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RESEARCH ARTICLE

On-farm conservation of 12 cereal crops among 15 ethnic groups in Yunnan (PR China)

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Abstract Due to the rapid diffusion of improved crop varieties, fewer and fewer landraces are being grown by farmers. The on-farm conservation of crop landraces has been proposed as means of conserving potentially important crop germplasm as an alternative to its *ex situ* conservation in gene banks, but the effectiveness of this approach is unproven. Particular attention is currently focused on producers sited in remote regions. Here, we report the outcomes of a survey focusing on the conservation and utilization of landraces of corn, rice, wheat, barley, buckwheat, broomcorn sorghum, Job's tears (coix), oats and finger, foxtail, broomcorn and barnyard millets grown by 15 ethnic groups from Yunnan province (China). Many local varieties are still in existence through their utilization on-farm. The varietal richness per village sampled was estimated to be 3.5 (maximum of 17), with rice and maize being the most heterogeneous, and glutinous sorghum and barnyard millet the least. Varietal richness was significantly and positively correlated with the number of villages surveyed, the number of families and the head of population. The choice of crops and varieties maintained varied between the ethnic groups, with the more westerly and north westerly situated villages conserving the most landraces. The number of crop species used was negatively correlated with per capita annual income, while the correlation coefficient between varietal

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richness and per capita annual income was less pronounced. The major factors determining the level of on-farm conservation were remoteness, fragmentation of the arable area and cultural needs. The data provide baseline information for the elaboration of optimal strategies for *in situ* conservation and utilization of crop germplasm in China.

Keywords Cereals · Ethnic minority · Ethnobotany · Minor crops · On-farm conservation · Varietal richness · Tannon

Introduction

Yunnan province is a very bio-diverse region, thanks to its remoteness and the variability of its climate and terrain. The crop species used belong to over 1,700 taxa, covering over 800 genera and 190 families (Li et al. 2011). At least 600 crop wild relative species are endemic to the region, which is a primary centre of origin of both cultivated rice and buckwheat, and a secondary centre of origin for waxy corn and Yunnan bread wheat (*Triticum aestivum* subsp. *yunnanense* King) (Zeng et al. 1999; Dai et al. 2001; Wang et al. 2004). The human population in Yunnan province is also culturally rich, and is home to 25 of China's 55 officially recognized minority ethnic groups. Among the 25 minority ethnic groups, 15 ethnic groups are unique to Yunnan province on account of more than 80 % of their population living in Yunnan. These ethnic groups are the Bai, Hani, Dai, Lisu, Lahu, Wa, Naxi, Jingpo, Bulang, Achang, Pumi, Nu, Jinuo, Deang and Dulong. The strong local traditions of these ethnic groups, along with the remoteness and heterogeneity of the region have resulted in the creation and conservation of a diversity of crop landraces.

Following the acceptance of the importance of landrace varieties since early in the 20th century, substantial efforts have been made to collect such materials, largely in the form of accessions in *ex situ* gene banks. This mode of conservation prevents any further evolution of the populations, and also excludes local farmers from playing any management or selection role for their improvement (Bellon et al. 1997; Lu et al. 2002; Fowler and Hodgkin 2004). As an alternative, *in situ* conservation in the form of on-farm maintenance has been proposed (Brush 1991; Bretting and Duvick 1997; Bisht et al. 2007). The practice of on-farm conservation for several crop species in various parts of the world has been elaborated and improved over recent years (Brush 1995; Bretting and Duvick 1997; Borromeo 2006; Jarvis et al. 2008; Chen and Liang 2011). As yet, the diversity of traditional crop varieties used by the various ethnic groups in Yunnan province has not been documented. Here, we present the outcome of a survey of the landraces of corn, rice, wheat, barley, buckwheat, broomcorn sorghum, Job's tears (coix), oats and finger, foxtail, broomcorn and barnyard millets cultivated in 306 villages. An assessment was made of the richness of on-farm conserved crops and varieties, and the reasons for the continued existence of these local varieties explored, in an attempt to provide baseline information for the elaboration of optimal strategies for *in situ* conservation and utilization of crop germplasm in China.

Methods

Local populations and survey sites

For the eight larger ethnic groups (Hani, Dai, Wa, Lahu, Jingpo, Bai, Naxi and Lisu), which were each represented by a population of at least 100,000, the survey considered geographical and ecological area, proportion of the population of a given ethnicity, since the groups are settled over a wide geographical area and are well inter-mixed. The other seven ethnic groups (Jinuo, Bulang, Deang, Achang, Pumi, Nu, and Dulong) are, in contrast, small with respect to population size and settled in distinct localities, so the survey in this case could be based on ethnic group. The Hani, Dai, Jinuo, Bulang, Wa, Lahu, Deang, Jingpo and Achange are based in the south and southwest of Yunnan, while the others are largely restricted to the west and northwest of the province. For the eight larger ethnic groups, the first step was to check the related literatures, the second step was to survey the agricultural and biological resources with questionare in 50 % of counties in Yunnan province. The third step was to carry out field survey in 50 % of previously-surveyed counties in the second step according to the results in the two steps, following which a representative selection of villages was made. Three representative villages per township were chosen, taking in three townships per county. For the smaller ethnic groups, the choice of village depended

on a particular ethnic group constituting at least 50 % of the population. Yunnan province includes a total of 124,206 villages associated with 1,348 townships, and is divided into 130 counties, grouped into 16 prefectures. The survey sampled in all 306 villages associated with 124 townships, located in 36 counties and 11 prefectures (detailed list not shown, but available on request). The geographical distribution of the villages and other general information concerning the ethnic groups are given in Fig. 1 and Table 1, respectively.

Survey procedure

The investigation was conducted by six operators over the period 2007–2010. A questionnaire was distributed to relevant local officials working for the various county agriculture bureaux, agricultural technicians, village clerks and some experienced farmers. The field investigation protocol followed the participatory rural appraisal method described by Christinck et al. (2000) and the indigenous agricultural knowledge investigation method of Dai et al. (2008). The operators were initially trained to ensure their full understanding of the goals of the investigation and the standards which needed to be adhered to. The timing of visits was based on identifying the optimal local growing season and the expected crop diversity present. The operators focused their questions to determine how the local farmers viewed, utilized and conserved their landrace materials. Plant samples were collected following the recommendations of Zheng et al. (2007). The emphasis was on the cereal crops: corn, rice, wheat, barley, buckwheat, broomcorn and glutinous sorghums, finger, barnyard and foxtail millets, Job's tears and oats.

Analysis of crop and varietal diversity

An assessment was made of crop richness (the number of crop species cultivated) and varietal richness (the number of distinct landraces cultivated). Since it is common place both for different landraces to share the same name, and for landraces having different names to be identical, special measures were taken to minimize potential confusion generated by these problems. One strategy was to ensure that the sample villages were well separated from one another geographically, and another that the cultural and ecological environment of the sample villages should be as

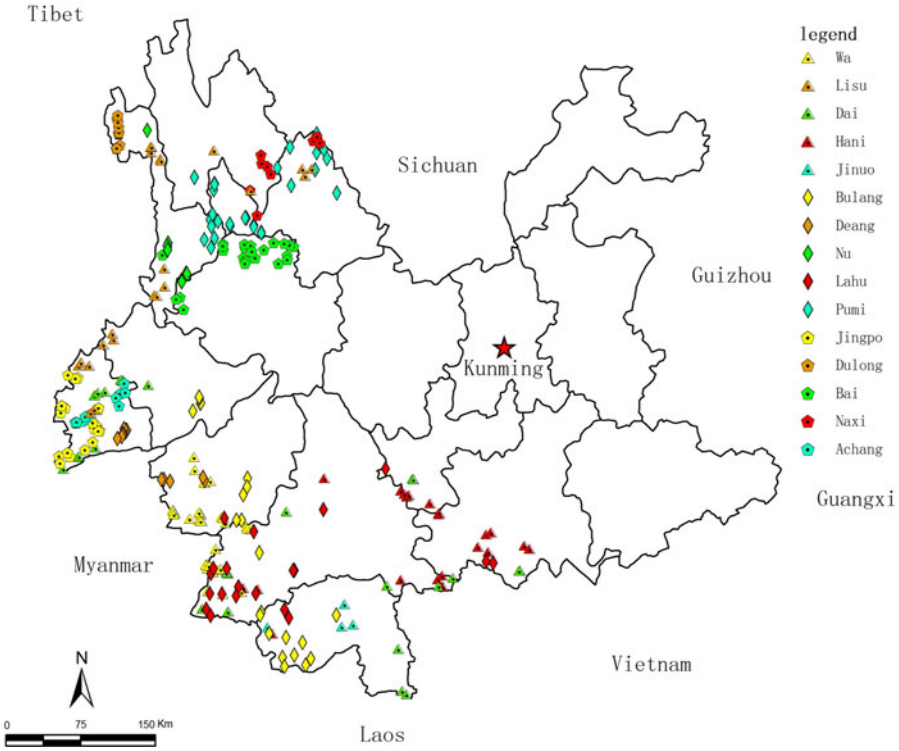

Fig. 1 Distribution of the surveyed villages of 15 ethnic groups in Yunnan province

Table 1 Basic information regarding the 15 ethnic groups in Yunnan province

Ethnic group	No. of prefecture	No. of county	No. of township	No. of administrative village	Natural village	Elevation (m)	Precipitation (mm)	Annual average temp. (°C)	Total families	Population	Population ratio (%)	Arable land per capita (m^2)	Net annual income per capita (Yuan)
Hani	4	8	14	20	23	1,419.5	1,864.5	18.4	2,100	9,608	95.8	1,380.1	1,676.9
Dai	7	12	18	22	31	889.0	1,580.8	20.1	3,637	16,279	97.1	1,505.0	2,531.4
Jinuo	1	1	1	5	5	1,000.0	1,400.0	18.6	393	1,431	97.1	1,530.7	1,927.0
Bulang	4	5	12	19	22	1,419.0	1,410.8	18.6	2,732	11,954	93.3	1,323.9	1,294.9
Wa	2	6	14	24	37	1,495.3	1,868.2	19.0	5,305	16,355	96.9	1,926.5	1,293.3
Lahu	5	8	13	19	20	1,394.5	1,701.1	17.6	1,478	6,924	94.1	2,194.1	1,057.3
Deang	2	2	3	8	13	1,176.5	1,613.0	18.3	972	4,357	93.2	2,241.1	1,700.5
Jingpo	1	3	10	18	22	1,331.1	1,614.6	19.1	1,974	8,271	89.7	1,887.0	1,566.7
Achang	1	2	6	14	14	1,417.5	1,774.5	16.4	699	3,205	83.4	1,433.1	1,652.9
Bai	2	3	12	25	25	2,241.4	936.4	14.5	2,900	12,679	98.6	892.8	1,340.7
Pumi	3	4	17	24	32	2,621.0	917.5	11.5	1,730	8,383	85.2	1,840.6	1,355.7
Naxi	2	2	3	9	10	2,352.9	895.4	11.7	781	3,580	82.7	1,533.4	1,441.5
Lisu	5	7	12	23	26	1,635.7	1,881.3	14.4	774	3,352	92.9	1,034.2	1,273.3
Nu	1	3	4	8	14	1,763.3	1,067.8	16.8	1,247	4,418	91.9	1,166.2	987.3
Dulong	1	1	1	6	12	1,544.4	4,201.6	14.8	299	1,377	100.0	596.4	763.0
Average	–	–	–	–	–	1,580.1	1,648.5	16.7	1,801	7,478	92.8	1,499.0	1,457.5
In total	11	36	124	237	306	–	–	–	27,021	112,173	–	22,485.1	–

* Data from Yunnan digital country website (2008)

Table 2 Local information provided regarding on-farm conserved varieties in Laomian, Lila village, Mengsuo township, Ximeng county

Crop	Variety name	Sample no.	Local knowledge
Rice	Bairigu	2008532608	Good taste, disease and pest resistant
	Xiangnuo	2008532609	Aromatic, used for making rice cake in festivals
	Zinuo	2008532610	Good quality, disease and pest resistant, used for making rice cake in festivals, medicinally used for bone healing
	Mengzaka	2008532614	Good taste, disease resistant, pest-susceptible,, drought tolerant, poor nutrition tolerant
	Zaluo	2008532615	Good quality, susceptible to disease and pest, infertile-tolerant, early mature, the staple food on New Rice Festival
	Duoge	2008532616	Glutinous, pest and disease susceptible, drought-sensitive, infertile-sensitive
	Xiaogai	2008532617	Bad taste, pest resistant, disease susceptible, cold-, drought- susceptible, infertile-tolerant, short growth cycle, biannual, low plant height
	Baixiangnuo	2008532618	Good taste, aromatic, drought tolerant, pest susceptible, drought-tolerant, infertile-susceptible
	Zaxi	2008532644	Sweet, pest and disease susceptible, good for porridge and rice noodle
	Zaluma	2008532645	Good taste, aromatic, disease and pest resistant, cold tolerant, lodging easily, suitable for planting in areas of high altitude (1,500 m)
Maize	Mayabaogu	2008532619	High quality pest and disease resistant, infertile-tolerant
	Bainuobaogu	2008532620	Good taste, aromatic, pest and disease susceptible, cold-sensitive, edible when uncooked, can be used for making wine and for sale
	Zinuobaogu	2008532621	Good taste, sticky, moderate tolerant to disease and pest, drought sensitive, infertile-susceptible
	Huangnuobaogu	2008532622	Good taste when fresh, glutinous, disease tolerant
	Huangbaogu	2008532623	High quality, disease resistant, infertile tolerant
	Huanuobaogu	2008532624	Tasty, aromatic, disease and pest susceptible, cold-sensitive, infertile-susceptible
	Bainuobaogu	2008532646	High quality, sweet, disease and pest resistant
	Bendibaibaogu	2008532647	Moderate quality, disease and pest resistant

varied as possible. The landraces were identified according to methods given by Sadiki et al. (2007), Jarvis et al. (2008) and Xu et al. (2010), in addition to the information given by the local residents (Table 2). Local agricultural technicians and experienced farmers also participated in landrace identification.

Results

Diversity of on-farm conserved crops species and landraces

The number of cereal crops conserved per village ranged from one to five (mean 3.2). Three common combinations were encountered: (1) corn, wheat, barley, buckwheat and oats, (2) corn, rice, wheat, buckwheat and oats and (3) corn, rice, buckwheat, broomcorn sorghum and finger millet. The diversity of conserved cereal crops varied considerably among the ethnic groups (Table 3), with the Lisu conserving the highest number (10) and the Dai, Jinuo and Achang the lowest (3). The average crop richness per 100 ha of cultivated land, per 100 families and per 1,000 head of population was, respectively, 0.6, 0.4 and 0.9. The equivalent figures for the Dulong were the highest of all the ethnic groups (11.0, 3.0 and 6.5), and those for the Wa were the lowest (0.3, 0.2 and 0.5). The average crop richness per 100 ha of cultivated land, per 100 families and per 1,000 head of population among the western and north-western ethnic groups was, respectively 1.2, 0.6 and 1.5, while the equivalent figures for the southern and south-western groups were 0.4, 0.3 and 0.7.

The number of distinct landraces encountered was 1,083. Varietal richness per village ranged from 1 to 17 (mean 3.5). The most varietally rich crops were corn and rice (respectively, 411 and 371 landraces),

Table 3 The diversity of cereal crops cultivated by 15 ethnic groups from Yunnan province

Ethnic group	Crop richness	Variety richness	Crop richness per 100 ha	Crop richness per 100 families	Crop richness per 1,000 people	Variety richness per 100 ha	Variety richness per 100 families	Variety richness per 1,000 people
Hani	6	103	0.453	0.286	0.624	7.768	4.905	10.720
Dai	3	68	0.122	0.082	0.184	2.776	1.870	4.177
Jinuo	3	17	1.370	0.763	2.096	7.761	4.326	11.880
Bulang	9	80	0.569	0.329	0.753	5.055	2.928	6.692
Wa	8	154	0.254	0.151	0.489	4.888	2.903	9.416
Lahu	7	95	0.461	0.474	1.011	6.254	6.428	13.720
Deang	6	47	0.615	0.617	1.377	4.814	4.835	10.787
Jingpo	9	95	0.577	0.456	1.088	6.087	4.813	11.486
Achang	3	33	0.653	0.429	0.936	7.185	4.721	10.296
Bai	9	70	0.795	0.310	0.710	6.184	2.414	5.521
Pumi	6	92	0.389	0.347	0.716	5.963	5.318	10.975
Naxi	8	47	1.457	1.024	2.235	8.562	6.018	13.128
Lisu	10	100	2.885	1.292	2.983	28.848	12.920	29.833
Nu	7	33	1.359	0.561	1.584	6.405	2.646	7.469
Dulong	9	49	10.960	3.010	6.536	59.669	16.388	35.585
Average	6.9	72.2	0.592	0.381	0.918	6.220	4.008	9.655

followed by buckwheat (74). Broomcorn and barnyard millet were the least varietally rich (respectively, 3 and 5 landraces). Varietal richness varied considerably among the ethnic groups, ranging from 17 (Jinuo) to 154 (Wa). However, the overall mean varietal richness per 100 ha cultivated land, per 100 families and per 1,000 head of population was, respectively, 6.2, 4.0 and 9.7. Broken down into the various ethnic groups, the most varietally rich collections were conserved by the Dulong, who conserved 59.7 landraces per 100 ha cultivated land, 16.4 per 100 families and 35.6 per 1,000 head of population, followed by the Lisu (respectively 28.9, 12.9 and 29.8 landraces). The Dai conserved the lowest number of landraces (2.8, 1.9 and 4.2 respectively). The equivalent figures for varietal richness among the western and north-western groups were 9.4, 5.1 and 11.6, and among the southern and south-western groups 5.2, 3.6 and 8.8.

Across the whole region, many local landraces are still grown on-farm. The more widely grown crops (corn, rice, wheat, barley, buckwheat) are more varietally rich than the less widely cultivated ones (the four millets, broomcorn sorghum, Job's tears and oats). The ethnic groups differed in their attitude to conserving landraces. On the basis of crop and varietal richness per 100 ha cultivated land, per 100 families and per 1,000 head of population, the Dulong and Lisu were the most interested in conservation and the Dai the least interested. On the whole, the populations settled in the western and north-western part of the province were more concerned with landrace conservation than those settled in the southern and south-western part.

Varietal richness and the distribution of the various cereal crops

Corn was both the most varietally rich and the most widely distributed of the crops. It was grown in 192 (62.7 %) of the villages, and was represented by 411 landraces (mean of 2.1 landraces per village, maximum 8). The choice of landraces made by the various ethnic groups is shown in Fig. 2. The Wa and Lisu made use of 40 distinct landraces, while the Jinuo only used 4. Around 40.8 % of the corn landraces were glutinous (168 of 411), and 75 % of the glutinous corn landraces were concentrated in the southern and south-western part of the province, especially in areas settled by the Dai. About two-thirds of the landraces were consumed as food or used for brewing, while the remainder provided animal feed.

Rice was cultivated in 169 (55.2 %) of the villages, and was represented by 371 landraces (mean 2.2 per

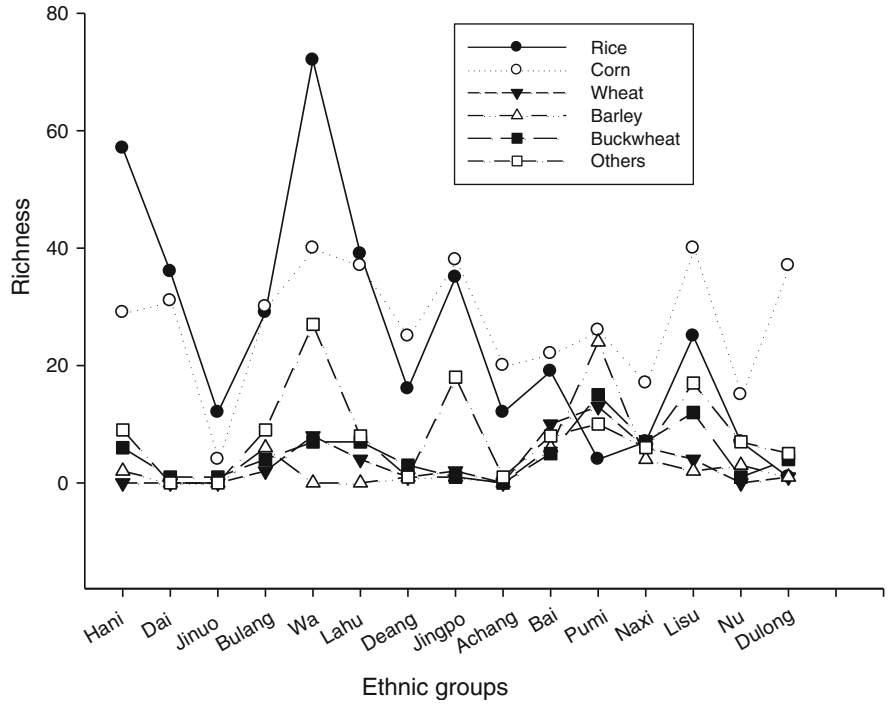

Fig. 2 Distribution of on-farm conservation cereal crops cultivated by 15 ethnic groups from Yunnan province

village, maximum 14). Of these, 135 (36.4 %) were glutinous, 74 (19.9 %) pigmented (including 36 purple and 38 red grain types) and 55 (14.8 %) aromatic. The distribution of these landraces among the various ethnic groups is shown in Fig. 2. The Wa conserved the most landraces (72) and the Dulong the fewest (1). The bulk of the landraces (83 %) was grown in the southern and south-western part of Yunnan; these included 99 upland landraces, and the majority (92.6 %) were glutinous. The majority (83.3 %) of the landraces conserved by the Dai were also glutinous.

Wheat was cultivated in 37 (12.1 %) of the villages, and was represented by 51 varieties (mean 1.4 per village, maximum 4). The number of landraces conserved by each minority group ranged from 0 (Hani, Dai, Jinuo, Achang, and Nu) to 13 (Pumi). *T. aestivum* subsp. *yunnanense* was not encountered in any of the villages. Thirty-four (66.7 %) conserved landraces were grown in the western and north-western part of the province.

Barley was cultivated in 35 (11.4 %) of the villages, and was represented by 50 landraces (mean 1.4 per village, maximum 3). Of these, 34 were of the hulled type (conserved in 28 villages) and 16 were of naked (14 villages). The number of landraces conserved by each minority group ranged from 0 (Dai, Jinuo, Wa, Lahu and Achang) to 24 (Pumi). The western and north-western ethnic groups conserved 40 of the 50 landraces.

Buckwheat was cultivated in 61 (19.9 %) of the villages, and was represented by 74 landraces (mean 1.2 per village, maximum 2). Of these, 31 were the sweet type (27 villages) and 43 the bitter type (41 villages). The number of landraces conserved by each minority group ranged from 0 (Achang) to 15 (Pumi). Eleven of the ethnic groups conserved both sweet and bitter buckwheat landraces. The Dai, Jingpo and Bulang only cultivated bitter types, while the Jinuo, Deang and Nu only cultivated sweet ones. The western and north-western ethnic groups conserved 44 of the 74 landraces.

The remaining seven crop species (the broomcorn sorghum, the millets, oats and Job's tears) were cultivated in 92 (29.7 %) of the villages, represented by 126 landraces. The most varietally rich of these minor cereal crops were broomcorn sorghum (35 landraces) and finger millet (27 landraces). Varietal richness varied among the ethnic groups, ranging from 0 (Dai and Jinuo) to 27 (Wa). Broomcorn sorghum was conserved by ten of the ethnic groups, associated with a varietal richness of from 1 to 6. Job's Tears was grown by nine of the ethnic groups (varietal richness

from 1 to 6). The southern and south-western ethnic groups only cultivated broomcorn sorghum, finger millet, Job's Tears and Foxtail millet (varietal richness 73). The western and north-western ethnic groups cultivated all these seven minor crops (varietal richness 53). Oats was only used by the Bai, Pumi, Naxi and Lisu, barnyard millet only by the Bai, Naxi and Dulong, and Broomcorn millet only by the Lisu.

Overall, of the cereal crops surveyed, corn was the most varietal rich and most widely distributed among the ethnic groups. Rice landraces (especially upland and glutinous types) were concentrated in the southern and south-western part of the province, while crop richness and varietal richness of wheat and other 9 crops in western and north-western was higher than those in southern and south-western part of the province. The Dai were particularly interested in glutinous rice and glutinous corn varieties. The remote, fragmented, cold, dry and poor ecological environment that hard for cropping and ethnic cultural needs were the two major factors determining the pattern of crop diversity conservation.

Correlations involving crop and varietal diversity

The correlation between the crop diversity and both the number of locations surveyed and their altitude is given in Table 4. Varietal richness was positively correlated with the number of townships, administrative villages, villages, families and head of population, with coefficients ranging from +0.73 to +0.88. The varietal richness of the wheat, barley and buckwheat landraces was positively correlated with one another (range of coefficients +0.67 to +0.75), and also with the altitude of the sampling site (range of coefficients +0.64 to +0.80), but negatively with annual average temperature (−0.62 to −0.64). For rice, varietal richness was positively correlated with annual average temperature (+0.61). Crop richness within ethnic groups was positively correlated with varietal richness for corn and the seven minor crops (respectively, +0.54 and +0.64). Crop richness was negatively correlated with per capita annual income (−0.70). The correlation coefficients between varietal richness and the per capita area of cultivated land ranged from +0.04 to +0.35 on a crop basis. The correlation coefficients between crop richness within ethnic groups and village altitude and that between varietal richness and village altitude were +0.44 and +0.41, respectively. Meanwhile, the correlation coefficient between total varietal richness within ethnic groups and per capita annual income was 0.05. The correlation coefficients between variety richness of a given crop species and per capita annual income ranged from −0.38 to +0.20. Overall, the larger the investigated area, the greater was the varietal richness. In some cases, varietal richness was heavily influenced by agro-ecology; for example, the higher the average annual temperature, the greater the varietal richness of the rice landraces. Similarly, the higher the altitude of the survey site which implied a lower average annual temperature, the greater the varietal richness of the wheat, barley and buckwheat landraces. There was also a relationship between crop and varietal richness and the per capita area of cultivated land and per capita annual income.

Discussion

North-western Yunnan has been identified as one of 25 global biodiversity hotspots (Myers et al. 2000; Long et al. 2003).The survey area featured about 17,000 ha of cultivated land in this region. Across the whole of Yunnan province, the area dedicated to the production of each of rice and corn is more than 1 Gha, while the area sown to each of wheat, barley and buckwheat is <1 Mha. The minor grain crops occupy <0.01 Mha. The survey highlighted that the 15 Yunnanese ethnic groups conserved many crop landraces on-farm. The most varietally rich crop was corn (probably because of its out-pollinating habit), followed by rice and buckwheat, both of which have one of their centres of origin in Yunnan. The seven minor crops retained some importance, as they were still cultivated in about one-third of the sample villages. As also noted by Jarvis et al. (2008), it is generally that major crops tend to be the most diverse. Cross-pollinating crops tend to be of high diversity. Xu et al. (2010) have suggested that traditional cultures, and diverse ecology, like Yuanyang Hani terraced field, helped to conserve the rice germplasm resources, and so promote the crop's diversity. In the study area, many of the ethnic groups still use traditional farming techniques, and have retained both their cultural identity as well as their traditional botanical knowledge; in so doing, they have successfully maintained and even improved the diversity of their crop plants (Li et al. 2011).

Table 4 Correlations between the diversity and either the number of villages surveyed or the altitude of the survey site

Items	Precipitation	Annual temperature	Acreage per capita	Annual net income per capita	Total variety richness	Corn richness	Rice richness	Wheat richness	Barley richness	Buckwheat richness	Variety richness of 7 minor crops	Crop richness
County	–	–	–	–	0.620*	0.492	0.642**	−0.037	−0.098	0.198	0.179	−0.116
Township	–	–	–	–	0.804**	0.519*	0.590*	0.427	0.355	0.449	0.411	0.040
Administrative villages	–	–	–	–	0.820**	0.549*	0.570*	0.562*	0.332	0.503	0.551*	0.228
Villages	–	–	–	–	0.875**	0.627*	0.615*	0.535*	0.335	0.483	0.631*	0.201
Altitude	−0.340	−0.890**	−0.189	−0.472	0.045	−0.11	−0.371	0.796**	0.742**	0.644**	0.209	0.408
Precipitation	–	0.109	−0.382	−0.325	0.009	0.471	0.001	−0.357	−0.366	−0.118	0.009	0.177
Annual average temperature	–	–	0.309	0.440	0.201	0.152	0.605*	−0.617*	−0.623*	−0.637*	0.017	−0.307
Families	–	–	0.207	0.217	0.751**	0.395	0.753**	0.333	0.009	0.052	0.536*	0.090
Population	–	–	0.182	0.316	0.725**	0.381	0.689**	0.325	0.100	0.061	0.393	0.045
Cultivated area per capita	–	–	–	0.286	0.315	0.081	0.351	0.119	0.043	0.068	0.126	0.027
Annual net income per capita	–	–	–	–	−0.045	−0.261	0.194	−0.279	−0.163	−0.338	−0.376	−0.701**
Total variety richness	–	–	–	–	–	0.763**	0.826**	0.463	0.126	0.536*	0.853**	0.441
Corn richness	–	–	–	–	–	–	0.536*	0.147	−0.093	0.343	0.629*	0.537*
Rice richness	–	–	–	–	–	–	–	0.000	−0.340	0.042	0.603*	0.081
Wheat richness	–	–	–	–	–	–	–	–	0.713**	0.746**	0.448	0.359
Barley richness	–	–	–	–	–	–	–	–	–	0.665**	0.067	0.088
Buckwheat richness	–	–	–	–	–	–	–	–	–	–	0.439	0.395
Variety richness of 7 Minor crops												0.635*

* Correlation significant at $p < 0.05$

** Correlation significant at $p < 0.01$

Varietal richness is an important parameter for the quantification of on-farm conservation. The larger the size of the investigated area, generally the higher the level of varietal richness is expected to be. The current study was no exception to this rule. For this reason, the decision was taken to judge crop and varietal richness on per family (population) or per area of cultivated land basis. The outcome of applying this approach was that both crop and landrace diversity varied significantly among the different ethnic groups, largely because of differences in the local agro-ecology, traditional culture and level of economic prosperity. The two factors which tended to encourage the maintenance of landraces the most were the remoteness and fragmentation of the site, and the lack of farms suitable for mechanized cropping. In these areas, substantial numbers of low input adapted corn, upland rice, barley, oats and buckwheat landraces have been maintained. Cultural factors could also be an important driver of landrace conservation. For example, Yunnan landraces included a large representation of glutinous and aromatic grain types, as well as red-grained rice. Two aspects of the conservation of crop diversity in the target area were conspicuous. Firstly, crop and varietal richness were positively correlated with the per capita area of cultivated land and the altitude of the surveyed site. This is in consistent with the observation that high levels of crop diversity have often been associated with areas where cropping is physically difficult (Wang and Zhang 2011). Secondly, the ethnic groups residing in the western and north-western part of Yunnan were more inclined to conserve their crop genetic resources than those residing in the southern and south-western part of the province. The topography of western and north-western Yunnan is mountainous and characterized by a highly diverse set of micro-environments. Much of the cultivated land is fragmented, and crop production is constrained by a lack of moisture and low temperatures. Nevertheless, the local ethnic groups, particularly the Dulong, Lisu and Pumi, are self-sufficient in terms of food production, so they conserved more crops and landrances. In contrast, southern and south-western Yunnan has a tropical/sub-tropical climate, and enjoys sufficient rainfall and fertile soils. The Dai, who reside in the southern part of Yunnan, have replaced most of their traditional crops with either improved varieties or with cash crops such as banana and sugarcane. The only traditional crops conserved by the Dai are glutinous rice and glutinous corn, since these form part of their traditional culture.

The conservation of local landraces is a dynamic process, realized through the activity of farmers working within a particular agro-ecological system, and is based on farmers' selection and management. The germplasm currently conserved on-farm could provide interesting materials for *ex situ* conservation, and also resources for adapting key crop species to the predicted changed environment resulting from global warming (Harlan 1975; Qualset et al. 1997; Teshome et al. 2001; Brush 2004; Fowler and Hodgkin 2004). Germplasm conservation, whether achieved by *in situ* and/or *ex situ* methods, may not have achieved the halting of genetic erosion, which has accelerated since the beginning of the 20th century. As an example, the number of vegetable varieties available in China has fallen by over 40 % during the past half century (Tilman 1998; Li 1999; Zhu et al. 2000; Qu 2001; Wang et al. 2011). In the survey area of Yunnan, local corn landraces were no longer cultivated in over one-third of the villages surveyed, nearly half of the villages had ceased growing local rice landraces, and hardly any of them maintained any local wheat landraces. *T. aestivum* subsp. *yunnanense*, which was widely cultivated as late as the 1970s, has effectively disappeared in the region. Overall, traditional corn, rice, wheat and barley landraces are currently planted over less than 10 % of their cultivated land, even though a substantial number of traditional rice and corn varieties persist, presumably because they meet specific cultural needs. The situation for the minor crops is different, traditional landraces dominate production, because little investment has been made in their improvement.

The conservation of crop diversity by local farmers is carried out to satisfy local requirements. As the national economy develops, modern technology will inevitably diffuse into traditional areas like Yunnan, and put pressure on the maintenance of local landraces. In the meantime, it will be important to investigate, collect and evaluate crop germplasm resources in regions where diverse agro-ecologies and traditional culture have combined to generate unique landraces, to prioritize the continued utilization of local landraces and minor crops where this is feasible, and to identify specific regions of high crop diversity which could be managed as a local, national

and global centre of agricultural heritage. An example of such an area is the site of the Hani rice terraces in Yuanyang, Yunnan province.

Conclusion

Many landraces are still conserved on-farm by the Yunnanese ethnic minorities, for reasons associated with the diversity of the local agro-ecology and to fulfil cultural requirements. The choice of crop species and the varietal richness within each crop varied greatly among the 15 ethnic groups. The weakening of cultural traditions resulting from economic development and the declining economic viability of farming in remote, unfavourable environments are together eroding the incentive to conserve traditional landraces on-farm and to maintain varietal richness.

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