Agro-morphological variation in "Jhinuwa" rice landraces (Oryza sativa L.) of Nepal

Article *in* Genetic Resources and Crop Evolution · December 2013

DOI: 10.1007/s10722-013-9992-1

Genet Resour Crop Evol
DOI 10.1007/s10722-013-9992-1

RESEARCH ARTICLE

Agro-morphological variation in "Jhinuwa" rice landraces (*Oryza sativa* L.) of Nepal

Mahendra P. Tripathi · Bhuwon R. Sthapit · Lakshmi P. Subedi · Srawan K. Sah · Sanjaya Gyawali

Received: 19 November 2012 / Accepted: 25 March 2013

Abstract *Jhinuwa* is an aromatic rice (*Oryza sativa* L.) landrace from the Pokhara Valley of Nepal. A total of 210 accessions comprising seven types of *Jhinuwa* rice landraces were randomly collected from the rice fields to evaluate inter- and intra-population variability based on agro-morphological traits. The experiment was conducted in factorial randomized complete block design with three replicates in 2005. The first six principal components (PCs) accounted for 76.6 % variation for agro-morphological traits. Major traits that accounted for the variation by six PCs includes days to heading, days to maturity, total grain panicle^{-1}, fertile grain panicle^{-1}, culm length, panicle length, milling recovery, head rice recovery, aroma, 1,000 grain weight, sterile grain panicle^{-1}, grain sterility %, and leaf characteristics. Both principal coordinate analysis and cluster analyses revealed four phenotypic groups, two of which represent *Bayarni*, *Jhinuwa*, and *Biramphul* while the other two account for *Tunde* and *Pakho Tunde*. *Tunde*, *Pakho Tunde*, *Kalo Bayarni*, and *Seto Bayarni* showed higher intra- as well as inter-population variation compared to other populations. The phenotypic and genotypic coefficients of variation, broad sense heritability (h^2B) and genetic advance (GA) as a percent of the mean assessed for 210 accessions revealed high h^2B and GA estimates for leaf width, leaf length breadth ratio, ligule length, sterile grain panicle^{-1}, grain sterility % and 1,000 grain weight. The current study demonstrates that improvement in *Jhinuwa* rice landrace is possible by selecting superior accessions from existing natural populations while selection should be focussed to market traits with higher h^2B and GA estimates.

Keywords Agro-morphology · Germplasm · Heritability · *Jhinuwa* landrace · *Oryza sativa* · Rice

Electronic supplementary material The online version of this article (doi:10.1007/s10722-013-9992-1) contains supplementary material, which is available to authorized users.

M. P. Tripathi · L. P. Subedi · S. K. Sah
Institute of Agriculture and Animal Sciences, Rampur, Chitwan, Nepal

Present Address:
M. P. Tripathi
National Maize Research Program, Nepal Agricultural Research Council, Rampur, Chitwan, Nepal

B. R. Sthapit
Bioversity International-Office for South Asia, NASC, DPS Marg, Pusa Campus, New Delhi, India

S. Gyawali (✉)
Local Initiatives for Biodiversity Research and Development (LI-BIRD), Narayangarh, Chitwan, Nepal
e-mail: gyawalisanjaya@gmail.com

Present Address:
S. Gyawali
International Center for Agricultural Research in the Dry Areas [ICARDA], Rabat, Morocco

Published online: 25 May 2013

Introduction

"Jhinuwa" is an aromatic rice (*Oryza sativa* L.) landrace of the Pokhara Valley of Nepal (Bajracharya et al. 2010; Tripathi 2008; Rijal et al. 1998). The literal meaning of *Jhinuwa* in the Nepalese language is fine-grained aromatic rice. In Nepal, farmers describe different types of *Jhinuwa* based on grain characteristics (*Kalo* = black; *Seto* = white; *Tunde* = awaned) or agronomic performance such as *Pakhe* (drought tolerant) etc. More than seven types of *Jhinuwa* rice landraces are maintained by the farmers of Pokhara Valley due to their quality traits (Rijal et al. 1998) as well as their comparative advantages and private values over modern cultivars (Gauchan et al. 2006; Rana et al. 2009). Farmers grow numbers of different types of *Jhinuwa* rice landraces within a short range of altitude differences in a small fragment of land near to sources of spring water or inlet regions of irrigation canals for their special quality (Bajracharya et al. 2010). *Bayarni Jhinuwa* types has been reported to have medicinal value whereas *Tunde Jhinuwa* types is grown in marginal environments and is considered tolerant of drought and low light intensity (shaded rice lands) (Bajracharya et al. 2010). *Biramphul Jhinuwa* type is a low-yielding rice landrace with superior post-harvest and eating quality traits. In Pokhara valley, consumers are ready to pay a higher market price (Poudel and Johnsen 2009) for high-quality rice landraces. There is greater demand for quality *Jhinuwa* rice in the market but often these landraces have a problem of quality variation. Because of higher post-harvest qualities, this landrace is often comparable to the *Jethobudho* landrace and even better in terms of cooking quality. Recently, Gyawali et al. (2010) have demonstrated that existing variability in *Jethobudho* landraces was successfully exploited to improve various agronomic and post-harvest quality traits where *Jethobuhdo* was improved by mass selection, and thus improved *Jethobudho* was released from the formal system for public cultivation in 2006 in Nepal. Comparable to *Jethobudho*, the *Jhinuwa* rice landrace has much greater intra- and inter-population variability for various agro-morphological traits (Sthapit, pers. comm.). The large variability of this landrace in terms of complex quantitative and qualitative traits still remains unexploited and not translated into benefits for humans. Agro-morphological characteristics are used traditionally to develop qualitative estimates of genetic similarities as well as relationships among landraces and crops (MacKey 1988). In recent years, agro-morphological traits have been used to improve performance of landraces, to confirm their suitability to specific cropping systems and to meet market demands. Therefore the objectives of the current study were to evaluate intra- and inter-population variability of *Jhinuwa* rice landraces based on agro-morphological traits; to evaluate the existing population structure pattern of *Jhinuwa* rice landraces and to identify the correlations between the characters in *Jhinuwa* rice landraces.

Materials and methods

Population sampling

Seven types of *Jhinuwa* landraces (recognized by farmers), namely *Kalo Bayarni*, *Seto Bayarni*, *Kalo Jhinuwa*, *Seto Jhinuwa*, *Tunde*, *Pakhe Tunde*, and *Biramphul,* were collected from Begnas village (28°11′35.10″N and 83°58′6.62″E) of Kaski during November 2004. Each type of *Jhinuwa* was collected from three farmers' fields and recognized as 21 *Jhinuwa* populations in total (Supplemental Table S1). For each *Jhinuwa* population, ten individual healthy panicles were sampled randomly from each standing rice field, totaling 210 accessions. While sampling panicles, neck blast-free panicles were sampled in order to avoid neck blast severity during the field experiment. Neck blast is caused by *Magnaporthe oryzae* (T.T. Hebert) M.E. Barr (Anamorph = *Pyricularia oryzae* Cavara) fungus and is a serious fungal disease in rice. One set of *Jhinuwa* was used in a field experiment at the Institute of Agriculture and Animal Science (IAAS) Rampur, Chitwan, while another set of *Jhinuwa* accessions was also grown in Begnas for selection of populations using farmer's knowledge and skills together with a team of plant breeders.

Field experiment

Evaluations of several agro-morphological traits were carried out at a research block of IAAS Rampur, Chitwan (27°39′14″N 84°21′5″E) between June and November 2005. The experiment was designed in a factorial randomized complete block design (RCBD) with three replicates. In the current experiment, the seven types of *Jhinuwa* (the types were defined by farmers) were considered as Factor A (Supplemental Table S1). Within each type, three *Jhinuwa* collected from three farmers were considered as Factor B. The whole experimental plot was divided into 21 treatments (21 *Jhinuwa* populations). For each *Jhinuwa* population, ten accessions, represented by ten panicles selected from each farmer's field, were planted in plots. Therefore, in total, 210 *Jhinuwa* accessions were planted in plots of 6 × 1.2 m^2 with three replicates. Data were collected from five hills per accessions in each replicate and averaged. Seed sowing and transplanting was done on 9 June and 24 July, 2005 respectively. Plant geometry was maintained at 20 cm × 20 cm row to row and hill to hill. Each hill consisted of a single rice seedling. The fertilizer applied was 100:30:30 NPK kg ha^{-1}. The total amount of phosphorous and potash as well as half of the amount of nitrogen was applied as basal dose. The remaining half of nitrogen was applied as top dressing after the second weeding, while two manual weedings were carried out during the crop season.

Data collection

Data were collected for several agro-morphological traits including flag leaf length (FLL), flag leaf breadth (FLB), leaf length (LL), leaf width (LW), ligule length (LigL), awn characters and color, apiculus color and seed coat color. Similarly, 12 agronomic traits, culm length (CL), panicle axis length (PAL), panicle length (PL), days to 50 % heading (DH), days to 85 % maturity (DM), number of panicle $hill^{-1}$ (NP), number of total grains $panicle^{-1}$ (TG), number of fertile grains $panicle^{-1}$ (FG), number of sterile grains $panicle^{-1}$ (SG), 1,000 grain weight (TGW), grain yield $hill^{-1}$ (GYH^{-1}), and grain yield $plot^{-1}$ were measured during data collection. Grain yield $plot^{-1}$ was converted to grain yield ha^{-1} (GY). The number of sterile grains $panicle^{-1}$ (SG) was also converted to sterile grain percentage (SG %). Post-harvest quality traits of the grain, such as milling recovery percentage (MR), head rice recovery percentage (HRR), broken rice percentage (BR) and aroma (Ar) of the grain were also recorded. Data collection on blast resistance of *Jhinuwa* landrace was not possible under controlled conditions due to lack of resources under the current study. However, selection of a higher level of neck blast tolerance in the *Jhinuwa* landrace was practiced jointly by farmers and plant breeders under natural inoculum pressure in field trials in Begnas village.

Data analysis

Multivariate analysis was performed on 24 qualitative and quantitative traits by using the procedure of principal component analysis (PCA) in Genstat 7.2 (Genstat 2003). Those principal components with Eigenvalue >1 were selected for further analysis. The cluster analysis was performed using the procedure average methods and the data matrix was the same as that used in PCA. The normalized distance of the square root from the mean was used for designating the cluster arbitrary (Horsley et al. 1995). In addition to the above, 19 agro-morphological traits were investigated to determine relatedness of traits using Pearson's correlation coefficients. The ANOVA, coefficient of variation (CV), broad sense heritability (h^2B) and genetic advance (GA) were also determined using quantitative data according to Falconer (1981). For multivariate analyses, all data from all 210 accessions were considered.

Results

Multivariate analysis

Principal component analysis using the 24 quantitative and qualitative traits, including agro-morphological, agronomic, yield components, and milling traits, indicated that more than 76.6 % variability was accounted for by six principal components (PCs) with Eigenvalues >1 (Table 1). The first PC explained 30.7 % of the total variance. Days to heading (DH), DM, CL, PL, LL, TG and FG, Ar, MR and HRR percentages were the variables with the largest positive loadings. Broken rice percentage, SG %, TGW, and NP had the largest negative loadings. As a result, the first PC differentiated between other accessions of *Jhinuwa* rice landraces that were mainly associated with contribution of DH, DM, low SG and low BR percentages. The second PC explained an additional 17.8 % of the total variance. Grain yield (GY), TGW, MR percentage, and CL were variable with high positive loadings. Flag leaf length (FLL), FLL/B, LL, LW, LL/B, and Lig L had quite high negative loadings. The second component basically identified agro-morphological variables presenting negative contributions. The third PC (9.7 % of total variance) was associated with highly negative loadings of TG, FG, SG percentage and SG along with positive loadings of PAL, MR and HRR percentages. The fourth PC explained 7.3 % of the total variance and related to highly positive loadings of CL, PAL, GY H^{-1} and TGW, SG, and SG percentages along with negative contributions of FLB and LW. The fifth PC explained 6.2 % of the total variance. Highly positive loadings were found in NP, GY, and highly negative loadings in SG and SG percentage. The sixth component explained 5.0 % of the total variance which was related to highly positive loadings to NP, MR and HRR percentage. PCoA analysis revealed two broad groups of the *Jhinuwa* landrace (Fig. 1). The first coordinate clearly separated *Tunde* and *Pakhe Tunde* from other *Jhinuwa* types. Most of these types—*Kalo Jhinuwa*, *Seto Jhinuwa*, *Kalo Bayarni, Seto Bayarni,* and *Biramphul*—are clustered into a group (here after referred as group 1 [G1]), while most *Tunde* and *Pakhe Tunde* were clustered into another group (hereafter referred as group 2 [G2]). However, a greater variability was also evident within both G1 and G2 groups (Fig. 1).

Cluster analysis

The *Jhinuwa* populations were grouped into five main clusters based on the evaluation of 23 variable traits recorded for 210 *Jhinuwa* accessions with 0.5 similarity coefficients (Supplemental Table S2). Cluster 1 was formed by 76 accessions of *Jhinuwa*, including 29 (96.7 %) accessions of *Kalo Jhinuwa,* 22 (73.3 %) accessions of *Kalo Bayarni*, 20 (66.7 %) accessions of *Biramphul* and 5 (16.7 %) accessions of *Seto Bayarni*. This cluster also represents the rice with short PAL, long LL, relatively higher LL/B and less numbers of SG. Cluster 2 was formed by a single accession (3.3 %) of *Seto Bayarni* collected from JR-SB-21. This accession had a lower mean value in all yield component traits such as NP, GY H^{-1} and TGW, but higher FLB. Cluster 3 was formed by 73 accessions, mostly by *Seto Jhinuwa* 30 (100 %), *Seto Bayarni* 24 (80 %), *Biramphul* 10 (33.3 %), *Kalo Bayarni* 8 (26.7 %) and one accession of *Kalo Jhinuwa* (3.33 %). This cluster includes the *Jhinuwa* accessions having traits with longer in CL; more SG but higher GY H^{-1}. Cluster 4 and 5 was formed mainly by different accessions of *Tunde* and *Pakhe Tunde*. Cluster 4 was formed by 40 accessions including 20 (66.7 %) of *Tunde* and 20 (66.7 %) of *Pakhe Tunde*. Cluster 5 was formed by 10 (33.3 %) accessions of *Tunde* and 10 (33.3 %) accessions of *Pakhe Tunde*. The most relevant characteristics in this Cluster 4 were lower FLL/B; lower LL/B, early DM and short CL while the characteristics of Cluster 5 include short CL, early DM, higher NP, lower numbers FG and lower MR percentage. The cluster means for each trait are presented in Supplemental Table S3.

Variance components and heritability

To compare the variation among traits, estimates of variance components (σ_p^2, σ_g^2), phenotypic (PCV) and genotypic (GCV) coefficients of variation, h^2B, GA, and GA as percent of the mean are given in Table 2. The PCV ranged from 14.56 to 94.56 %. The traits such as DM, PL, DH, CL, LW, and LL had the lowest PCV and SG %, SG, FG, TG, and LigL had the highest PCV. The GCV showed similar trends as PCV and ranged between 9.78 for DM to 66.24 for SG %. The h^2B estimates range from 5.20 for GY H^{-1} to 85.56 for LL. Heritability estimates in cultivated plants can be placed in the following categories according to Dabholkar (1992): low h^2B ranging from 5 to 10 %; medium h^2B ranging from 10 to 30 %; and high h^2B ranging from 30 to 60 %. From this point of view, GY H^{-1} had low h^2B; CL, NP, TG, and FG had medium h^2B; and PL, LL, LW, LL/B, LigL, DH, DM, SG, SG %, and TGW had high h^2B.

Correlation between characters

Simple correlation coefficients calculated among examined characteristics are shown in Table 3. There was strong and positive association among traits such as CL, PAL, PL, DH, TG, FG and GY H^{-1}. Positive and statistically significant ($P \leq 0.05$) relationships were found between: the FLL and FLB, LL, LL/B, LigL and NP; between FLB and FLL/B, LW; between LL with LL/B, LigL, DH, TG, FG, GY H^{-1}, and GY. Negative ($P \leq 0.05$) association were found between the CL and FLL, FLL/B, NP, SG; between PAL with FLL, NP, SG; between PL with NP, SG, TGW; between FLL with LW, GY; between FLB with FLL/B, between LL with NP, GS; between LW with LL/B, LigL; between DH with NP, GS; NP with TG, FG, between TG with SG, between FG with SG, between SG with GY H^{-1}.

Table 1 Principal component analysis of 24 traits among *Jhinuwa* rice landraces, Eigen values, percentage variability explained by first six components

Characteristics	PC1	PC2	PC3	PC4	PC5	PC6
Culm length (cm)	**0.23**[a]	0.16	0.01	**0.39**	0.07	−0.17
Panicle axis length (cm)	−0.12	0.05	**0.28**	**0.36**	**−0.26**	−0.17
Panicle length (cm)	**0.25**	0.01	−0.16	0.15	0.18	0.15
Flag leaf length (cm)	0.05	**−0.42**	−0.18	−0.02	0.06	−0.12
Flag leaf breath (cm)	0.02	0.18	−0.24	**−0.24**	−0.04	0.05
Flag leaf length breath ratio	0.03	**−0.45**	−0.03	0.03	0.00	−0.13
Leaf length (cm)	**0.26**	−0.22	−0.10	0.13	0.01	−0.12
Leaf width (cm)	0.00	**0.31**	−0.18	−0.20	**0.25**	−0.20
Leaf length breath ratio	0.17	**−0.35**	0.04	0.20	−0.14	0.05
Ligule length (cm)	0.09	**−0.37**	0.07	−0.13	0.13	−0.02
Days to 50 % heading	**0.32**	0.09	0.06	0.10	−0.11	−0.20
Days to 85 % maturity	**0.32**	0.09	0.06	0.10	−0.11	−0.19
No. of productive tillers $hill^{-1}$	−0.19	−0.14	0.02	0.19	**0.35**	**0.48**
No. of total grains $panicle^{-1}$	**0.26**	0.03	**−0.39**	−0.01	0.05	−0.03
No. of fertile grains $panicle^{-1}$	**0.28**	0.04	**−0.30**	−0.10	0.14	−0.12
No. of sterile grains $panicle^{-1}$	−0.05	0.01	**−0.52**	**0.28**	**−0.30**	0.20
Grain sterility (%)	**−0.23**	−0.02	**−0.31**	**0.26**	**−0.32**	0.22
Grain yield $hill^{-1}$ (g)	0.10	0.05	0.05	**0.37**	**0.60**	0.13
1,000 grains weight (g)	−0.19	0.16	0.09	**0.40**	0.06	−0.29
Grain yield (t ha^{-1})	0.15	**0.22**	−0.10	0.11	−0.07	0.13
Milling recovery (%)	**0.24**	0.16	0.19	−0.05	−0.09	**0.39**
Head rice recovery (%)	**0.29**	0.09	0.20	−0.04	−0.10	**0.36**
Broken rice (%)	**−0.24**	0.11	−0.12	−0.01	0.08	−0.11
Aroma	**0.23**	−0.02	0.19	−0.06	**−0.22**	0.12
Eigen value	7.36	4.28	2.32	1.74	1.49	1.20
% Variability	30.7	17.8	9.7	7.3	6.2	5.0
Cumulative variability	30.7	48.5	58.2	65.4	71.6	76.6

[a] Bold faced letter are relevant characteristics that explained respective components

Discussion

Jhinuwa landrace diversity

For centuries, farming communities have continuously contributed to the evolution, enrichment, and maintenance of landrace diversity on-farm (Brush 1995; Jarvis et al. 2008; FAO 2010). However, little has been done to understand the intra- and inter-landrace diversity as well as to improve these landraces. Sthapit and Rao (2009) suggested that landraces can be effectively improved by simple trait selection if these landraces offer sufficient natural variation in the population. Recently, Gyawali et al. (2010) demonstrated that intra-landrace variation can be exploited to improve rice landraces in Nepal. The current study revealed that *Jhinuwa* populations have tremendous variability within and between *Jhinuwa* types collected from the Pokhara Valley in Nepal. The study further suggests that landraces can be improved by trait selection and improved *Jhinuwa* can be brought back into the competitive rice market.

In India, Mathure et al. (2011) reported higher diversity in aromatic rice landraces from Maharashtra state by assessing agronomic and quality traits. Based on multivariate analyses of agro-morphological traits in the current study, it is revealed that there might be two major groups, G1 and G2, of *Jhinuwa* in Nepal. This grouping was evident from both PCoA and cluster analyses using 24 quantitative traits. The first

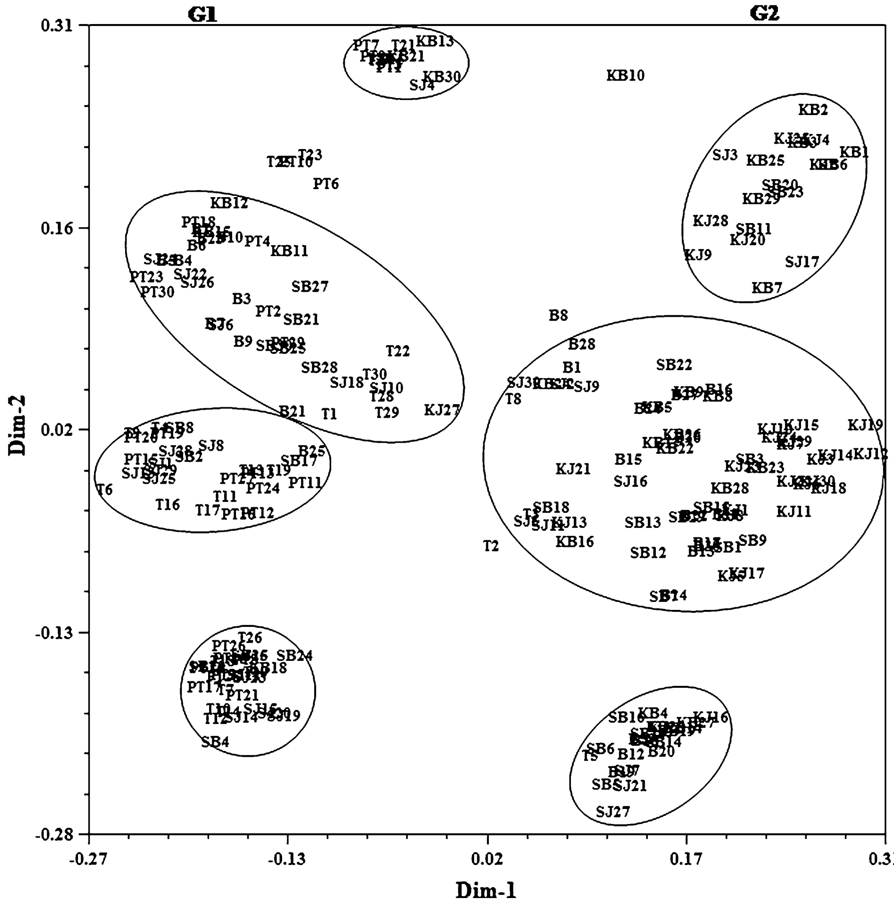

Fig. 1 Principal co-ordinate analysis of 210 *Jhinuwa* accessions using 24 quantitative traits. Group 1 (G1) represents *Tunde* (T1-30) and *Pakhe Tunde* (PT1-30) while group 2 (G2) represents *Kalo Bayarni* (KB1-30), *Seto Bayarni* (SB1-30), *Kalo Jhinuwa* (KJ1-30), *Seto Jhinuwa* (SJ1-30), and *Biramphul* (B1-30)

principal coordinate separates *Tunde* and *Pakhe Tunde* (which literally means rice with awn) (G1) from the rest of the *Jhinuwa* although it was evident that there was higher variability within each *Jhinuwa* types as well. In Pokhara Valley, *Tunde* and *Pakhe Tunde* are adapted to the rice fields with limited moisture and are drought-tolerant *Jhinuwa* types, while other *Jhinuwa,* such as *Kalo Bayarni, Seto Bayarni*, *Kalo Jhinuwa*, *Seto Jhinuwa*, and *Biramphul* are adapted to irrigated rice fields or rice fields with higher moisture availability during the rice-growing season compared to *Tunde* types (Sthapit et al. 2001). Environmental heterogeneity acts as a diversifying force by providing many selection pressures. Recent evidence from other plant species such as *Triticum dicoccoides* and *Hordeum spontaneum* also suggest that ecological differences such as sunlight and moisture availability affect the genetic structure of plant populations (Li et al. 2002; Turpeinen et al. 2001). *Tunde* and *Pakhe Tunde* might have evolved from a common gene pool and may be regarded as G1 with a higher level of drought tolerance, while *Kalo Jhinuwa, Seto Jhinuwa, Kalo Bayarni, Seto Bayarni* and *Biramphul* might have evolved from another common gene pool, G2, which corresponds to their adaptation to higher levels of moisture requirement during growth. It is evident from PCoA that there is tremendous variation within G1 and G2 gene pools, with some level of separation in *Kalo* (which literally means black lemma and palea) and Seto (literally white/yellow lemma and palea) *Jhinuwa*. Often, discrepancies are found in naming landraces at farm level. In addition, the current study shows no uniformity in naming the *Jhinuwa* types among Nepalese farmers. Therefore some overlapping

Table 2 Estimates of variance components (σ^2_p, σ^2_g), phenotypic (PCV) and genotypic (GCV) coefficients of variation, broad sense heritability (h^2B) and genetic advance (GA) and GA as percent of the mean in *Jhinuwa* rice landraces

Traits	Mean	σ^2_p	σ^2_g	PCV (%)	GCV (%)	H^2B (%)	GA	GA (% of mean)
Culm length (cm)	133.4	1,195.33	275.63	25.92	12.45	23.06	16.42	12.31
Panicle length (cm)	28.78	24.07	8.47	17.05	10.11	35.18	3.56	12.35
Leaf length (cm)	48.36	223.41	191.16	30.91	28.59	85.56	26.35	54.48
Leaf width (cm)	0.89	0.07	0.02	29.23	16.54	32.02	0.17	19.28
Leaf length breath ratio	56.09	574.86	450.67	42.75	37.85	78.40	38.72	69.03
Ligule length (cm)	1.74	0.91	0.71	54.67	48.43	78.45	1.54	88.36
Days to 50 % heading	124.2	504.47	227.67	18.08	12.15	45.13	20.88	16.81
Days to 85 % maturity	154.2	504.30	227.60	14.56	9.78	45.13	20.88	13.54
No. of productive tillers hill^{-1}	4.82	5.77	1.57	49.82	25.97	27.17	1.34	27.88
No. of total grains panicle^{-1}	143.7	9,503.17	1,513.27	67.84	27.07	15.92	31.98	22.25
No. of fertile grains panicle^{-1}	118.7	8,424.10	1,189.40	77.32	29.05	14.12	26.70	22.49
No. of sterile grains panicle^{-1}	24.28	396.30	224.10	81.99	61.66	56.55	23.19	95.51
Grains sterility (%)	17.32	268.21	131.63	94.56	66.24	49.08	16.56	95.60
Grain yield hill^{-1} (g)	10.35	25.00	1.30	48.31	11.02	5.20	0.54	5.17
1,000 grains weight (g)	17.26	44.40	31.10	38.61	32.31	70.05	9.61	55.71

of genotypes from different clusters was observed. Sharma et al. (2007) found inconsistencies in naming rice varieties by farmers while evaluating rice landraces from lowland (*terai*) and hills in Nepal. Fukuoka et al. (2006) also found similar discrepancies in naming rice landraces by farmers in Vietnam. Therefore the traditional system of naming rice landraces is not sufficient and needs further attention on the part of breeders and germplasm curators when characterizing landraces.

In the middle hills of Nepal, rice landrace diversity was reported the highest compared to *terai* (regions with flat farming lands) and high hills (Bajracharya et al. 2010). In Pokhara Valley, farmers grow a mosaic of rice landraces in their fields (Rijal et al. 1998). This facilitates the pollen from the adjoining fields moving towards the neighboring populations. Amagain et al. (2005) reported that Nepalese landraces had higher outcrossing and resultant frequent gene flow among landraces as well as their wild relatives. Jarvis and Hodgkin (1999) showed that bringing genes from one population to another by recombination increases the variation within local populations. Furthermore, Pokhara Valley is known as an excellent habitat of perennial wild rice, *Oryza rufipogon* (Griff.). For centuries farmers have grown rice landraces nearby the habitat of wild rice (Joshi et al. 2008). Often hybrid swarms occur in their rice fields when landraces or improved cultivars are grown near wild rice (Khush 1997) and farmers often select new ideotypes from these hybrid swarms in Pokhara Valley (Rijal, pers. Comm.). The movement of genes from one population to another was the major force for this variation within and between populations in rice landraces in Nepal, followed by selection over several generations. In addition, seed dispersal is a major factor shaping population structure. Rieseberg (1997) explained that seed dispersal, the proportion of seeds that are planted by the farmers who produced them, the proportion that migrate through farmer exchange and the local system of seed exchange also affect the population structure. In Nepal farmer-to-farmer seed exchange is very common. In the community, certain farmers are recognized as nodal farmers who play key roles in seed exchange. In addition to environmental heterogeneity, socio-economic and cultural preferences also help to maintain an array of landraces (Cleveland et al. 1994). This is especially true in the middle hills of Nepal (Bajracharya et al. 2010; Rana et al. 2007). Farmers have selected and maintained numbers of landraces over several generations in response to varying ecological, economic, social and cultural conditions to satisfy a complex set of local needs (Prain and Hagmann 2000; Fukuoka et al. 2006; Bajracharya et al. 2010; Rana et al. 2007; Jarvis et al. 2008). Phenotypic variability within and between

Table 3 Correlation coefficients between traits among seven types of *Jhinuwa* rice landraces

Traits	CL	PAL	PL	FLL	FLB	FLL/B	LL	LW	LL/B	LigL	DH	NP	TG	FG	SG	S(%)	GY/H	TGW
PAL	0.39**																	
PL	0.48**	0.17**																
FLL	−0.10**	−0.08*	0.09															
FLB	0.01	−0.05	0.01	−0.03														
FLL/B	−0.10**	−0.01	0.03	0.83**	−0.24**													
LL	0.24**	−0.01	0.35**	0.59**	0.02	0.42**												
LW	0.12**	−0.04	−0.02	−0.17**	0.24**	−0.38**	−0.01											
LL/B	0.09*	0.04	0.25**	0.54**	−0.16**	0.57**	0.67**	−0.69**										
LigL	−0.07	0.01	0.16**	0.62**	0.004	0.54**	0.44**	−0.17**	0.41**									
DH	0.69**	0.28*	0.44**	−0.03	0.02	−0.05	0.37**	0.07	0.19**	0.05								
NP	−0.29**	−0.20**	−0.18**	0.10*	−0.06	0.11**	−0.12**	−0.08	−0.03	0.06	−0.56**							
TG	0.37**	0.00	0.42**	0.06	−0.01	0.07	0.20**	−0.–02	0.14**	−0.02	0.38**	−0.25**						
FG	0.40**	−0.01	0.41**	0.04	−0.01	0.06	0.21**	0.00	0.12**	0.02	0.42**	−0.27**	0.96**					
SG	−0.03	−0.04	0.07	0.06	−0.01	0.02	−0.02	−0.03	0.00	−0.16**	−0.11**	0.07	0.41**	0.23**				
S (%)	−0.36**	−0.10**	−0.26**	0.03	−0.02	0.00	−0.20**	−0.04	−0.11**	−0.17**	−0.50**	0.30**	−0.23**	−0.40**	0.74**			
GYH^{-1}	0.43**	0.06	0.28**	0.004	−0.04	−0.01	0.11**	0.04	0.03	−0.01	0.20**	0.38**	0.28**	0.32**	−0.09**	−0.32**		
TGW	0.19**	0.24**	−0.18**	−0.21**	0.002	−0.20**	−0.27**	0.14**	−0.27**	−0.32**	−0.04	−0.04	−0.26**	−0.28**	−0.01	0.17**	0.18**	
GY	0.24**	−0.03	0.15**	−0.15**	0.11	−0.21**	0.17**	0.20**	−0.01	−0.17**	0.20**	−0.07	0.11**	0.11**	0.03	−0.06	0.04	0.001

CL culm length (cm), *PAL* panicle axis length (cm), *PL* panicle length (cm), *FLL* flag leaf length (cm), *FLB* flag leaf breath (cm), *FLL/B* flag leaf L/B ratio, *LL* leaf length (cm), *LW* leaf width (cm), *LL/B* leaf L/B ratio, *LigL* ligule length (cm), *DH* days to 50 % heading, *NP* no. of paniclehill^{-1}, *TG* no. of total grainspanicle^{-1}, *FG* no. of fertile grainspanicle^{-1}, *SG* no. of sterile grainspanicle^{-1}, *S* (%) sterility percentage, *GYH*$^{-1}$ grain yieldhill^{-1} (g), *TGW* thousands grain weight (g), *GY* grain yield (tha^{-1})

*, ** Significant at $P \leq 0.05$ and $P \leq 0.01$ level of significance, respectively

populations in *Jhinuwa* rice landraces is an example of the combined effect of genetic reshuffling, gene flow (including seed exchange), natural and human selection, environmental heterogeneity and socio-economic and cultural preferences to meet local needs.

Variation in traits

Assessment of local landraces for economically important agronomic traits has been important for many breeding programs and existing variation can be used to improve landraces (Gyawali et al. 2010; Sharma et al. 2007; Patra and Dhua 2003; Sanni et al. 2012; Sarhadi et al. 2009). Gyawali et al. (2010) assessed variation of economically important traits in a *Jethobudho* collection in order to improve agronomic and post-harvest quality traits in this landrace from Nepal. They combined agronomic and post-harvest quality traits in selected *Jethobudho*. They successfully improved organoleptic (eating qualities) as well as milling traits, grain yield, lodging and disease tolerances by utilizing inherent variation in *Jethobudho*. In the current study, assessment of *Jhinuwa* diversity was focused on various agronomic traits with higher, broad sense heritability (h^2B) and genetic advance (GA) combined with improved market traits such as higher milling recovery and post-harvest quality traits. The characteristics that showed a high degree of h^2B suggest that they are less influenced by environmental factors and thereby greater correspondence may be expected between phenotypic and breeding values. Likewise, moderate to high expected GA for CL, LL, LL/B, DH, DM, TG, FG, SG and SG % signify that considerable improvement could be achieved in these traits by selection of superior accessions from the populations. For example, DH has significant positive correlation ($P < 0.01$) with many yield components including PL, TG, FG, GY H^{-1}, and GY while it has significant positive correlations ($P < 0.01$) with SG and S %. Interestingly, these traits have higher h^2B and GA except for GY. The high h^2B and high expected genetic gain, coupled with moderate GCV exhibited by these traits, imply that these are under additive genetic effect and could be relied upon for further selection based on phenotypic performance. However, high h^2B does not always necessarily mean high genetic gain. The utility of h^2B estimates is, therefore, increased when they are used to estimate genetic advance (GA) (Johnson et al. 1955), which in turn indicates the degree of gain in a trait obtained under a particular selection pressure (Falconer 1981). The leaf characteristics had higher h^2B than grain characteristics, which is in agreement with the findings of Rao et al. (1997). High h^2B, coupled with high genetic advance in LL, LL/B and SG %, indicates that the environmental effect was low on the trait, which was mostly governed by additive gene actions. Though neck blast, caused by *Magnaporthe grisea*, is an important disease in rice in Nepal, *Jhinuwa* selection for a higher level of tolerance to neck blast was not performed in on-station experiments. However, several of the other agronomic traits offer a greater scope for further improvement of *Jhinuwa* through simple selection. The current study suggests that CL, PL, DH, NP, FG are the most important yield-determining characteristics for any *Jhinuwa* improvement program.

Jhinuwa improvement

A set of field-tested materials was also given to a participatory plant breeding (PPB) group of Begnas for testing and selection of useful traits under a target environment. Nine selected accessions of *Kalo Bayarni* and *Kalo Jhinuwa* with minimal neck blast infestations were further selected for improved agronomic and quality traits and then bulked populations were maintained in diversity blocks. The purpose of the exercise was to register these accessions as farmer varieties and provide access to improved seed by interested farmers, the national gene bank and plant breeders for further improvement. The materials can be used as parents for future improvement of unique traits of aromatic rice with better field tolerance of neck blast. As demonstrated in *Jethobudho* improvement, *Jhinuwa* offers tremendous opportunity for improving yield and yield components, for disease resistance and for post-harvest quality traits. Currently, many of the *Jhinuwa* landraces are grown in small areas by few farmers; therefore access to *Jhinuwa* seed is limited for farmer-to-farmer dissemination. In addition, knowledge associated with specific *Jhinuwa* types is limited to few farmers, while this knowledge is not accessible to the farming community and local plant breeders. Therefore, the current study has implications for rice landrace improvement. First, both intra- as well as inter-rice landrace diversity is tremendous in Nepal. This study offers opportunities to improve diverse *Jhinuwa* types in Nepal. Second, the rice breeding programs in centres of diversity of rice, especially Nepal and India, are not able to produce the practical case studies that benefit from the use of landrace diversity. One of the reasons is the lack of plant breeders willing to work on harnessing benefits offered by this diversity, as well as lack of investment towards improving local landraces. The current study showed that the variability of *Jhinuwa* populations has potential for breeders to harness agronomic and quality aspects of the population by selecting and bulking unique traits. Third, the re-introductions of improved *Jhinuwa* into local seed systems through massive distribution of diversity kits and participatory variety selection are needed. These actions will ensure enhanced farmer-to-farmer seed exchange as well as increased frequency of *Jhinuwa* growers in farming community. These efforts will address the conservation and developmental aspects of important genetic resources on-farm.

Conclusions

The population structure of *Jhinuwa* suggests two broad groups within these landraces. With respect to agro-morphological traits, *Pakhe Tunde* and *Tunde* were the most variable *Jhinuwa* compared to *Kalo Bayarni*, *Seto Bayarni*, *Kalo Jhinuwa*, *Seto Jhinuwa* and *Biramphul*. However, inter- and intra-population variability was observed in *Jhinuwa* rice landraces collected from the Pokhara Valley, which offers greater opportunities for rice breeders to improve this landrace by focusing selection on traits with higher h^2B and GA estimates. Improved *Jhinuwa* landraces should be re-introduced into the farming community together with knowledge associated with its unique agronomic and quality traits.

Acknowledgments This study was partially funded by the LI-BIRD and IDRC/SDC-funded *in situ* conservation project of LI-BIRD/NARC/IPGRI. The authors are grateful to farmers of Begnas village for kindly supplying *Jhinuwa* accessions for this study. Technicians from the Department of Plant Breeding and Genetics, IAAS are thanked for their kind cooperation in field experiments. The authors express sincere thanks to Dr. Devra Jarvis (Senior Scientist, Bioversity International) and Judith Thompson (Science Editor, Bioversity International) for English and technical edits of manuscript.

References

Amagain RB, Shrestha P, Joshi BK, Adhikari NP, Gyawali S, Upadhyay MP, Sthapit BR, Baniya BK (2005) On-farm evaluation of traits influencing outcrossing among rice (*Oryza sativa* L.) landraces of Central Terai, Kachorwa, Bara, Nepal In: Sthapit BR, Upadhyay MP, Shrestha PK, Jarvis DI (eds) On-farm conservation of agricultural biodiversity in Nepal. Volume I. Assessing the amount and distribution of genetic diversity on-farm. Proceedings of the Second National Workshop, Nagarkot, Nepal, 25–27 August 2004 2005. International Plant Genetic Resources Institute Rome, Italy, pp 54–63

Bajracharya J, Rana RB, Gauchan D, Sthapit BR, Jarvis DI, Witcombe JR (2010) Rice landrace diversity in Nepal. Socio-economic and ecological factors determining rice landrace diversity in three agro-ecozones of Nepal based on farm surveys. Genet Resour Crop Evol 57(7):1013–1022. doi:10.1007/s10722-010-9544-x

Brush SB (1995) *In situ* conservation of landraces in centers of crop diversity. Crop Sci 35(2):346–354. doi:10.2135/cropsci1995.0011183X003500020009x

Cleveland DA, Soleri D, Smith SE (1994) Do folk crop varieties have a role in sustainable agriculture? Incorporating folk varieties into the development of locally based agriculture may be the best approach. Bioscience 44(11):740–751

Dabholkar AR (1992) Elements of biometrical genetics. Concept publishing company, New Delhi, pp 117–187

Falconer DS (1981) Introduction to quantitative genetics Longman Scientific and Technical, London

FAO (2010) Second report on the world's plant genetic resources for food and agriculture. Food and Agriculture Organization, Rome, Italy ftp://fao.org/docrep/fao/meeting/017/ak528e.pdf

Fukuoka S, Suu T, Ebana K, Trinh L, Nagamine T, Okuno K (2006) Diversity in phenotypic profiles in landrace populations of Vietnamese rice: a case study of agronomic characters for conserving crop genetic diversity on farm. Genet Resour Crop Evol 53(4):753–761. doi:10.1007/s10722-004-4635-1

Gauchan D, Smale M, Maxted N, Cole M (2006) Managing rice biodiversity on-farms: the choices of farmers and breeders in Nepal. In: Smale M (ed) Valuing crop biodiversity: on-farm genetic resources and economic change. CABI Publishing, Wallingford, pp 162–176

Genstat (2003) Genstat 7.2. Genstat, Inc., Lawes Agricultural trust, IACR, Rothamsted

Gyawali S, Sthapit BR, Bhandari B, Bajracharya J, Shrestha PK, Upadhyay MP, Jarvis DI (2010) Participatory crop improvement and formal release of *Jethobudho* rice landrace in Nepal. Euphytica 176(1):59–78. doi:10.1007/s10681-010-0213-0

Horsley RD, Schwarz PB, Hammond JJ (1995) Genetic diversity in malt quality of North American six-rowed spring barley. Crop Sci 35(1):113–118

Jarvis DI, Hodgkin T (1999) Wild relatives and crop cultivars: detecting natural introgression and farmer selection of new genetic combinations in agroecosystems. Mol Ecol 8(12 SUPPL. 1):S159–S173

Jarvis DI, Brown AHD, Pham HC, Collado-Panduro L, Latournerie-Moreno L, Gyawali S, Tanto T, Sawadogo M, Mar I, Sadiki M, Hue NTN, Arias-Reyes L, Balma D, Bajracharya J, Castillo F, Rijal D, Belqadi L, Rana R, Saidi S, Ouedraogo J, Zangre R, Rhrib K, Chavez JL, Schoen D, Sthapit B, De Santis P, Fadda C, Hodgkin T (2008) A global perspective of the richness and evenness of traditional crop-variety diversity maintained by farming communities. Proc Natl Acad Sci USA 105(14):5326–5331. doi:10.1073/pnas.0800607105

Johnson HW, Robinson HF, Comstock RE (1955) Estimates of genetic and environmental variability in soybeans. Agron J 47(7):314–318. doi:10.2134/agronj1955.00021962004700070009x

Joshi BK, KC HB, Upadhyay MP, Gupta SR, Lu BR, Mathur PN, Sthapit BR (2008) *Ex situ* and *in situ* management of wild and weedy rice in Nepal using a geographical information system. Plant Genet Resour Newsl 155:60–74

Khush GS (1997) Origin, dispersal, cultivation and variation of rice. Plant Mol Biol 35(1):25–34. doi:10.1023/a:1005810616885

Li YC, Roder MS, Fahima T, Kirzhner VM, Beiles A, Korol AB, Nevo E (2002) Climatic effects on microsatellite diversity in wild emmer wheat (*Triticum dicoccoides*) at the Yehudiyya microsite, Israel. Heredity 89(2):127–132

MacKey J (1988) A plant breeder's aspect on the taxonomy of cultivated plants. Biol Zent Bl 107:369–379

Mathure S, Shaikh A, Renuka N, Wakte K, Jawali N, Thengane R, Nadaf A (2011) Characterisation of aromatic rice (*Oryza sativa* L.) germplasm and correlation between their agronomic and quality traits. Euphytica 179(2):237–246. doi:10.1007/s10681-010-0294-9

Patra BC, Dhua SR (2003) Agro-morphological diversity scenario in upland rice germplasm of Jeypore tract. Genet Resour Crop Evol 50(8):825–828. doi:10.1023/a:1025963411919

Poudel D, Johnsen FH (2009) Valuation of crop genetic resources in Kaski, Nepal: farmers' willingness to pay for rice landraces conservation. J Environ Manage 90(1):483–491. doi:10.1016/j.jenvman.2007.12.020

Prain G, Hagmann J (2000) Farmers management of diversity in local systems. In: Almekinders C, de Boef W (eds) Encouraging diversity: the conservation and development of crop genetic resources. Intermediate Technology Publications, UK, pp 94–100

Rana RB, Garforth C, Sthapit B, Jarvis D (2007) Influence of socio-economic and cultural factors in rice varietal diversity management on-farm in Nepal. Agric Hum Values 24(4):461–472. doi:10.1007/s10460-007-9082-0

Rana RB, Garforth CJ, Sthapit BR (2009) Farmers' management of rice varietal diversity in the mid-hills of Nepal: implications for on-farm conservation and crop improvement. Plant Genet Resour 7(1):50–62. doi:10.1017/s1479262108048259

Rao SA, Khan MA, McNeilly T, Khan AA (1997) Cause and effect relations of yield and yield components in rice (*Oryza sativa* L.). J Genet Breed 51(1):1–5

Rieseberg LH (1997) Hybrid origins of plant species. Annu Rev Ecol Syst 28:359–389. doi:10.1146/annurev.ecolsys.28.1.359

Rijal DK, Kadayat KB, Joshi KD, Sthapit BR (1998) Inventory of indigenous rainfed and aromatic rice landraces in Seti River Valley, Pokhara, Nepal. LI-BIRD Technical paper No 2. LI-BIRD, Pokhara, p 29

Sanni KA, Fawole I, Ogunbayo A, Tia D, Somado EA, Futakuchi K, Sié M, Nwilene FE, Guei RG (2012) Multivariate analysis of diversity of landrace rice germplasm. Crop Sci 52(2):494–504. doi:10.2135/cropsci2010.12.0739

Sarhadi WA, Ookawa T, Yoshihashi T, Madadi AK, Yosofzai W, Oikawa Y, Hirata Y (2009) Characterization of aroma and agronomic traits in Afghan native rice cultivars. Plant Prod Sci 12(1):63–69. doi:10.1626/pps.12.63

Sharma RC, Chaudhary NK, Ojha B, Yadav L, Pandey MP, Shrestha SM (2007) Variation in rice landraces adapted to the lowlands and hills in Nepal. Plant Genet Resour 5(3):120–127. doi:10.1017/s1479262107837828

Sthapit BR, Rao VR (2009) Consolidating community's role in local crop development by promoting farmer innovation to maximise the use of local crop diversity for the well-being of people. ISHS Acta Horticulturae 806:669–676 http://www.actahort.org/books/806/806_683.htm

Sthapit BR, Joshi KD, Rana RB, Upadhaya MP, Eyzaguirre P, Jarvis D (2001) Enhancing biodiversity and production through participatory plant breeding: setting breeding goals. Paper presented at the Proceeding of the International symposium on PPB and participatory plant genetic resource enhancement: an exchange of experiences from South and South East Asia, Pokhara, Nepal, 1–5 May 2000

Tripathi MP (2008) Population structure and character correlation in *Jhinuwa* rice landraces. Institute of Agriculture and Animal Sciences, Tribhuwan University, Dissertation

Turpeinen T, Tenhola T, Manninen O, Nevo E, Nissilä E (2001) Microsatellite diversity associated with ecological factors in *Hordeum spontaneum* populations in Israel. Mol Ecol 10(6):1577–1591. doi:10.1046/j.1365-294X.2001.01281.x