); this was also verified in on-farm trials (Asai and Pheunphit 2017). Under the current conditions of the expanding market for cash crops, local farmers may have concluded that under poor soil conditions, cash crop production could be more economically beneficial than upland rice production. In other words, the current high demand for adaptability to good soil implies that upland rice production should be practiced not under poor soil conditions, but under good soil conditions.

It is widely accepted that the late maturity trait is disadvantageous for rice production under

rainfed conditions where the rainfall pattern is generally erratic, because upland rice is susceptible to damage from terminal drought (Kamoshita et al. 2008). However, our results indicate that upland farmers preferentially grow the late maturity types. This is in part because local farmers believe that the long vegetative period of late maturity types could be beneficial for upland rice production, particularly under good soil conditions. A previous case study also reported that the late maturity type was mainly grown on fertile soils, whereas the early maturity type was grown on infertile soils (Asai et al. 2017). This suggests that the wide acceptance of late maturity was closely related to the environmental shift in rice cultivation from poor soils to good soils. With regard to the risk of drought damage, the majority of upland farmers believe that drought after sowing is more critical to rice production, leading to poor germination and often resulting in resowing. In contrast, there are few farmers who regard the terminal drought as a yield constraint. Although the reason is unclear, Kiyono et al. (2008) pointed out that in the mountainous areas of Lao, morning fog rises every day in the dry season and could supply a considerable amount of water to soil even without a precipitation event. Thus, it is possible that the damage from terminal drought is minimized by the water supply from morning fog.

In Lao, the Upland Agriculture Research Center has the functional roles of seed production and distribution. Four upland rice varieties selected in the late 1990s have been distributed to smallholders as recommended varieties. However, all of these varieties were categorized as early or middle maturity and adaptable to poor soil. Therefore, the new variety selection for the late maturity type needs to be advanced, particularly in good soil environments. The maturity trait is relatively easy to evaluate, whereas the evaluation of the soil adaptability trait is time-consuming and labor-intensive, because a multilocation trial is inevitable. Our dataset demonstrated that the trend for environment adaptability has a relationship with tiller number and grain weight (Fig. 4). The group with adaptability to poor soil has the higher proportion of varieties producing many tillers and small grain weight, whereas the group with adaptability to good soil shows the opposite trends. These trends were consistent with previous studies, which reported that the indica varieties, which have a high tillering capacity and small grain size, had better yield performance under poor soil conditions (Linguist et al. 2006; Saito et al. 2007; Asai et al. 2009, 2017). These results indicate that information on tiller number and grain size can be simple parameters for soil adaptability classification. Our study concluded that under the current socioeconomic conditions, farmers prefer to grow varieties with late maturity and adaptability to good soil. However, these desirable agronomic traits were not always sufficient to account for farmers' variety selection. Saito et al. (2007) reported that despite superior yield performance, several improved varieties were not highly valued because these varieties are non-glutinous and have poor grain texture. Therefore, grain quality needs to be considered in new variety selection.

In the upland study in progress, we focused not only the productivity but also value addition, especially on grain texture and functional metabolite in rice. In this presentation, we explained the research activities to identify the productive rice, the healthy rice and delicious rice (Fig.5) For productive rice, the participatory variety trial is in progress to identify the recommended variety for seed distribution. For healthy rice, we are using the latest mass spectrometry

technology to identify the healthy rice with high anti-oxidant effects. For delicious rice, the grain quality were measured by RVA (rapid viscosity analyzer) to understand the texture variation in Lao rice genotypes. Genome sequence with next generation sequencer was performed for all of these genotypes used for texture analysis and metabolite analysis in order to conduct the coupling analysis between phenotype and genotype. These genotypes, named as “Lao Upland Rice Core Collection” will be distributed for academic use with genome sequence data in future.

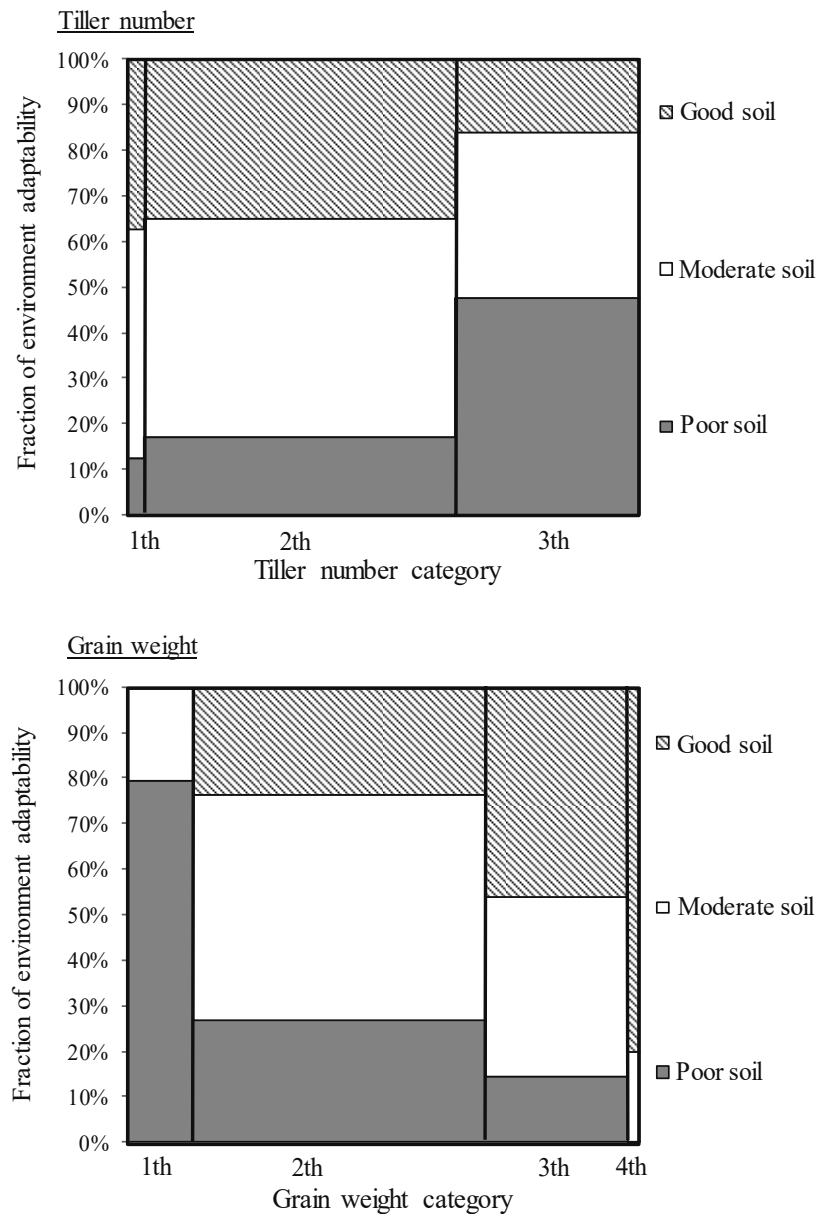


Fig. 4. Mosaic graphs of the relationship between soil adaptability and tiller number (above) and grain weight (below) (Asai et al. 2016).

For the tiller number categories, 1st indicates little tillering, 2nd indicates moderate tillering, and 3rd indicates high tillering. For the grain weight categories, 1st indicates 20 to 30 mg grain⁻¹, 2nd indicates 30 to 40 mg grain⁻¹, 3rd indicates 40 to 50 mg grain⁻¹, and 4th indicates 50 to 60 mg grain⁻¹.

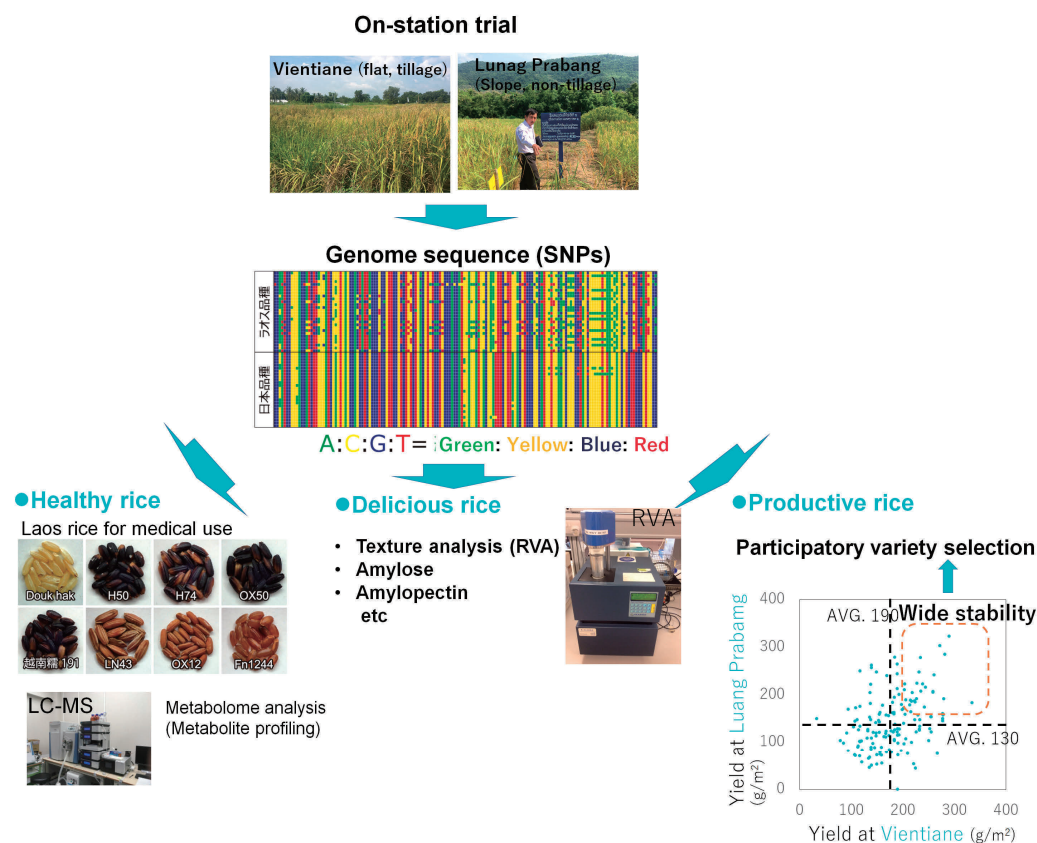


Fig. 5. Research activities for identification for productive, healthy and delicious rice.

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