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Crop Interdependence, Adaptation to Climate Change and the Multilateral Systems of Access and Benefit Sharing: The Case of Nepal

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Improving farmers' access to more plant diversity is expected to be an effective strategy to respond to climate changes. Degrees of current crop interdependency were estimated based on the origin and pedigree analysis of modern varieties of rice, wheat and potato cultivated in Nepal. Geographical information system (GIS) was applied to identify germplasm from the global and national gene pools with respect to current and future climate analogue sites. In Nepal, 76% of 275 released varieties originated outside Nepal. Forty seven landraces originating in 12 countries were used to develop 20 mid- and high-hills rice cultivars and 35 landraces originating in 11 countries were used to develop 28 Tarai rice cultivars. Only exotic parents were used to develop 35 modern wheat varieties; 89 ancestors originated in 22 countries, mostly from the United States (13%), India (13%), France (12%), Argentina (6%), and Italy (6%). Only exotic parents were used to develop eight modern varieties of potato. Nepal is 95–100% dependent on foreign germplasm for varietal development. Using the Climate Analogue Tool (CAT), the analysis identified current, future, and past analogue sites within and outside Nepal, suggesting that there might be useful genetic materials that could be exchanged between such regions. To do so, Nepal has to be capable to make better use of the MLS-ITPGRFA. Right now more than 2500 genotypes of rice, wheat and potato are introduced annually for field evaluation in Nepal. This number could be increased with a fully operational MLS.

Key Words: Analogue sites, Genebank, Origin, Pedigree

Introduction

Nepal is agrobiodiversity rich country however; she depends very largely on agricultural plant genetic resources (APGRs) that originated elsewhere. Access to diverse APGRs are necessary for secure crop harvest. The strong interdependence of countries on APGRs is a key rationale for the creation of the multilateral system (MLS) of access and benefit sharing under the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA). Most people are unaware of the current and future importance of interdependence and how the flow of genetic materials between countries contributes to national food security. Nepal is no exception in this regard. To effectively implement the MLS and facilitate exchange of genetic materials, it is important to generate empirical evidence of the extent to which Nepal is dependent on foreign-sourced APGRs for its agricultural research and development (including breeding) and, ultimately, food and nutrition security.

Over 4.6 million crop accessions are available in the public domain, and the CGIAR centres alone preserve more than 700 thousand accessions of crops and forage species collected from over 100 countries (Halewood *et al.,* 2013). These materials have been distributed mainly (more than 90%) through public research organizations, universities, regional organizations, germplasm networks, and genebanks; about 80% of distributed material goes to developing countries and countries with economies in transition (SGRP, 2011).

Climate change is one of the most pressing challenges facing the world; it has already had a profound impact on APGRs and the livelihoods of people, mainly smallholders living in marginal environments (FAO, 2011). Climate change may render locally available APGRs inadequate, thus underscoring the importance of access to other APGR sources (Esquinas-Alcazar, 2005; FAO, 2011; Fujisaka *et al.,* 2011). Novel strategies to conserve and use APGRs are likely required to strengthen farmers' capacities to adapt to climate change. The MLS of ITPGRFA could be of great help in putting these strategies into practice.

The use of "climate analogues" is one such strategy. Climate Analogue Tool (CAT) is an open-access

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tool developed by the program on Climate Change, Agriculture and Food Security in conjunction with the International Center for Tropical Agriculture and the Walker Institute (Ramírez-Villegas *et al.,* 2011). The tool can be used to identify future climate conditions at a particular location, sites that currently resemble these conditions, and locations that have or will have similar climate conditions. Based on careful analyses using the tool and data from actual conditions in farmers' fields, scientists can formulate possible intervention strategies, including identification of appropriate APGRs or development of new varieties for specific locations of interest (Vernooy *et al.,* 2015). Yield gap between research station and farmers' field is large and one of the reasons may be due to difference in climate (Joshi *et al.,* 2008a) between research station and farmers' field as shown in following equation.

Yield gap (Research station – Farmer's field) = Climatic differences (Research station – Farmer's field)

One of the notions of recommending variety based on analog site is to improve adaptation through reducing the climatic differences between research station and farmers' field. CAT helps to identify germplasm based on the analog sites for better adaptation and increasing options to diverse genotypes. The high degree of intra and inter-specific crop diversity may result in reducing the agricultural problems mainly related to abiotic and biotic stresses. In this paper, country dependency on foreign APGRs was reported based on the pedigree analysis and origin of modern varieties and ancestors. Analog sites and climate smart rice germplasm were identified from global and national gene pools using CAT.

Materials and Methods

Three crops (rice, wheat and potato) were chosen for detail study on germplasm flows into and out of the country. Information was gathered related to the reliance of APGR users in the country on APGR originating in other countries. Interviews and focus group discussions were organized. Crop dependency was estimated based on the origin of released varieties and area coverage, and origin of ancestors through pedigree analysis. Complete pedigree tree of each modern variety as in Fig. 1, was generated for knowing the origin of ancestors (Joshi, 2005; Joshi *et al.,* 2006). The numbers of native and

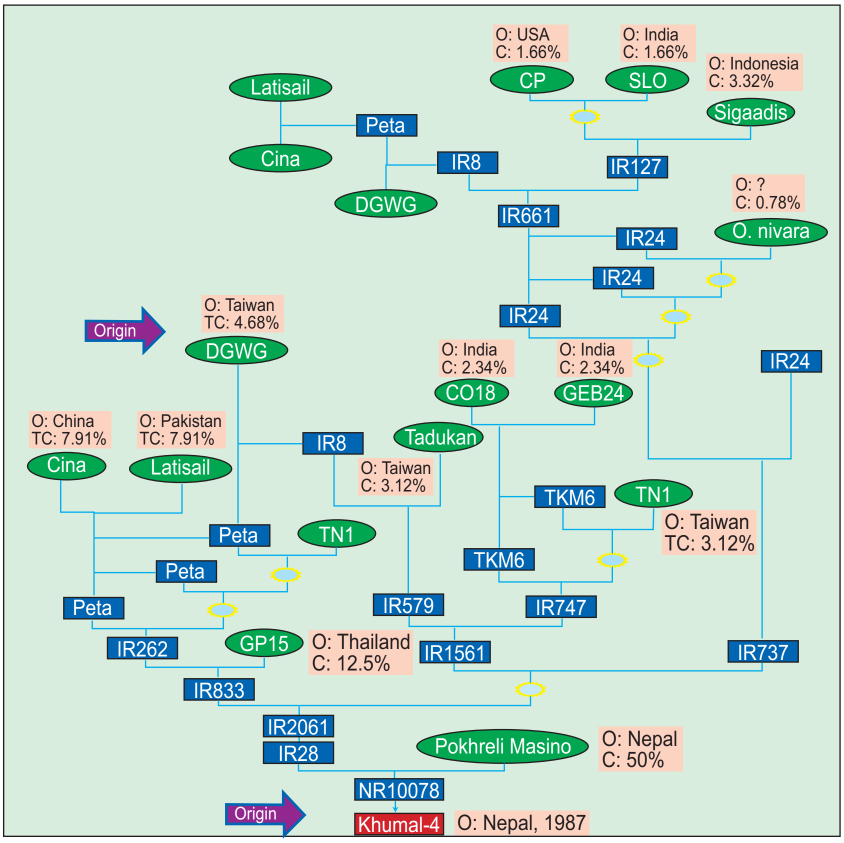

Fig. 1. Pedigree analysis and origin of ancestors of Khumal-4 rice variety for analyzing the interdependency (O, origin, TC, total contribution)

exotic parents used in developing a variety were counted as far back as possible. Detail pedigree analysis is described by Joshi *et al.* (2016).

For adaptation to climate change, we selected two districts for reference sites, representing mid hill (Begnas village of Kaski district) and Tarai (Kachorwa village of Bara district) region. The sites are rich in agrobiodiversity at species, variety and gene levels (Rana *et al.,* 2000), several of which are rare and localized or on verge of extinction (Chaudhary *et al.,* 2004; Joshi *et al.,* 2005). Rice was chosen for this study, as it is the most important staple crop grown by a large number of farmers in large area in Nepal.

We used online software called Climate Analogue Tool (CAT) to assess the current and future climates and identify analogues sites with the help of the reference sites and DivaGIS software to refine the maps produced using CAT (Joshi *et al.,* 2008b). CAT can identify two or more similar locations, and a location whose current situation resembles the past or future situation of another location. The matching sites were grouped into four categories based on likelihood or probability of matching: with 0.75-1 probability (highly matching sites), 0.5-0.75 probability (moderately matching sites), 0.25-0.5 (less likely matching sites), and 0-0.25 (no to very less likely matching sites). Based on the analog sites, rice accessions were identified from global and national gene pools for current and future use in these sites. Chaudhary *et al.* (2016) has described in detail the method of using CAT for identifying analog sites.

Results and Discussion

Germplasm flow

The import and export of germplasm in Nepal has not been systematized, and rules and regulations are not strictly followed. Import and export of germplasm is currently under the authority of the Seed Quality Control Centre and the National Plant Quarantine Office. However, a considerable amount of germplasm enters and leaves the country "informally." A large number of improved materials are being transferred from CGIAR centres' breeding programs to Nepal. Breeding programs and seed suppliers are independently collecting APGRs in Nepal as well from CGIAR centres and from India and China. Major crops introduced regularly from outside the country are rice, wheat, maize, potatoes, lentils, some vegetables, and some forage crops. Rice, wheat, and some vegetables are regularly sent to other countries, mainly Bhutan, India, and Kenya, for research and production. Some vegetables are regularly exchanged within countries of the South Asian Association for Regional Cooperation.

The National Rice Research Program (NRRP) has been acquiring International Network for Genetic Evaluation of Rice (INGER) nurseries of rice from IRRI for testing under different agro-ecological conditions; 14 nurseries are received annually, each consisting of 30–100 genotypes. In 2010, NRRP sent three rice varieties for INGER evaluation through IRRI. National Wheat Research Program receives more than 1000 genotypes annually. New trials and nurseries are added to address various biotic and abiotic stresses and find high-yielding lines. Similarly, Nepal receives more than 50 potato genotypes yearly from the CIP. In the 1990s, Nepal shared wheat genetic materials, particularly Helminthosporium Leaf Blight resistant germplasm, regionally and globally through CIMMYT. Indian wheat breeders, especially those in the eastern plains have used Nepalese lines extensively in their breeding programs, and Bhutan has used Nepalese cold-tolerant rice and wheat varieties.

Crop interdependency

Of the 254 crop varieties released for general cultivation, 185 (73%) originated outside the country and 52 were from CGIAR centres (Figure 2). Although Nepal is rich in rice diversity, 68% of rice varieties originated outside the country; for wheat and potato varieties that number increases to 80%.

Twenty improved rice varieties adapted to the mid- and high hills of Nepal and released between 1967 and 2002 were analyzed regarding their ancestors and origin. A total of 47 ancestors (landraces) originating in 12 countries, mainly in Asia, were used to develop these rice cultivars. Most ancestors were from India and Taiwan followed by China and Nepal. Only four landraces, Jarneli, Jumli Marshi, Pokhreli Masino, and Ghankdruk Local from Nepal were used in developing these cultivars, although 2000 landraces have been reported to exist (Mallick, 1981). Among the ancestors, 48.94% were of the long-grained indica ecotype and 23.40% short-grained japonica; 97.87% were *Oryza sativa* species and 2.13% were *O. nivara*.

A complete pedigree tree for one common rice variety, Khumal-4, is depicted in Fig. 1. A total of 13 landraces originating in eight countries were used to develop Khumal-4, indicating the dependency on

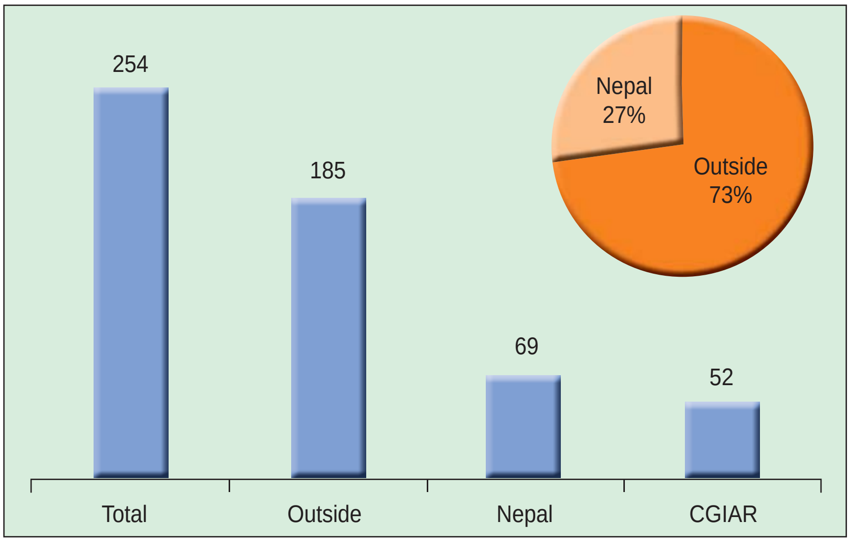

Fig. 2. Origin of crop varieties released in Nepal

foreign genetic materials. The highest proportion of genetic material comes from a landrace originating in Nepal. Two landraces originating in Malaysia and Taiwan were used in breeding Masuli, which has been the most popular variety in the last few years.

The 35 varieties of wheat released in Nepal originated in India (16 varieties), Mexico (14), Nepal, and Kenya. In Nepal four cultivars were bred and developed using foreign landraces. The genetic contribution of landraces from these countries was 25%, 25%, and 50%, respectively (Figure 3). A total of 89 ancestors from 22 countries were used to develop these cultivars (Figure 4). Most were from India followed by the United States and Kenya. Pedigree analysis of modern wheat varieties in Nepal shows that all ancestors and landraces were from other countries and international organizations, empirical evidence of Nepal's dependency on foreign PGRs for wheat research and development. Only exotic ancestors were used for developing 35 modern wheat varieties.

Only exotic parents have been used to develop the eight modern varieties of potato in Nepal. One variety was developed in Nepal using foreign landraces, but most varieties are from CIP and India. Most of the ancestors used in developing these potato varieties were from Germany. For example, 14 landraces originating in Germany were used to produce Janak Dev.

For generations, farmers have been relying on each other to conserve, use, and improve plant genetic resources (PGRs) and associated knowledge and skills

Table 1. Frequency of native and exotic parents used in developing Nepal's major crop varieties and area coverage by improved varieties

Crop	No. varieties	Native parents	Exotic parents	Area coverage, %
Rice				92
Hill set	20	4	43	
Terai set	28	1	34	
Wheat	35	0	87	97
Potato	8	0	All	85

to ensure on-farm diversity as a strategy to secure livelihoods (FAO, 2011). In addition to the unconscious actions of farmers, scientists have been making deliberate efforts to create diversity and develop biotic and abiotic stress-resistant, high-yielding varieties by manipulating genetic materials from around the world (Zeven and De Wet, 1982; Ramirez-Villegas *et al.*, 2013). No country in the world is self-sufficient in APGRs in terms of meeting domestic needs and international market demand (IPGRI, 1996; Boring, 2000).

Interdependence on PGRs at all levels, from local to global scales, is increasing and becoming more complex as a result of globalization and easier means of transportation. For example, some south and central African countries rely on external sources for over 80% of the germplasm they use (Palacios, 1998; Ramirez-Villegas *et al.*, 2013). Similarly, forage grasses originating in sub-Saharan Africa cover about 90% of all land under forage grasses worldwide (Boonman, 1993); alfalfa (*Medicago sativa*), a forage legume species, alone covers 79 million ha of land (Putnam *et al.*, 2007).

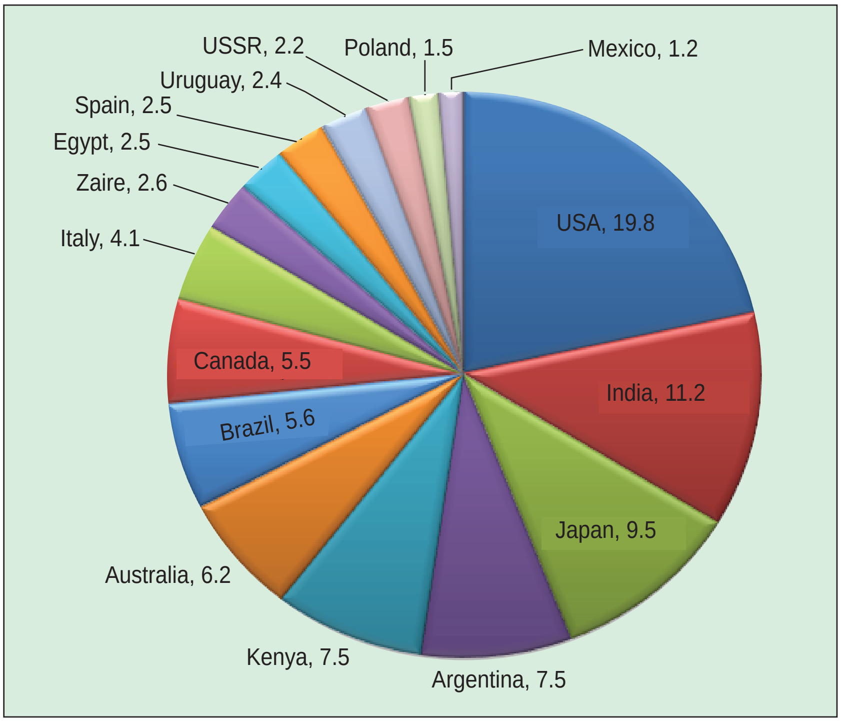

Fig. 3. Country-wise cumulative contribution of ancestors to Nepalese wheat varieties

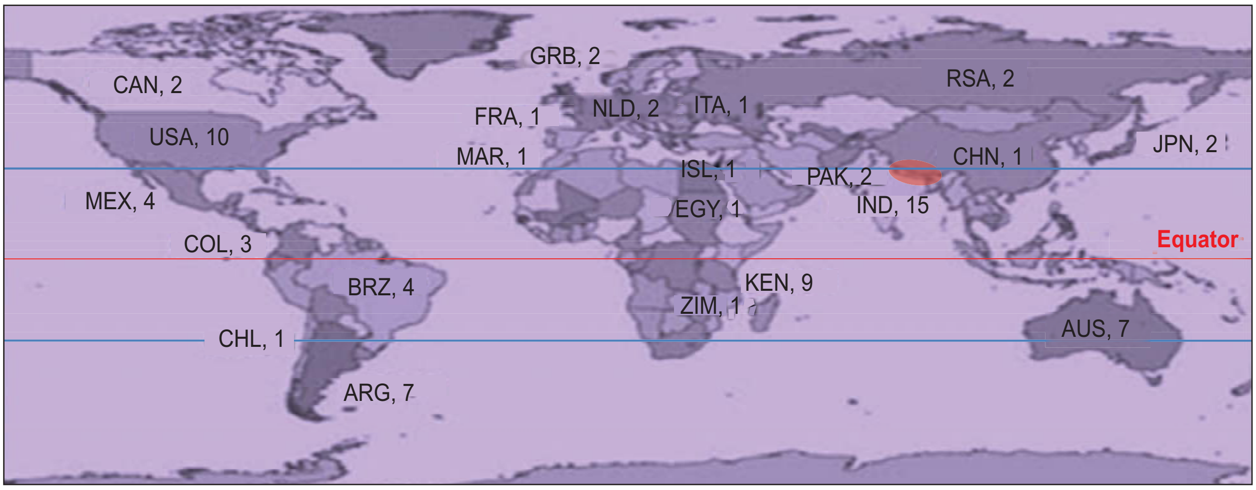

Fig. 4. Origin of ancestors of 35 modern wheat varieties released in Nepal (figure after country code is number of ancestors originated from this country and used in Nepalese wheat varieties)

Analog Sites and Climate Smart Rice Germplasm

We found a number of locations around the world that match at present, will match in future, and matched in the past the current conditions at the reference sites. Highly matching analogous sites for Begnas are found in some parts of China, and for Kachorwa such sites are found in Bihar, Jharkhand, Madhya Pradesh, and Uttar Pradesh, India. Current analogous sites for Begnas and Kachorwa in Asia are listed in Table 2. Current analogous sites for Kachorwa, Bara are depicted in Fig. 5.

The national genebank (the National Agriculture Genetic Resources Centre), an agency in the public domain, preserves more than 11 000 accessions of various crop species (1141 species of rice alone) that were once grown or are currently grown in the country. Similarly, 2839 accessions from various parts of the country have

Table 2. Locations in Asia that could be analogous to sites in Begnas and Kachorwa

Probability of matching	Analogue sites of Begnas	Analogue sites of Kachorwa
Highly likely (0.75–1)	Wucunxiang, China	Bariarpur Kuntari, Bihar, India; Tati, Jharkhand, India; Dindori, Madhya Pradesh, India and Sisotar, Uttar Pradesh, India
Moderately likely (0.5–0.75)	Gowaryo, Pakistan; Kerman and Horozygon, Iran; Hainana Sheng, China; Salavan, Laos	Shandong Sheng, China; Indus river side Pakistan; Henan Sheng, China; Vietnam; Pichaguntrahalli, Karnataka, India; Gorja, Pakistan; Kerman, Iran; Baldwyn, Saudi Arabia
Less likely (0.25–0.5)	Most of the Asian region	Most parts of Asia
Unlikely (0–0.25)	Zhejiang, China; Ayni, Tajikistan; Victoria, Sri-Lanka; Shirmine, Japan	Gifu-shi, Gifu-ken, Japan; Meghalaya Kynshi, India; Changsha Shi, Changsha Xian, China; Hasalaka Road side, Ulpathagama, Sri Lanka; Chatkal, Kyrgyzstan; and many others

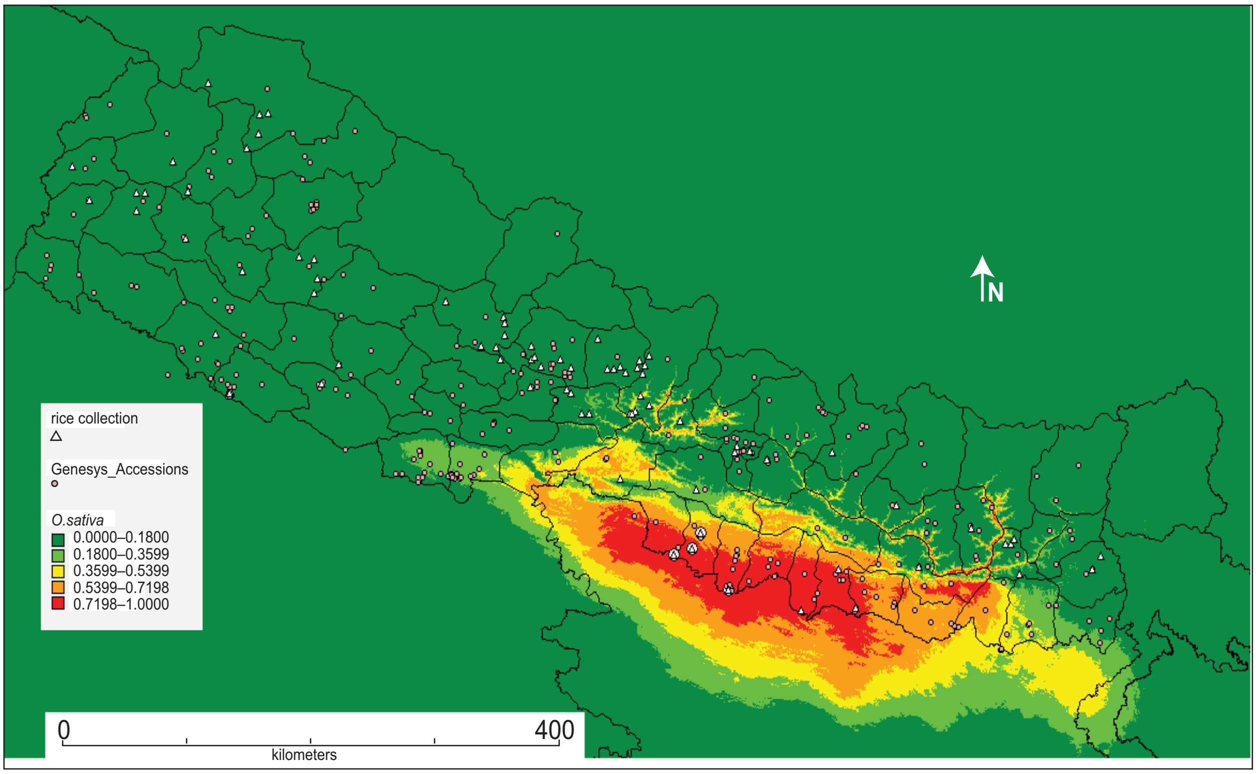

Fig. 5. Nepalese rice collection map from GeneSys database and analog sites of Kachorwa Bara, over layered for identification of rice germpalsm for analog sites

already been added to the global gene pool, mainly via the International Rice Research Institute, other CGIAR centres, and the United States Agency for International Development. A total of 100 rice accessions from the Kachorwa site can be found in Genesys and 15 in the National Agriculture Genetic Resources Centre.

Using rice as example for Begnas site, Kaski, we developed a potential flow chart to identify and/or develop climate smart rice germplasm (Fig. 6). In this process, the first step is to identify the analogue sites of Begnas using the three types of CAT relations, i.e. current-current, current-past and current-future. Potentially climate smart rice germplasm for Begnas includes germplasm found in all the analogue sites of Begnas. Potentially useful rice germplasm currently grown in analogue sites of Begnas based on the current-current analysis could be directly introduced for cultivation in Begnas. Such germplasm could also be identified in the National Genebank collection considering appropriate collection years and sites.

The concept of climate smart plant breeding is depicted in Fig. 7 based on the analog sites. With the concept of analogue sites, the breeding station and testing sites should focus on developing climate smart varieties. Based on the future climate of target site, breeder can select parental lines or landraces from analogue sites.

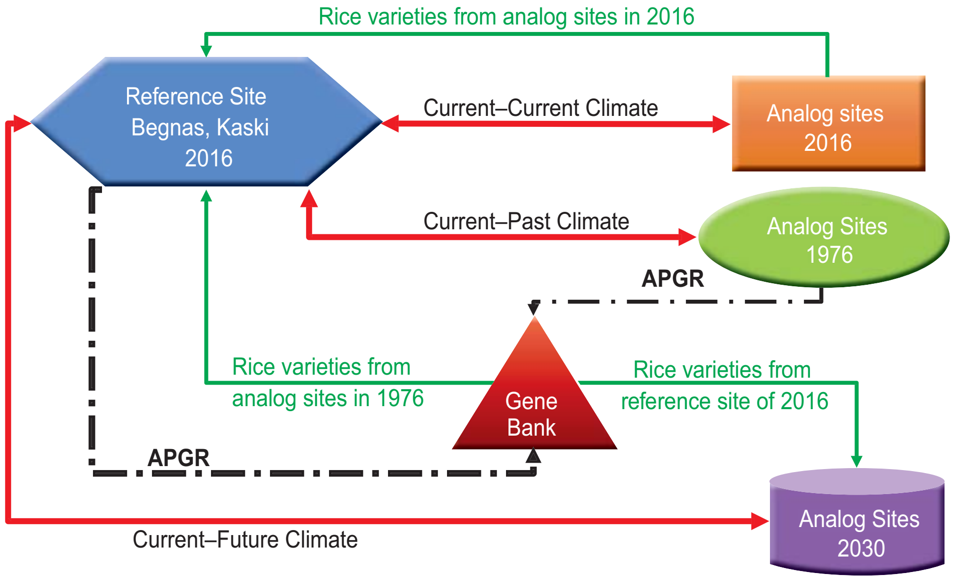

Fig. 6. Steps for identification of climate smart rice germplasm

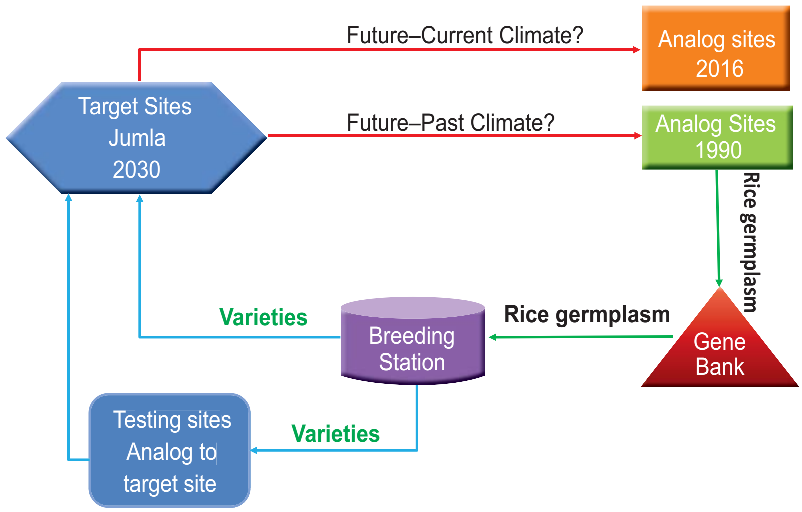

Fig. 7. Conceptual framework for climate smart plant breeding

Such landraces can directly be collected on-farm or searched for in the Genebank. After developing new genotypes, these need to be tested in similar sites of future climate of target site. Alternatively, given that genetic changes in stored materials of the Genebank are negligible and such old collections can be introduced in sites that are of similar climate as the collections sites during the time of collection.

In the future, we intend to identify more precisely which analogue sites could be used to develop location-specific strategies to adapt to climate change and build the resilience of farmers. Field-testing of novel genetic material will be the ultimate test of the utility of the CAT.

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