Population Heterogeneity of Upland Rice in Northern Thailand

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Abstract

Landraces upland rice have low productivity, in northern Thailand; averaging only 0.9 t ha^{-1}. The cultivation gains a low input system, the fluctuation environment, the less crop protection, the genetic potential to utilize higher input and the heterogeneity in the rice populations may also factors causing these low yields. This study was to quantify the extent of genotype heterogeneity within the upland rice populations. Rice panicles were sampled in farmers' fields prior to harvesting. Heterogeneity was identified as variation in colors of husk, levels of grain amylose and variation in the ratio of decorticated grain length to width. Grain yield was calculated. Results showed that average estimated yield based on grain filling in farmers' field was 1.16 t ha^{-1}. Percent of unfilled spikelets was high (42.61% on average) and suspected to be a major factor in lowering the grain yield in the area. By contrast, panicle density was medium (PANO=90) and grain weight was high (Wg=31.6 g). Grain production was potentially as high as 1.72 t ha^{-1} if the filled spikelets percentage was 85%, as in the standard lowland rice. The mixture of *indica* and *japonica* types most likely explains the high proportion of unfilled spikelets because the *japonica* is thermosensitive, and will flower approximately a month later than *indica*. Purification of this heterogeneity may be needed to improve grain yield. The improvement should be base carefully upon the villagers' wisdom, culture and traditions. The results contrast with the studies that have reported on the advantage of genetic diversity in landrace varieties of upland rice, and suggest that a significant yield penalty maybe an outcome of such diversity in some circumstances.

Keywords: population heterogeneity, *Indica* and *Japonica* types, grain yield, genetic diversification

Introduction

Rice varieties cultivated in the uplands of Southeast Asia are derived either from natural selection for tolerance to particular constraints or from selection during a long period of domestication. Such varieties often exhibit considerable heterogeneity, with a mixture of phenotypes. Genetic diversity of varieties may be morphologically invisible, but it is generally considered to enhance the population grain yield, as it increases tolerance to a range of biotic and abiotic stresses not tolerated by modern rice varieties (Wofte, 2000; Zhu et al.,) The adoption of new improved varieties means the area planted to landraces are gradually disappearing. Collection landraces are needed for conservation and characterization them for future rice breeding program (Ogunbayo et al., 2007).

Upland rice cultivated in northern Thailand has been reported to have a rather low yield (0.6-0.9 t ha^{-1}), raising questions about the value of genetic diversity within the varieties grown. The ethnic group farming in this area originated in Tibet, and migrated through Yunnan in southern China, (a subtropical ecotype of agroecological zone 5) to their new habitat of Myanmar, Laos and northern Thailand (the agroecological tropical zone 2) (Maclean et al., 2002). During their long migration, changes in rice cultivation ecology may have affected the physiological mechanism, ultimately causing a reduction of grain yield. In this report, we examine the heterogeneity of the upland rice cultivars currently cultivated in the Chiang Rai province of northern Thailand by identifying the variation in colors of husk and types of starch in the grains of ecogeographical races. Estimation of grain yield was calculated from components of yield. Experiments were conducted on-site at the farms and at the central laboratory of the Faculty of Agriculture, Chiang Mai University during the 2009-10 growing season.

Materials and Methods

Five local varieties of upland rice (*Oryza sativa* L.) from five farmers' fields in Chiang Rai province (Lat. 20^{o}N, Long. 99.9^{o}E) were chosen for experimentation using randomized in complete block design (BIB) with 3 replicates. The varieties were Gako, Ja De, Chae Sa, Chae Na and Chae Ma. An improved lowland (irrigated rice) cultivar RD6 was used as a check; it was cultivated and sampled in the experimental field of Chiang Mai University (Lat. 16^{o}N, Long. 99.5^{o}E). The average chemical soil properties of the sample field at 0-30 cm of soil depth were: pH 4.71, organic matter 3.12 g 100 g^{-1}, nitrogen 0.20 g 100 g^{-1}, phosphorus 19.76 mg 100 g^{-1} and potassium 131.10 mg 100 g^{-1}. Ten of 1.0 m^2 areas of rice were sampled randomly throughout each of the five fields. Panicle numbers per m^2 (PANO), spikelets per panicle (SPP), weight of a 1000 grains sample (Wg) and fraction of filled spikelets (FSP) were examined as yield components. Grain yield (Y) was then calculated, using Yoshida's (1981) equation:

$$Y\,(\text{t ha}^{-1}) = PANO \times SPP \times FSP \times Wg \times 10^{-5}$$

Filled spikelets were estimated from the number of grains that fell in saline solution (SG = 1.06) divided by the total number of spikelets (Casanova et al., 2002). Diversity of the population was assessed for variation in:

a. Husk color (brown, purplish brown and purple)

b. Length to width ratio (L/W) of brown rice grain (Amano, 1997); *indica* type (L/W >2.0) and japonica type (L/W 1.4-2.0)

c. Shape of brown rice grain (Matsuo et al., 1997), classified as long grain (L/W >3.0mm.), medium grain (L/W 2.1-3.0) and short grain (L/W< 2.1mm.)

d. Amylose content in the endosperm, classified as glutinous (amylose 1-8.9%), intermediate (amylose 9-12.0%) and non-glutinous (amylose >12%). The AOAC method 14.069 (AOAC, 1995) was used in analyzing amylose content.

Results

Grain Yield Performance

As demonstrated by the yield component data (Table 1), the five upland rice varieties exhibited a moderate panicle density (PANO=90), high SPP and Wg (72 spikelets and 31.61 g, respectively), but low FSP (57.4%). Grains were large in most cultivars (Wg>30g). Only the Chae Sa cultivar had a rather small grain (Wg = 22.23). The cultivars, Ja De and Chae Na had low panicle density (PANO=80 and 48, respectively) but produced the high SPP (99 and 98, respectively). In contrast, cultivars Chae Sa and Chae Ma, with high PANO (112 each), had a low SPP (55 and 57, respectively), and high FSP (0.679 and 0.670, respectively). Their percentages of unfilled spikelets (%UFS) were more than 32% and 33 %, respectively, which was much less than the overall average of 42.6%, but still relatively high for rice.

The estimated grain yield in Table 2 was calculated from the equation, using the actual FSP value in Table 1. The potential yield was calculated using an upgraded value for FSP of 0.85, the FSP value of the commercial variety RD 6. The average estimated yield was low (1.16 ton.ha^{-1}), but this average could be improved with the improvement of FSP (0.85) up to 1.72 ton.ha^{-1}. The most improving cultivar was Ga Ko, with a 94.14% yield increase. Yield of Chae Sa was improved only 25%, while the others were approximately 50%.

Table 1 Component of yield and percent unfilled spikelets (UFS) of the five upland rice varieties sampled from the farmers' cultivated fields prior to harvesting.

Variety	panicle density	spikelet per panicle	1000 seed weight (g)	filled spikelet	unfilled spikelet
				(--------------- %	---------------)
Gako	96	49	31.5	0.44	56.2
Ja De	80	99	32.5	0.53	46.6
Chae Sa	112	55	22.2	0.68	32.1
Chae Na	48	98	32.4	0.55	45.1
Chae Ma	112	57	39.4	0.67	33.0
average	90	72	31.6	0.57	42.6
RD 6	160	181	23.31	0.85	15.0

Genetic Diversification to Classify Population Heterogeneity

Phenotypic Differing in Husk Color

Only two colored seeds (brown and purplish brown) were present in the populations (Table 3). Only variety Chae Na had uniform husk color. The other exhibited both brown and purplish-brown colors.

Length to Width Ratio of Unpolished Rice Grain

Most of the upland rice populations were a heterogeneous mixture of *indica* and *japonica* races (Figure 1). Only the Chae Ma variety was a homogeneous *indica*. Heterogeneity in grain shape was detected in all five varieties, classified as short grain and medium grain. Four varieties exhibited short and medium grain heterogeneity, while Chae Ma considered of medium and long grain. This could explain its high Wg in Table 1. The *japonica* race is a short grain type, but *indica* could be either medium or long grain type. The L/W ratio ranged from 1.00 in Ga ko (Figure 1) to as high as 3.2 in Chae Ma (Figure 2). The Chae Sa had the narrowest variants of the ratio (Figure 3).

Amylose Content in Endosperm

Grain amylose contents were as low as 9.65% to as high as 18.6%. Two cases of heterogeneity, glutinous/non-glutinous and intermediate/non-glutinous were identified. Chae Ma, an *indica* type, considered of both glutinous and non-glutinous starch. There was a relationship between races and

Table 2 Yield calculated from Yoshida's equation with actual FSP in comparison with yield calculated with the FSP of a standard of rice variety A.

Variety	Estimated Yield (actual FSP)	Potential Yield (upgraded FSP=0.85)
	(--------------- $t\ ha^{-1}$	----------------)
Gako	0.649	1.26
Ja De	1.375	2.18
Chae Sa	0.928	1.16
Chae Na	0.838	1.29
Chae Ma	1.687	2.13
average	1.164	1.72

Table 3 Phenotypic heterogeneity in color of husk of five rice varieties.

variety	Color of husk	
	Brown	Purplish-brown
Ga ko	√	√
Ja De	√	√
Chae Sa	√	√
Chae Na	X	√
Chae Ma	√	√

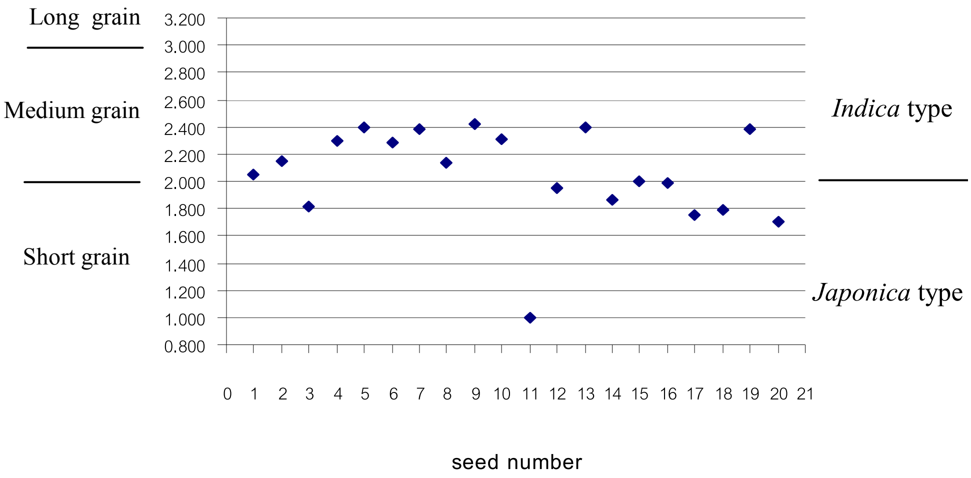

Figure 1 Length/width ratio of individual unpolished rice grain of variety Ga ko, in relation to characteristics of *indica* and *japonica* type grains and standard definitions for grain shape.

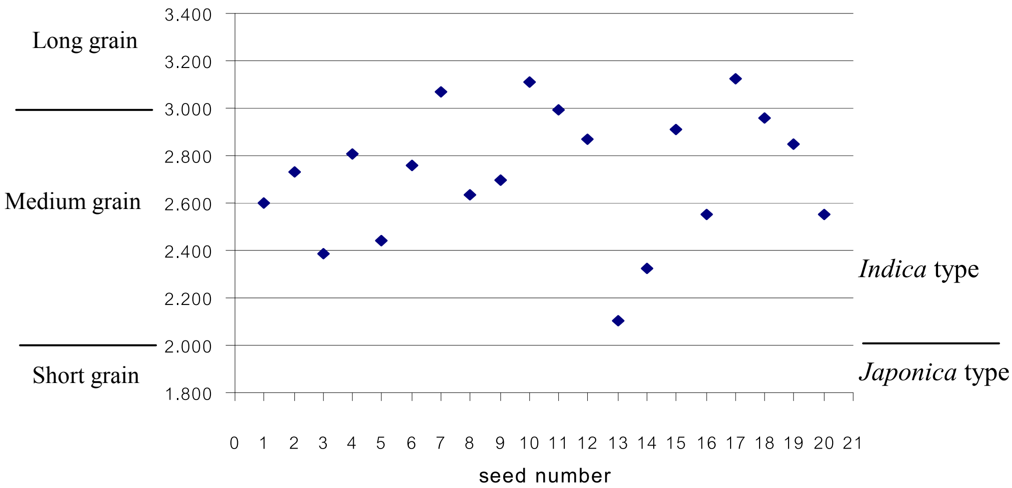

Figure 2 Length/width ratio of individual unpolished rice grain of variety Chae Ma, in relation to characteristics of *indica* and *japonica* type grains and standard definitions for grain shape.

starch types, but race was not associated with husk color. Brown husks could be either *indica* or *japonica* and either non-glutinous or intermediate starch. While the *japonica* exhibited only non-glutinous starch, *indica* could be either of the three starch types (Table 4).

Discussion

Upland rice yield generally yields 1-2 t ha^{-1}, but could yield up to 2.5 t ha^{-1} with increased nitrogen input (Maclean et al., 2002). In this study, average yield was moderate (1.16 $t.ha^{-1}$) and many varieties yielded less than 1.0 t ha^{-1}. Only Ja De and Chae Ma had an above average yielded, close to the potential based on an FSP of 0.85, which is typical of the standard lowland rice variety, RD6. The average Wg (31.6 g) was much higher than the modern rice variety RD6 (23.31 g), indicating a large seed type. Large seeds appear to compensate for the low SSP (72 vs181 of RD6). As the herlitability of grain yield was consistently lower than grain size (Sadras and Slafer, 2012), therefore, with this Wg value fixed, it is rather difficult to improve SSP. With a high panicle density (90), the five varieties were considered to be the highly adapted genotypes to the eco-geographical environment of the target area. Introducing genotypes

Table 4 Grain amylose content (%) and starch type of five upland rice varieties sampled from farmers' fields (after harvesting).

Variety	Husk color	Race	Amylose (%)	Starch type
Ga ko	purplish-brown	*indica*	11.9	Intermediate
	brown	*japonica*	16.7	Non-glutinous
Ja De	brown	*japonica*	12.9	Non-glutinous
	purplish-brown	*indica*	10.9	Intermediate
Chae Sa	purplish-brown	*indica*	9.65	Intermediate
	brown	*japonica*	12.9	Non-glutinous
Chae Na	Purpish-brown	*indica*	15.9	Non-glutinous
	purplish-brown	*japonica*	20.2	Non-glutinous
Chae Ma	purplish-brown	*indica*	8.79	Glutinous
	brown	*indica*	18.6	Non-glutinous

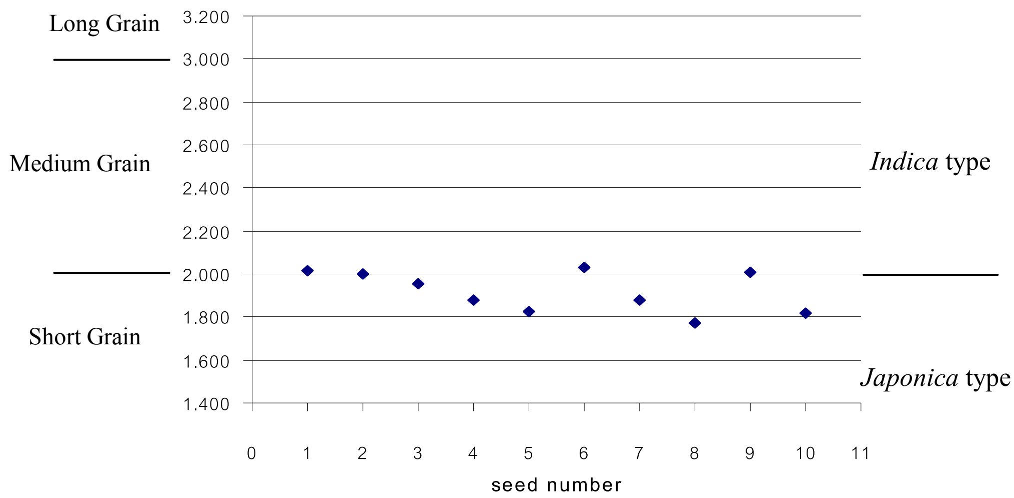

Figure 3 Length/width ratio of individual unpolished rice grain of variety Chae Sa, in relation to characteristics of indica and japonica type grains and standard definitions for grain shape.

from other ecotypes is not necessary. Improving soil fertility to enhance translocation of nutrients during the seed formation period is important. Furthermore, in order to stimulate the release of enough micronutrients into the soil to prevent physiological process disorder, a reduction of soil toxicity (due to high Al and Mn) is needed**.** FSP would be consequently enhanced.

The occurrence of purplish brown color on the husks means that there is heterogeneity in the gene pool for anthocyanin synthesis. Since the husk is not useful for human consumption, the genes controlling this characteristic were not subjected to the artificial selection in domestication.

Diversification of the *indica* and *japonica* races in terms of the L/W ratio, signified a many generations of domestication and evolution. The Akha tribe, which originated in Tibet, then migrated along the agroecological zone 5, where the *japonica*-like type is diverse. Therefore, they first domesticated rice that was those of a round (short) grain of the *japonica* race. Once they migrated further down to the Southeast Asia (agroecographical zone is zone 2), the *japonica* race type then began adapting to the cultivation environment. However, the *japonica* race might have adapted well to the new ecotype because of other morphological processes, except their flowering behavior, which is highly thermosensitive (Kuriyama, 1965). This characteristic remains favorable given the low temperature at the high altitudes in the mountainous area of northern

Thailand. However, its thermosensitive condition could not match the photosensitive condition of the *indica* type. In Chiang Rai province, the short day-length for photosensitivity starts in mid-September, but the low temperature for thermosensitivity starts at mid-November. This had caused flowering period of this *indica-japonica* mixed population to range widely. By the time of harvesting in early December, many tillers of *japonica* remained either in the flowering stage or early seed developing stage, since they are immature usually the final result is unfilled spikelets. This may be another reason for the high FSP.

Heterogeneity among types of brown rice grain is a result of the mixing of race types. The intermediate grain type signifies the evolution of both *indica* and *japonica* (Watanabe, 1997). The absence of the long grain type indicates that the five varieties are mainly under the stabilizing natural selection i.e. genes have not been manipulated artificially. Also, agronomic selection may have reinforced natural selection leading to a relative narrow seed size (Sadras, 2007). As genetic diversity is a basic prerequisite for successful exploitation of desirable traits through breeding (Koutroubas et al., 2004). This genetic heterogeneity could be a significant diversity for achieving the goal of improving the crop and high yielding potential varieties. Information on grain amylose content explains the hill tribe people's tradition of rice eating. The mixed grains of intermediate and non-glutinous starch types would be moderately sticky after being cooked, which perhaps, is more pleasant in its taste. Heterogeneity is therefore advantageous by providing a healthy source of nourishment, which could be another piece of ancient hill tribe wisdom.

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