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Local Knowledge on Climate-induced Traits in Rice for Improving Crop Yield, Food Security and Climate Resilience

Deepak Upadhya*, Rajeev Dhakal, Kamal Khadka, Sony Rana, Pratibha Acharya, Ram Rana and Pashupati Chaudhary*
Local initiatives for Biodiversity, Research and Development (LI-BIRD), Pokhara, Nepal
Email: pchaudhary@libird.org (Corresponding Author*)

Abstract – **Farmers' knowledge in describing and distinguishing climate-induced traits and selecting niche-specific crop varieties is important for developing farmer-preferred varieties and increasing crop yield, thereby improving food security and resilience to climate change. However, there has been poor attempt to document local knowledge on climate change related traits, while local knowledge documentation in general has made significant progress in the past. Taking rice as an example, this paper attempts to document farmers' knowledge on climate-induced traits in local and modern varieties, characterize varieties against different climate stress-tolerant traits, compare farmer knowledge with scientific knowledge, and discuss its implications for improving crop yield, food security and resilience to climate change. Information was collected using a 'Functional Trait Matrix' and sources of information include Focus Group Discussions (FGD), Key Informant Surveys, direct observations, and review of secondary literature. The results revealed that farmers consider both abiotic factors (drought, cold weather, edaphic factors, water logging, lodging), and biotic factors (insect resistance, disease resistance) as climate-induced problems and have their own way of describing varietal traits, measuring strengths and weaknesses of varieties, and making informed decisions based on varietal response to those factors. Local Landraces (LRs) are found to be more resistant and tolerant against different traits than the Modern Varieties (MVs) grown, which could be largely because of long-term adaptation and evolution of LRs in the local environment. Farmers' knowledge was found similar to scientist descriptors and descriptor states used in characterizing varieties, which suggests that local and scientific knowledge can play complementary role and combination of two can give better results than one or the other. Specifically, farmers' knowledge can be used to choose local parents in breeding, especially if resource is a limitation. The tool developed in this study can be widely used globally in understanding farmer knowledge and distinguishing local and modern varieties against climate stress tolerance and making apt decision, as well as promoting conservation of agro-biodiversity on-farm for food security and long-term resilience.**

Keywords – **Resistance, Descriptors, Functional Traits.**

I. Introduction

Generation and promotion of appropriate technologies including crop varieties are necessary for increasing crop productivity and uplifting smallholder farmers from food insecurity and abject poverty. New technologies need to be relevant to farmers, replicable, robust and resource-efficient to be able to reach and benefit a large number of farmers currently deprived of benefits from new technologies. They should be adaptive to local niches in the light of climate changes and the vagaries ensued by it, as climate change is impacting agriculture worldwide, making current plants, practices and strategies inappropriate [1], [2]. Despite great achievements in science and technologies worldwide, new technologies in many cases deem inappropriate to the smallholder farmers largely in the developing countries [3]. [4], [5]. It is mainly because farmers' knowledge and interests are not adequately assessed and local adaptation criteria are not properly considered in technology development [6], [7], [8].The poor consultation of farmers lead to poor understanding among scientists of descriptors which farmers use to make appropriate decisions on adoption of new varieties and their deployment in different types of fields[9], [10], [11]. Past studies such as [12]' [13], [14], [15], [16] and [17] had been made to analyzed farmers' knowledge on climate change and suggest to combine local knowledge with scientific knowledge, but poorly consider climate change impacts on agriculture. Farmers are knowledgeable about locally grown varieties and their growing environments. They use their local knowledge for deploying different varieties to suitable environments based on crop genotypes, growing environments and social contexts [11], [18], [19]. Farmers grow both local and Modern Varieties (MVs) to meet multiple needs [19], [20] and each of the varieties receives differential preferences in different ecological niches, whereby LRs are found better adapted in environmental stress conditions as compared to MVs [21], [22], [23]. Farmers also distinguish agricultural lands and name them differently based on their characteristics on agro-ecological conditions such as soil color, texture, fertility, vegetative indicators, water retention and permeability [19], [25], [26].

Participatory approach has been emerged as a method to develop locally viable and beneficial technologies (e.g. varieties) by engaging farmers and using their knowledge and genetic resources. Participatory approaches for variety development engage farmers in the process of variety development and apply their knowledge while performing breeding activities—parent selection, crossing, selection and saving of seeds, maintenance of population, and generation advancement [27], [28], [29]. Participatory Plant Breeding (PPB) helps develop varieties aspired by farmers and allow them to select plants with traits of their interest. The approach is highly relevant in the light of climate change that demands new set of adaptive traits in new varieties, to cope with changes emanated by climate change. However, many scientists fail to document farmer descriptors and consequently poorly consider climate-induced descriptors used by farmers in their breeding programs. Even practitioners of Participatory Crop Improvement (PCI) or breeding have poorly considered climate stress traits in the past as they have mostly focused on yield, disease resistance, and post-harvest traits such as cooking quality during planning phase.

There is lack of reliable, universal and comprehensive techniques available for scientists in understanding local descriptors and combining that with scientific knowledge. Tools used in participatory approaches are often adopted or contextualized based on local situations. Common approaches are useful for practitioners of PCI while documenting local knowledge on varietal traits and devising breeding plans. Precisely, they need to assess the way farmers describe their crop varieties against climate change stress traits, the extent they resemble scientific descriptors and descriptor states and then make informed decisions.

Using a case of rice, we examine the descriptors farmers in Nepal use to distinguish rice varieties in the context of climate-related stress conditions, compare the farmers' descriptors with scientific descriptors, and discuss the relevance of combining farmer and scientific descriptors for future breeding programs. Rice is the main staple crop in Nepal and is grown in 1.56 million hectare (71% of total cultivable land) mainly in the foothills and the Terai regions[30]. The data were collected using Focus Group Discussions (FGDs) conducted in Bara (Terai) and Kaski (mid-hill) districts, which was supplemented and triangulated through Key Informant Interviews with knowledgeable farmers. Secondary information was also drawn from the documents prepared by different project in the past and published papers.

II. Methodology

2.1. Research Sites

We conducted this study in two biodiversity-rich geographic regions, the Terai and mid-hills, of Nepal, where NGOs and national agricultural research stations have been implementing various on-farm conservation related projects such as *in situ* conservation of agro biodiversity on-farm, Community-based Biodiversity Management (CBM), promotion of neglected and underutilized species, potato research, etc., since 1998. Begnas VDC of Kaski district from the mid hill and Kachorwa VDC of Bara district from the Terai were selected for a detailed study. Begnas is located in the western development regions with moderate access to advanced technologies and markets and poorly developed infrastructures due to topography. Kachorwa, on contrary, located in the central development region, has better access to advanced technologies and markets and infrastructure is better as compared to Begnas [11], [31]. Other Biophysical, socio-economic and demographic features of the project sites are given in Table 1.

Table 1: Socioeconomic, demographic and geographic condition of project sites

VDC	Begnas	Kachorwa
Total Population**	2,891	10,958
Total Household**	596	1,614
Literacy rate**	84	42.42
Altitude(m)^	668-1206	80-90
Longitude#	84°4'33.53"to 84°8'47.96" E	85°8'36.02"to 85°10' 43.04"E
Latitude#	28°8' 50.79" to 28°11'57.84"N	26°52'5.56" to 26°54'6.75"N
Type of road^	Pitched	Unmetalled (Rough)
Accessibility (km from HQ)^	16 Km	27 Km
Total Area (ha)#	2,450	840
Diversity of Paddy^	48	99 (Many revived)
Overall Development Index() *District development index position among 75 districts*	6	55

Source:
** Indicates data taken from National Population and Housing Census 2011(Village Development Committee/Municipality)
#Indicates data taken from Google earth
^ Indicates data derived from FGD and survey conducted in Jumla, Begnas and Kachorwa
() Indicates data taken from CBS

2.2. Data Collection Methods and tools

We conducted four FGDs in each research site where men and women farmers were invited to participate in the discussions held in participatory fashion. A checklist was used to systematically guide our discussions and properly record information. During FGDs, we listed the local and modern rice varieties grown in the villages and discussed on the major climate change related stresses facing the communities and agreed on the traits to be considered for the detailed analysis. The climate-stress traits were grouped into the following two categories: abiotic factors (drought, cold weather, edaphic factors, water logging, lodging), and biotic factors (insect resistance, disease resistance). Then Functional Trait Matrix was used to evaluate the varieties against climate change related functional traits. For each trait, farmers were asked to evaluate varieties and their responses were converted into 'scales' similar to 'descriptor states' used by scientists.

Key informant interviews were conducted to validate and triangulate information collected through FGD. Specifically, knowledgeable persons were interviewed to get their views and corroborate that with the results obtained through FGD. The key informants included both men and women farmers of the studied villages who are extensively involved in farming for a long period of time and thus have relatively better knowledge on local diversity and their characteristics than their fellow farmers.

We performed review of available secondary information. LI-BIRD's and NARC's project documents, reports, and publications were reviewed to gather necessary information about the sites. In addition, several other literatures were reviewed to support our findings.

2.3. Data analysis tools and techniques

We compared LRs with modern varieties against the climate-stress traits in rice growing environment. Frequency was calculated for the varieties receiving 'present' response for different climate-stress traits. Analysis was done by counting frequency for different traits farmers use and they are presented in bar graph in Figure 1 to 5. This was done separately for LRs and MVs.

III. Results

3.1. Local Varietal Diversity

The rice diversity of the study sites is presented in Table 2. A total of100 varieties were reported in Kachorwa, out of which 84 were local landraces (LRs)and 16modern varieties (MVs). In Begnas,48 varieties were recorded, of which 39 were LRs and 9were MVs. The number of LRs was about six times the number of MVs.

Table 2: Rice varieties grown in Begnas and Kachorwa grouped based on days to maturity

Districts	**Local Landraces**	**Modern Varieties**
Kachorwa (100 cutivars)	Nakhisaro, Sotwa, Raango, Sikichan, Mutmur, Gajargaul, Dhudisaro, Saathi Kalo, Bagadi, Bhelsaro, Jharlajhi, Kataush, Lalka Basmati, Kariya Kamoudh, Ramani, Barambhushi, Ujarka Basmati, Baharni, Maalbhog, Ramjawain, Ghiukumar, Laajhi, Balmasar, Mahajogani, Bhathii, Jagarnathiya, Silhot, Laltager, Rajala, Madhumala, Karma, Dhudhraaj, Chatraaj, Harinker, Mansaara, Aamadhauj, Parewapwakh seto, Parewapwakh Kalo, Kheraha seto, Kheraha Kalo, Aanga, Pakhar, Rata gola 1, Lalka Jesaria, Batsar, Budhidain 1, Bangaliya, Bhadsar, Anadi, Kanhar, Jagadh, Sakhar, Bidhi, Guthni Saro, Gokulchan, Rato Tude, Seto Basmati, Kalo Nuniya, Basmati Jhapa, Nimoi, Kankirabi, Gahuma, Rato Anadi, Kesharbachhi, Chanachur, Kalo Tulasi, Belguthi, Pakhanyauli, Malathheate, Chiure, Kastauri, Kusumkali, Nyauri, Rato Tude, Dhusara, Ratin, Kajha, Seto Dalle, Dhunmunia Seto, Devsar, Budhhidain 3, Anajana, Karangi and Seto Sathi **(N= 84)**	Sabitri, Sona Mansuli, Rajindra, Hardinath 1, Sayug 52, Katarni Bhadaiya, Parbhat, Kachorwa 4, Hiramoti, Jaya, Ramdhan, Sawa Mansuli, Sunaulo Suganda, Barkhe 2014, Chaite 4 and Chandhan. **(N= 16)**
Begnas (48 cultivars)	Ekle, Thulo Gurdi, Lahare Gurdi, Biramphool, Mansara, Anadi Rato, Anadi Seto, Jhinuwa, Bayerni, Aanga, Pakhe Mansuli, Kathe Gurdi, Thulo Madhese, Sano Madhese, Seto Gurdi, Mansara, Jethobudho, Pahele, Laame, Paakhe Jarneli, Dhabe Jarneli, Jhauri, Jyaudi Khole, Mala, Koili, Jhinuwa, Madrasi, Naal Tumme, Nabho, Mansara 3, Mansara 4, Mana Muri, Kana Jeera Jhinuwa, chobo, Neute, Dhabe Gauriya, Biramphool 3, Biramphool 6, Samundrafij **(N= 39)**	Radha 9, Sano Mansuli, Thulo Mansuli, Radha 7, Makwanpure, Sabitri, Malaysia, CH-45, Chiniya **(N= 9)**

3.2. Farmers' Descriptors used to Distinguish Rice Varieties

Farmers were found to have been using their own descriptors to evaluate rice varieties. Generally, farmers have practice of grouping functional traits into three categories: high, medium and low except for some traits like cold tolerance.

3.2.1. Response to Drought

It was found that drought is one of the important factors that limit the rice productivity. Farmers in Kachorwa indicated a variety as a highly drought tolerant variety if it has very thick shoot for storing more water; very long roots up to about 25 cm (later converted from local measurement units such as 'bitta' meaning the distance between tips of thumb and baby fingers when they are stretched against each other, and 'haat' meaning length from elbow to the tip of middle finger) which can extract water from lower profile of soil; and the variety which can withstand longer drought without compromising yield. Moderately tolerant varieties are those which have thick shoots and long roots are up to 20 cm length; can withstand short drought period but there is some decline in yield when there is prolonged drought. The varieties that have very thin stem and shorter roots ranging from 10-15 cm and, experience leaf rolled and yield loss in case of prolonged drought are regarded as drought susceptible varieties. Farmers in Begnas have used different criteria to categorize rice varieties as tolerant and no to slight tolerant (Table 3). According to the farmers, early varieties are usually drought tolerant and these varieties can bear short drought period, without significant decrease in crop yield.On contrary, varieties susceptible to drought require continuous supply of irrigation water and there is large reduction on yield if there is any drought period.

3.2.2. Response to Cold

Kachorwahas sub-tropical climate and it was found that farmers did not consider cold tolerance in rice an important trait as they grow rice in the monsoon season. Farmers in Begnas reported a few cases of spiklet sterility and incidence of disease in rice varieties under severe cold environment. They classified rice varieties into two groups: cold resistant and cold susceptible varieties.

3.2.3. Response to Soil Conditions

Farmers observed that normal growth and performance of rice varieties varies with various abiotic factors and soil fertility is one of those. Farmers consider soil fertility as one of the most important yield attributing factors. Based on the performance of the varieties in the diverse types of soil including less fertile soil, farmers have grouped rice varieties accordingly into three types: higher, medium and poor performers. Varieties which perform satisfactory in very marginal and poor soil conditions and adaptive to a variety of soil conditions (loam, clay and sand) were regarded as best/better performer varieties. Similarly, moderate performer varieties exhibit satisfactory performance in less and fertile soil fertility conditions and in loam and clay type of soil. The farmers have less regard to those varieties which perform better only in the good soil and highly fertile conditions.

Table 3: Descriptors related to Climatic Factors

S.N.	Traits	Descriptor states	Farmers' depiction of the descriptor (Kachorwa)	Farmers' depiction of the descriptor (Begnas)
1	Response to drought conditions	Highly tolerant	• Very thick shoots; very long roots up to 25 cm and can withstand longer drought	NA
		Moderately tolerant	• Thick shoots; long roots are up to 20 cm and can withstand short drought period	• Early maturing varieties
		Poorly tolerant/susceptible	• Thin stem and shorter roots ranging from 10-15 cm and, experience leaf rolled and yield loss.	• Late maturing varieties • Require continuous supply of irrigation water
2	Response to cold conditions	Resistant	NA	• No sterility and disease problems.
		Not resistant	NA	• Sterility and disease incidence is high.
4	Response to soil conditions	Highly responsive	• Performs well in very marginal and poor soil conditions.	• Can perform well in very infertile soil conditions.
		Moderately responsive	• Perform satisfactory in loam soil followed by clay soil but not in sandy soil.	• Can perform satisfactory in less fertile and also in fertile soil conditions.
		Poorly responsive	• Can perform well only in loam (Domat) soil	• Can perform well in fertile soil.
5	Response to water logged conditions	Highly tolerant	• Can tolerate knee height submergence for longer duration.	• Can tolerate water up to 4-5 inch for some days
		Moderately tolerant	• Tolerate water up to ankle height for long time.	• Tolerate water up to 2-3 inch for some days only.
		Not tolerant	• Cannot withstand water logged condition even for short duration	• Cannot withstand water logged condition even for short duration
6	Lodging	No lodging	• Dwarf and have thick and strong stem.	• Dwarf in stature and have hard and strong stem.
		Moderate lodging	• Tall but have thick and strong stem.	• Tall but stem are hard and strong which resist lodging under normal condition.
		High lodging	• Very tall (e.g. Bhatti, Silhat) and have thin stem (e.g. Basmati)	• Quit tall, and have thin and weak stem; and are not suitable for growing in fertile soil conditions.

Note: NA indicates not available

3.2.4. Response to Water Logged Conditions

Water logging is the state when the ground water level becomes too high affecting the agricultural activities due to poor drainage and eventually reducing crop yield and increasing infection of insect and disease pests. Farmers' grouped response to water logged conditions into three types: highly tolerant, moderately tolerant and susceptible to highly susceptible to waterlogged conditions. Kachorwa farmers regarded the varieties that can tolerate knee height level logged water after 30-35 days of transplanting for around 25-30 days as highly tolerant varieties to water logged conditions. Similarly, moderately tolerant varieties can tolerate ankle height water for about 15-25 days. Farmers demarked susceptible varieties for those which cannot withstand water logged conditions even for 4-5 days. Furthermore, farmers stated that these kinds of varieties perform well under normal irrigated system. Begnas farmers mentioned that varieties surviving in water level of 4-5 inches for about 25-30 days were highly tolerant varieties to the waterlogged conditions. Similarly, moderately tolerant varieties can tolerate water up to 2-3 inches for about 15-25 days. The definition of susceptible rice varieties by the famers of Begnas matches with the definition of the farmers of Kachorwa.

3.2.5. Response to Lodging

Farmers categorized rice varieties into three groups based on the performance of the varieties they have observed: highly, moderately and susceptible based on response to lodging. According to the farmers the dwarf statured varieties with hard and strong stem are the characteristics of highly lodging tolerant varieties. Conversely, susceptible varieties are usually tall with thin and weak stem. Farmers in both the study sites describe these traits in similar fashion.

3.2.6. *Response to Insect Infestation*

Among the three types of responses on insect infestation, Kachorwa farmers categorized the varieties into highly tolerant varieties for those varieties which possess hard grains with long awns, thick and hard stalks, large and wide leaves, panicle enclosed in leaf sheath and the performance of these varieties is excellent in normal weather and soil conditions. According to the farmers' classification, moderately tolerant varieties have hard and thick stem, hard grains and large leaves; and there is less infestation in normal weather conditions. However, those varieties which are infested by insects even in normal situations are regarded as susceptible varieties. Farmers in Kachorwa defined the highly disease tolerant as the varieties in which there is no any loss in yield even if there is some disease in the unfavorable environments. Similarly in the moderately disease tolerant varieties, there is some loss in yield but it is not significant. Further, susceptible varieties get diseases even in the normal weather conditions and there is significant loss in the yield of the crop. The response of the farmers of Begnas was similar to that of farmers in Kachorwa for insect severity. But they expressed that Bugs, shoot borers, grass hoppers, leaf rollers, mealy bug, stem borer are common problems in susceptible varieties. In general farmers have observed fine and aromatic varieties more affected by diseases and insects compared to non-aromatic varieties.

3.2.7. *Response to Disease Infestation*

In both the study sites farmers regarded disease as one of the major factors limiting the rice yield. The farmers have noticed the incidence of Blast, Bacterial blight, Sheath blight and false smut in rice field. Realizing the significant impact of diseases on rice yield, farmers in both the study sites have grouped response of rice varieties to disease severity into: highly, moderately and poorly tolerant.

Farmers have defined unfavorable weather conditions in terms of rainfall pattern or interval of rainfall. More precisely, disease infestation on highly tolerant varieties is very low even if rainfall doesn't occurs for about a month before flowering stage. Farmers have observed incidence of fungal diseases is less in highly tolerant varieties in both normal and unfavorable weather conditions. Similarly, moderately tolerant varieties are those, which are slightly affected by diseases if there is unfavorable weather condition for about 15-20 days. Incidence of fungal diseases and seed blight is common among susceptible varieties even in normal weather and normal soil conditions. The adaptive characters of tolerant varieties in Begnas site were found to be similar to that of Kachorwa site. Additionally, Begnas farmers reported that, LRs fall under tolerant category. They also indicated that early varieties are more susceptible than late varieties because critical stages of early maturing varieties coincide with disease conducive period.

Table 4: Descriptors related to biotic factors

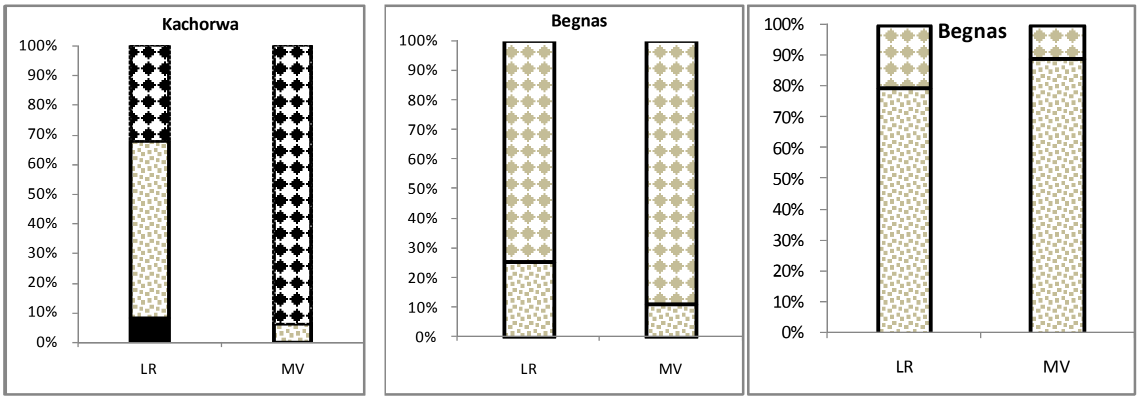
S.N.	Traits	Descriptor classes/states?	Farmers' depiction of the descriptor (Kachorwa)	Farmers' depiction of the descriptor (Begnas)
2	Response to insect infestation	Highly tolerant	• Hard grains with long awns; thick and hard stalks; large and wide leaves	• Thick stem, hard grains and medium or poor in eating quality.
		Moderately tolerant	• Hard and thick stem, hard grains and large leaves.	• Thick stem, thick pericarp and occasional insect pest infestation.
		Not/slightly resistant	• The grains have thin and very soft outer cover.	• The grains have thin and very soft outer cover.
3	Response to disease infestation	Highly resistant	• Low incidence of diseases even in prolonged disease conducive conditions (upto one month)	• Low incidence of diseases even in prolonged disease conducive conditions
		Moderately resistant	• Slightly affected by diseases if there is unfavorable weather for about 15-20 days	• Disease incidence occurs only in disease conducive conditions.
		Not/Slightly resistant	• Incidence of fungal diseases is more even in normal weather and soil conditions.	• There is heavy infestation of rust, blight and wilting even in normal weather conditions.

3.3. *Varietal Characteristics using Farmers' Descriptors*

We grouped the rice cultivars into different groups based on their response to drought, cold, insect-pest and disease infestation according to the respondents. About 60 percent of LRs in Kachorwa were categorized under moderately tolerant to drought conditions and about 30 percent of the varieties highly susceptible to drought. A few varieties were also categorized under highly drought tolerant. However, in case or the MVs only 8 % were regarded as moderately tolerant to drought. Similarly, in Begnas, nearly 25 percent of LRs and 10 percent of MVs were recorded moderately tolerant to drought (Fig. 1).

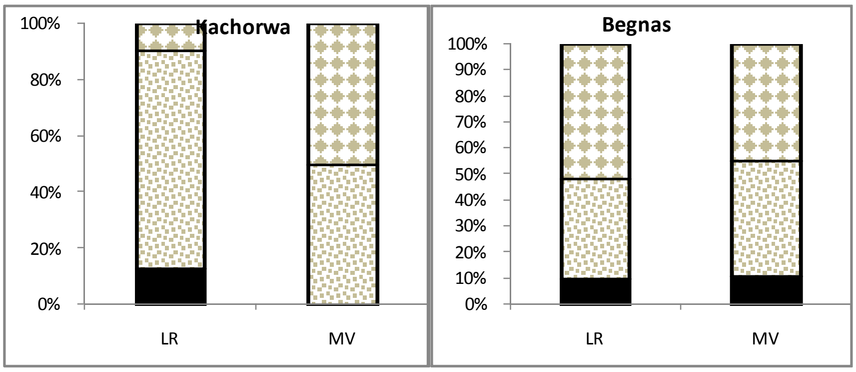
According to the farmers in Begnas, it was found that both LRs and MVs have potential to adapt to cold weather. About 80 percent of the LRs and about 90 percent of the MVs were recorded as cold tolerant varieties. In terms of numbers, 31 out of 39 LRs and 8 out of 9 MVs were reported to be cold tolerant. Further, farmers shared these varieties have maintained tolerance to cold conditions due to long and continuous exposure and adaptation to local conditions.

The result also showed that the majority (>75%) of LRs give medium yield under marginal soil environments in Kachorwa. According to the farmers there are more than 5 percent LRs that yield higher in the low fertility condition. Among the improved varieties 50 percent give medium level of performance under marginal soils while the rest of the varieties do not perform well in poor fertility conditions.



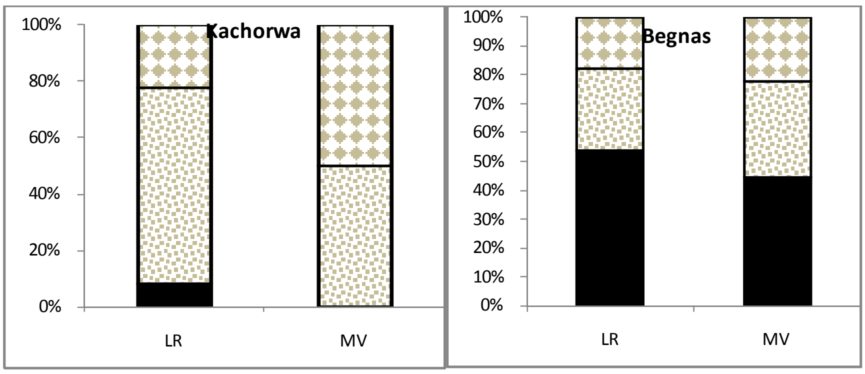
A B C

Fig. 1. Proportion of rice varieties based on drought tolerance (A & B) and cold tolerance (C). Legend: Black/dark (Highly tolerant), dotted (moderately tolerant) and diamond (no or slightly tolerant)



A B

Fig. 2. Proportion of rice varieties based on the descriptors related to the soil and crop performance



C D

Fig. 3. Proportion of rice varieties based on the descriptors related to the performance of the rice varieties under waterlogged conditions (Black = Highly tolerant; dotted = moderately tolerant, and diamond = poorly tolerant)

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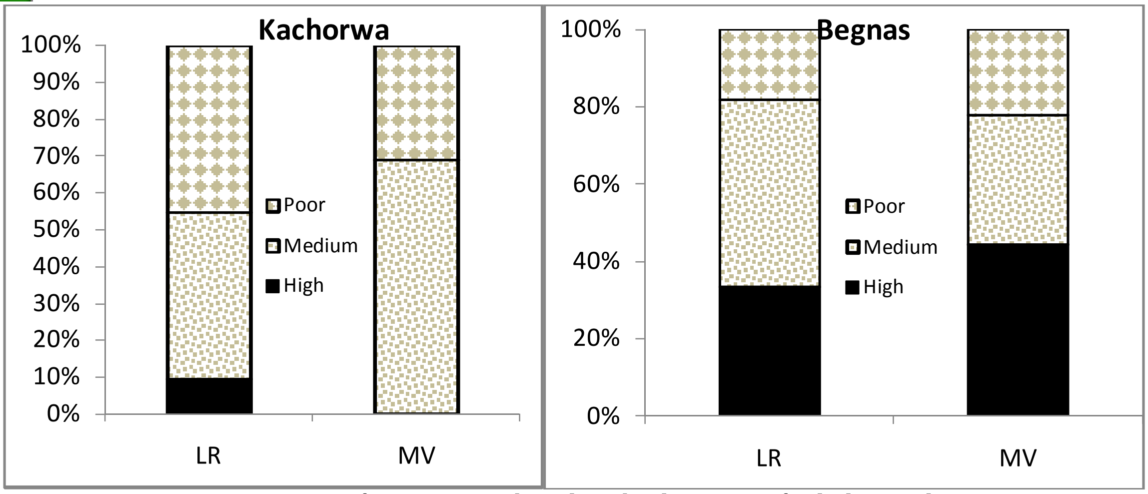
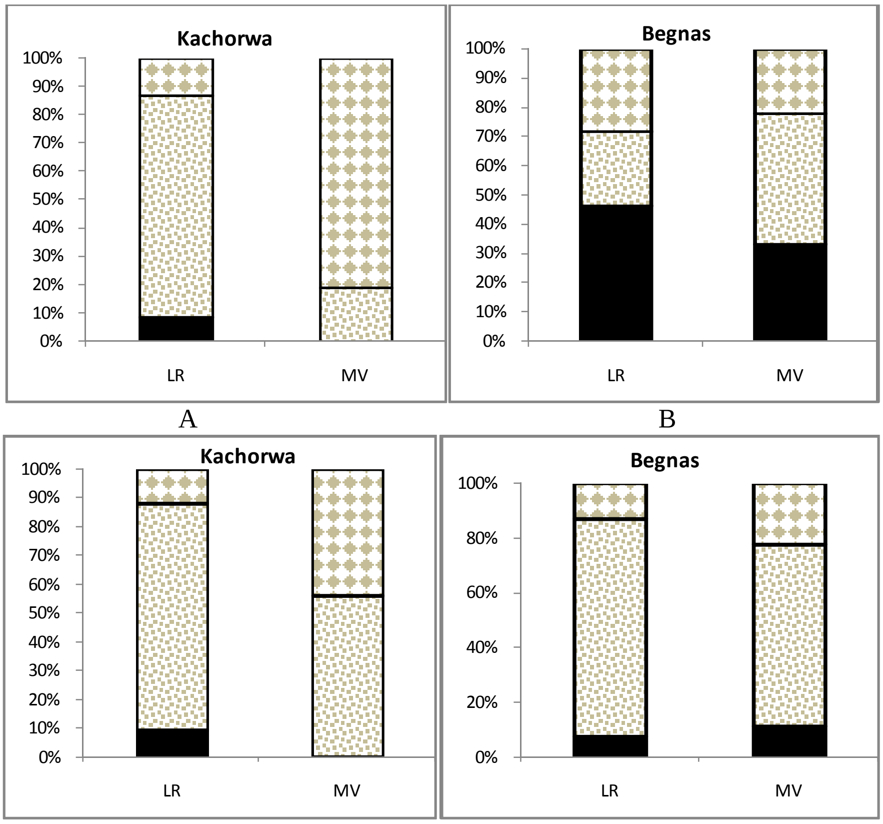


Fig. 4. Proportion of rice varieties based on the descriptors for lodging tolerance



C D

Fig. 5. Proportion of rice varieties based on the descriptors for insect pest (A & B) and disease resistance (C & D).
Legend: Black (Highly tolerant), dotted (moderately tolerant) and diamond (no or slightly tolerant).

About 65 percent of LRs in Kachorwa give medium yield in water-logged conditions while 25 percent of them are highly susceptible to water logging. The remaining 10 percent can withstand waterlogging without reduction in the yield. In Begnas, more than 50 percent LRs and more than 40 percent of MVs are highly tolerant to water logging conditions. Similarly, almost 30 percent of the LRs and MVs can withstand some level of water logging.

Results shows that around 10% of LRs in Kachorwa have no lodging problem while no single modern varieties were reported with such traits. However, in totality, higher proportion of MVs showed tolerance to lodging as compared to LRs. In Begnas, more than 40 percent MVs and 30 percent of LRs were reported to have non-lodging behavior.

Farmers in Kachorwa grouped 90% of the LRs under highly to moderately resistant to insect infestation while only about 18% of MVs are moderately tolerant. Similarly, in Begnas about 45% of LRs and about 30% of MVs are highly resistant to insects.

Farmers' perception on the disease tolerance showed that slightly more than 10 percent of LRs in Kachorwa are highly resistance to different diseases while almost 80% of the LRs have medium level of tolerance to diseases. In case of the MVs about 50% are moderately resistance and the rest are susceptible. Similarly, the results also showed that in Begnas, approximately 90 percent of LRs and 80 percent of MVs are highly and moderately resistance to various diseases respectively.

IV. DISCUSSION

The findings revealed that farmers use their own method to describe the climate stress related traits and evaluate their rice varieties using those traits in both of the research sites. Generally, farmers have a practice of grouping functional traits into different qualitative traits and farmers' methods of describing crops corroborate the modern varieties. These traits are systematically described below.

4.1. Response to Drought

Drought is a complex trait to measure, but its impacts are widely studied. Drought directly or indirectly affects crop production by changing the amount of sugar production [32], [33] mainly in stem, which is essential for rice plants to offset water loss [34]. Drought changes morphology and leaf area development [35], [36] and plants at different development stages—early stage physiology, phenology, grain formation, and eventually yield have different levels of sensitivity to drought[37], [38], [39]. Thus, farmers use their own methods to group the varieties they grow into different categories to make a distinction among the varieties. Farmers from both the study sites categorized the response of rice varieties to drought conditions into three groups viz. highly tolerant, moderately tolerant and no or poorly tolerant (susceptible) and this was found to be coherent with the findings of [40] who reported rice varieties, based on their responses to drought, could be classified into highly resistant, moderately resistant and sensitive.

Farrmers' knowledge does not completely differ from the scientific knowledge scientific verification but should be done with caution to ensure farmer knowledge are appropriately interpreted. Farmers' understandings are very critical in decision-making, especially while making the selection of the varieties, mainly in the regions like Nepal with poor access to government's extension system[41], [42], [43], [44]. Farmers in Kachorwa reported that varieties having very thick shoot and very long roots can withstand longer drought conditions. In fact, various studies like [45] and [46] showed that deep, long and thick root systems are the important traits for drought tolerance in rice varieties. IRRI has also been putting efforts to develop drought tolerant varieties with 'deep and thick' roots. Farmers' experiences showed that the early varieties are usually drought tolerant and these varieties can bear short drought period, without losing crop yield. This result matched with the findings of [47], which revealed that early to medium maturing varieties have a better chance of escaping the late season drought. In an experiment with upland rice varieties, researchers concluded that early flowering germplasms have advantages over late flowering in terms of higher spikelet fertility, higher harvest index, and higher yield [48].

The results show that major proportion of LRs in both research sites was found to be highly to moderately tolerant to drought conditions whereas, none of the MVs were reported as highly tolerant. This could be because of the reason that the modern varieties were mostly bred under better management and are likely to perform poorly in the stress environments despite research on stress tolerance initiated in the recent few years [49], [50]. [51]. Also [21], [22] and [23] reported that different LRs were more tolerant to drought and resilient to wide range to environmental stresses. [52] observed that yield performance of LRs are satisfactory even in water stress conditions due to their stress tolerance capacity. Similarly, [53] reported that rice landraces, *Katush and Guthinisaro*, are being cultivated by farmers in drought-prone and rainfed areas of Jhapa and Kailali, Nepal due to its inherent drought tolerant ability.

4.2. Response to Cold Conditions

In Nepal, spikelet sterility in rice due to chilling injuries is common in high altitude areas [54]. According to [55], only few of the released varieties have been adopted by farmers and other many of the released varieties are not in cultivation. Kachorwa has sub-tropical climate with mean monthly temperature ranging from29-32^{0}C [56]during rice growing seasons and farmers did not report any issues related to cold stress. But farmers in Begnas reported spikelet sterility and incidence of diseases in rice varieties under severe cold environment on the higher elevations. Some of internationally popular lines were found to be cold tolerant only during vegetative growth with failure of grain production due to incomplete panicle exertion or spikelet sterility. The sterility problem in cold tolerant varieties corrobo rates with [57]. They have found that yield of susceptible rice varieties goes down under long cold water irrigation. It has also been reported that during the cold stress at critical time of reproduction, rice plants may fail to produce grains due to failure in formation of fertile pollen[58].

The results from Begnas clearly indicate that both LRs and MVs have more diversity of rice for cold tolerance with proportionately higher diversity of cold tolerant varieties in LRs.[59] reported variation for chilling injuries in indigenous rice varieties and concluded indigenous varieties were likely to be more adaptive to the particular environment conditions predominately to temperature conditions in the respective areas as compared to MVs. Furthermore, they also explicated that high altitudes areas are abundant with important genetic resources for tolerance to chilling injuries.

4.3. Response to Soil Fertility Conditions

"Soil fertility is a component of overall soil productivity which deals with nutrient status available and its ability to provide nutrients out of its own reserves and through external applications for crop production. It combines several soil properties (biological, chemical and physical), all of which affect directly or indirectly nutrient dynamics and availability [60] EI-Ramady 2014)."

Despite of the scientific knowledge, farmers, in both the sites, classified soil into loam, clay and sandy soil. According to these types of soils, they also classified the rice cultivars as poor performer, medium performer and high/good performer. [61]conducted similar research and concluded that farmers classify soil as clay, loam and sandy, and preference of farmers was loamy soil to sandy soil. Similar findings were reported by [62]. Generally, black loamy and clay soil are reported to have high fertility than soils with other colors (like red, yellow and white). Likewise, according to some others [63],[64],[65], soil physical properties closely correlate with farmers' soil evaluation. [11]also document farmers' knowledge on agroecology and soil properties and their decisions in deploying different varieties in accordance with agroecological conditions.

Local farmers experience that the majority of LRs in the study sites yield medium to high in all type of soils, while modern varieties yield poorer under medium to poor soil conditions. [66]reported similar results concluding that modern varieties have high yielding potential in well-irrigated and fertile lands. In contrary, local landraces are even good yielders in areas with modest fertility. Despite the fact that LRs are low yielding, farmers grow such landraces because of their potentialities to perform in low fertility and higher tolerance to adverse conditions than modern varieties whose production hinges on chemical fertilizers [67].

4.4. Response to Water Logging

As we know especially in rainfed low land areas water logging and flooding are the major constraints for rice production. The depth and duration on the rice field varies mainly due to erratic rainfall patterns and poor drainage of rice field [68]. For the convenience, farmers classified the varieties into three types with regards to the response of the varieties to the state of water logging; i.e. level and duration of water stagnation in the field, viz highly tolerant, moderately tolerant and susceptible. Similar, classification was reported by [69] who grouped flooding into four types mainly based upon plant traits and varietal types that are adapted to conditions; flooding during germination, flash flooding (sub-mergence), stagnant flooding (medium or semi deep) and deeper stagnant flooding (deep water or floating rice). Moreover, this type of classification based upon duration and depth of water logging conditions are in accordance with the farmer perception in both the study sites.

The results indicate that higher proportion of LRs were moderate to higher performer even at different level of water logged conditions as compared to MVs. Similar findings was observed by some researchers[70],[71] and [72] who reported that MVs, despite high yielding traits, perform poorly at water logged conditions. They added that due to faster elongation and early nodal differentiation, LRs have wider adaptability to stress caused by waterlogging.

4.5. Response to Lodging

Based upon the plant characters, farmers in both sites grouped different cultivars into non-lodging, moderately lodging and highly lodging. Dwarf varieties with thick and strong stem were grouped under non-lodging whereas highly lodging varieties were found to be taller and with thin stem. [73] Also reported that semi-tall varieties with stiff stem/hills are less susceptible to lodging than tall varieties. [74], [75], [76] and[77] reported that apart from plant height culm strength is the determining factor for lodging tolerance where varieties with weak culms are found to be more prone to lodging than varieties with strong culms.

According to farmers of Kachorwa, only small portion of LRs were non-lodging and none of the MVs present were non-lodging. These landraces showed non-lodging behavior because they are evolved through adaptation to local conditions over longer continuum, whereas, in Begnas, proportion of non-lodging MVs were higher than non-lodging LRs. [78]reported that MVs are more tolerant to lodging than LRs which was in contrary with the results for Kachorwa and in accordance with the results for Begnas.

4.6. Response on Insect Infestation

IRRI developed different scales, 0 to 9, for scoring the level of damage caused by insects and simultaneously grouped into immune, satisfactory, acceptable and unsatisfactory [79]. These categorizations are mainly done on the basis of severity of insect damage. In both of the cases in our study, farmers have distinguished response of insect infestation into highly tolerant, moderately tolerant, and susceptible depending upon the plant characters. Moreover, in both of the research sites, farmers are clear on the plant characters responsible for making it tolerant to insect damage. The findings of this study also resemble the earlier studies where scientists have classified insect tolerance into broad spectrum of highly tolerant, moderately tolerant, and susceptible (REF). [80]classified insect resistance status of Nerica rice varieties into four groups: moderately resistance, moderately susceptible, moderately susceptible and highly susceptible, on the basis of level of termite attack.

Hard grains, long awn, thick and hard stalks, enclosed panicle in leaf sheath (found in certain cultivars only), and large leaves were considered as distinctive characters for insect tolerance by the farmers of the study sites. The results of this study corroborate the results of [81]that suggests hard grains, long awns, hard stalks and panicle enclosed in leaf sheath are the important traits for insect tolerance. References [82], [83] and [84] concluded that rice varietals tolerance to insect infestation is directly correlated with grain tightness. However, the results of [81] and[85] stated that tall varieties with long and wide leaves and large stem are generally susceptible to insect. Farmers in Begnas link aromatic varieties with higher susceptibility to insects compared to the non-aromatic, which is consistent with a present finding by [86]. References [87] and[88] reported that aromatic varieties are generally tall and late maturing and thus more prone to insect attack.

In both the study sites the number of LRs with distinct characters for insect tolerance are more compared to the number of MVs with such traits. [89] assessed factors behind production variability of modern varieties and reported insect severity as one of the important causes. Further, they have stated that MVs are resistance to only specific insect pest for which they were screened and they lack resistance to wide spectra of pest tolerance as compared to LRs. [90] observed that a large number of insect pest attack high yielding modern varieties thereby causing severe loss in crop yield while [91] compared the level of insect damage on exotic and LRs and found more severe infestation in exotic varieties as compared to LRs.

4.7. Response to Disease Infestation

The scientific classification of the varieties based on the disease reaction varies with the type of disease. However, the broad classification as resistant, moderately resistant, susceptible or tolerant is similar to that of farmers' classification. Farmers' usually do not have broader knowledge on specific diseases but they observe the disease infestation as a whole considering the visual damage or any symptoms shown by the disease.

Farmers' believed that aromatic varieties are more vulnerable to disease and this is fully supported by earlier studies. Blast and Bacterial Blight and Baknae are very serious diseases of aromatic rice varieties [92]. Aromatic rice varieties are usually tall and late in maturity [87] while [93] also showed that the aromatic rice varieties have longer maturity, dense canopy and are more prone to a number of diseases.

V. Conclusions

Historically farmers have been using their local knowledge on the management and conservation of agricultural diversity on-farm and its utilization for their livelihoods. Through years of experience, farmers are making decisions, especially in identifying desired functional traits, making varietal choice and adopting varieties, by using their own traditional knowledge or expertise. Such long-evolved local knowledge, when combined with scientific knowledge, is useful for agricultural research and breeding, especially in choosing parents or identifying traits that need to be improved, retained or removed. This study clearly revealed that farmers in the study sites have rich experiences and they use their own criteria in distinguishing crop varieties against various climate stress related traits. LRs are found to be more resistant and tolerant against different traits than the MVs grown, which could be largely because of long-term adaptation and evolution of LRs in the local environment. Thus some of LRs can be used as parents in resistant breeding, while some other LRs could be improved through selection in stress conditions depending upon farmers' preferences. It is also prudent to preserve highly resilient varieties in the national gene bank and community seed banks if they are also vulnerable to erosion.

Despite several varieties with desired stress tolerant functional traits, scientific community is deprived of such information, which ultimately is leading to loss of valuable genetic resources from the farming system. It is necessity to incorporate farmers' varieties into the scientific research system so as to control overwhelming genetic loss and this kind of study can serve the first step towards that goal. Functional Trait Matrix research tool can be replicated or adopted globally, mainly in the developing countries with diverse land type and high diversity of local varieties and the countries posing a threat to climate change. This kind of study will help conservationists plan *in situ* conservation work since it helps identify high quality varieties in terms of climate change resilience. Further it helps compare varieties against biotic and climate factors and choose highly adaptable varieties and varietal traits for breeding, in order to improve crop yield and food security.

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