

## Adaptability of Naked Barley Landraces in Mountain Agro-ecosystem of Nepal

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### ABSTRACT

Naked barley (*Hordeum vulgare* var. *nudum* L.) is an important food crop in mountain regions of Nepal, however, its production area and genetic diversity is known to be shrinking fast. One of the reasons could be the poor productivity. To improve the productivity of crops, it is essential that new site-specific, high-yielding and widely adopted varietal options for farmers should be developed for sustainability. To identify the varietal responses to environment, multi-location testing is one of the main tools. Following this, we evaluated agronomic performance of eight naked barley landraces collected from five different locations of Nepal with altitude ranging from 1370 to 2500 meter elevations from the sea level during the winter season of 2014/15 in order to assess the landraces adaptability across different locations. Combined analysis of variances revealed that NGRC02306, NGRC04902 and NGRC04894 were the high yielding landraces. The landrace namely NGRC04894 was found the most stable genotype with better adaptability to all tested environments whereas NGRC02306 and NGRC04902 were high yielding landraces adapted to high yielding environment namely Khumaltar. However, the lower yielding landrace NGRC02327 was the earliest and could be preferred by farmers as its maturity allows it to fit better in the rice based cropping system. Our study showed that these landraces need to be verified further in farmers' fields and the release of one or more of them would help to diversify the genetic base of naked barley varieties in the seed supply system.

**Keywords:** Adaptability, GxE interaction, landrace, naked barley, stable genotype

### सारांश

उवा नेपालको हिमाली भेगको एक महत्वपूर्ण खाद्यान्न बाली हो तर यसको उत्पादन क्षेत्रफल र आनुवंशिक विविधता द्रुततर गतिमा घट्दो छ, जसको प्रमुख कारण न्यून उत्पादकत्व नै हो। उत्पादकत्वमा सुधारको निमित्त धेरै फल्ले, छिटो पाक्ने, स्थान विशेष र धेरै ठाउँहरूमा खेती गर्न सकिने जातहरू छनोट गरी कृषकहरूलाई वैकल्पिक जातहरू उपलब्ध गराउनु अत्यन्त जरुरी हुन्छ। विविध जातहरूको विभिन्न हावापानीमा हुने अन्तरकृया थाह पाउन बहुस्थलीय परिक्षणहरू उपयुक्त माध्यम हुन्छन्। आठवटा जातहरू समावेश गरी वि.सं. २०७१ सालको हिउँदमा उच्च पहाडी तथा हिमाली भेगका समुन्द्र सतहबाट १३७० देखि २५०० मिटरसम्म उचाइका पाँच स्थानहरूमा उवाको जातीय परिक्षणहरू संचालन गरिएको थियो। परिक्षणको नतिजाले NGRC02306, NGRC04902 र NGRC04894 ले धेरै उत्पादन दिएको देखायो। तर उत्पादन कम भए तापनि अरुभन्दा छिटो पाक्ने र धान बालीमा आधारित बाली प्रणालीमा सुहाउँदो भएकोले NGRC02327 लाई कृषकहरूले धेरै मन पराउन सक्ने देखिन्छ। परिक्षण गरिएका जातहरू र वातावरण (स्थानहरू) बीचमा उच्च अन्तरक्रिया देखिएकोले स्थान विशेषको लागि छुट्टाछुट्टै जातहरू छनोट गर्नुपर्ने देखिन्छ। स्थानको औसत र जातको औसतलाई विश्लेषण गर्दा NGRC04894 सबै स्थानमा राम्रो गरेकोले सबैभन्दा स्थिर जात देखिएको छ भने NGRC02306 र NGRC04902 चाहिँ खुमलटार जस्तो राम्रो र धेरै उत्पादन दिने वातावरणमा धेरै फल्ले देखिन्छ। यी जातहरूलाई अझै व्यापक रूपमा कृषकको खेतबारीमा परिक्षण गरी सिफारिस गर्न सकेमा उवाको बीउ वितरण प्रणालीमा सुधार आउने र हिमाली भेगको खाद्य सुरक्षामा टेवा पुग्ने देखिन्छ।

## INTRODUCTION

Barley (*Hordeum vulgare* L.) is a winter self-pollinated cereal grain known to be cultivated since ancient time. The barley is known to be originated in the Himalayan region, particularly in Bhutan, Nepal and Tibet of China (Singh 1983, Rajbhandari and Bhatta 2008). It is the second most important winter crop in mountainous regions of Nepal. It is grown in different cropping patterns in both *Khet* (irrigated lowlands) and *Bari* (non-irrigated uplands) conditions. Barley landraces dominate cultivation and grows in the low fertility rainfed environment of the high-hills of Nepal. It is the second most preferred crop after rice in Jumla (Baniya et al 1997). Studies revealed diversity in Nepalese barley landraces in accordance the theory that Nepal is a primary center of diversity (Witcombe 1975, Witcombe and Gilani 1979, Murphy and Witcombe 1986, Bajracharya et al 2012).

Two types of barley are being cultivated in Nepal: hulled or covered and hullless or naked. Naked barley differs from covered barley by the loose husk cover of caryopsis that is easily separable upon threshing in contrast to hulled barley (Bhatty 1999). Although naked barley is less yielding than the hulled type, it received more attention recently as healthy human food due to the abundance of dietary factors mainly  $\beta$ -glucans (which is an inhibitor of cholesterol synthesis), and vitamins (Manjunatha et al 2011, Tonoka et al 2009). Naked and covered barley differ greatly in their spike morphology (Murphy and Witcombe 1986).

Naked barley (*Hordeum vulgare* var. *nudum* L.) is an important food crop in mountain region of Nepal but production area and genetic diversity is shrinking fast. Only one variety *viz* Solu uwa is released which was selected from landrace of the Solukhumbu district. In order to increase varietal options, field trials were designed to identify high-yielding, early-maturing and site-specific as well as widely adopted landraces of naked barley for the mountain region.

In Nepal, barley is grown in 28053 ha area with the average productivity of 1.33 t/ha (MOAD, 2015), however, disaggregated data for naked barley are lacking. As compared to covered barley, naked barley grains contain up to 16% higher protein content (Saud, 2010). It is utilized as different traditional food items, quality beverages and feed for animals in high mountain areas of Nepal. It is a neglected and under-utilized crop species. No varieties have been released by the Nepal Agricultural Research Council (NARC) after releasing the only variety *Solu uwa* 27 years ago (Joshi et al 2017, NARC 2012, SQCC 2016) suggesting inadequate research attention for the crop. Despite the several nutritional benefits of naked barley, its cultivation is declining due to changing local food habit, low awareness of the nutritional benefits of naked barley and its low productivity.

In Chhipra village of Humla district, naked barley is the major component to prepare local beer (*Chhyang*), even though it's area and production is decreasing. Hulled barley is a main crop in Hanku of Jumla Valley and many parts of Jumla district which fits well in rice-barley cropping pattern in well-drained banded fields (*khet* land). Naked barley is not commonly grown in Hanku village of Jumla district and nearby areas as it is not a traditionally accepted food and existing landraces of naked barley are low yielding compared with hulled barley at Ghanpokhara and Jugu villages in Lamjung and Dolakha districts, respectively. Therefore, we conducted this research with the objectives of: i) introducing the new crop as well as some landraces diversity collected from other parts of the country to these sites for adaptation, and ii) identifying high yielding and early maturing landraces for different mountain agro-ecosystems.

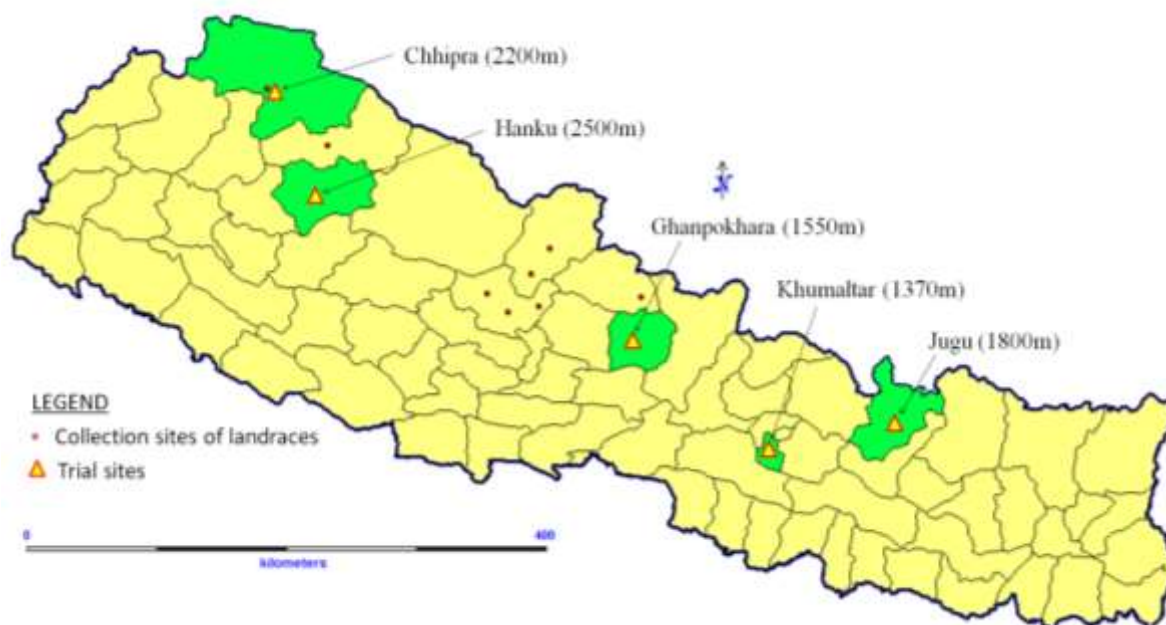
## MATERIAL AND METHODS

### Experimental location

Experiment was conducted at five different locations given in [Table 1](#) and [Figure 1](#).

**Table 1. Geographic and climatic information of experimental locations**

Location	Geo-reference			Climate	
	Latitude (N)	Longitude (E)	Altitude (masl)	Average temperature range (oC)	Annual rainfall (mm)
Chhipra, Humla	29.941°	81.853°	2200	0-20	50
Hanku, Jumla	29.232°	82.095°	2500	2-22	729
Ghanpokhara, Lamjung	28.306°	84.324°	1550	15-27	2944
Jugu, Dolakha	27.678°	86.189°	1800	4-22	2000
Khumaltar, Lalitpur	27.647°	85.324°	1370	3-29	1382

**Figure 1.** Map of Nepal showing collection sites of test landraces and experiment sites.

### Plant materials

Eight landraces of naked barley, collected from different mountain districts of Nepal were used (Table 2).

**Table 2. Details of landraces evaluated in 5 different sites during winter of 2014/015**

SN	Accession number	Local name	Grain (pericarp) colour	Collected district	Altitude (m)
1	NGRC04003	Jau	Black	Mustang	2800
2	NGRC02327	Uwa	White	Myagdi	1280
3	NGRC04894	Jau	Purple	Humla	3500
4	NGRC02306	Uwa	Black	Mustang	2800
5	NGRC04903	Jhuse uwa	Black	Mugu	2400
6	NGRC04902	Local uwa	White	Manang	2050
7	NGRC04901	Uwa	Purple	Myagdi	1543
8	NGRC01137	Uwa	Black	Myagdi	NA

### Experimental design and cultural practices

The experiment was conducted in a randomized complete block design (RCBD) with 3 replications. Plot size was 8 rows of 3 m length (2m x 3m) with spacing of 25 cm between rows and continuous plants within rows. Fertilizers and other management practices were applied as per the farmers' practice of respective sites. Seeding was done on 27<sup>th</sup> November, 2014 at Chhipra, 13<sup>th</sup> Nov, 2014 at Hanku, 6<sup>th</sup> Nov, 2014 at Ghanpokhara, 14<sup>th</sup> Nov, 2014 at Jugu and 10<sup>th</sup> Nov, 2014 at Khumaltar.

### Data observation and statistical analysis

Agronomic characteristics such as time to heading (days), time to maturity (days), plant height (cm) and grain yield (kg/ha) were recorded following IPGRI descriptors (IPGRI, 1994). Grain yield was recorded after sun drying. Data were analyzed with Microsoft Excel, 2008 and MINITAB V14.1 statistical software. Analysis of variance (ANOVA) was performed using General Linear Model. Regression analysis was used to estimate stability and adaptation of the genotypes (Finley and Wilkinson 1963). The site mean yield was used as the independent variable and the individual genotype yield was used as the dependent variables. Adaptation and stability of genotypes were interpreted based upon the results of regression coefficient ( $b$ ) and coefficient of determination ( $R^2$ ) as described by Bilbro and Ray (1976). If regression coefficient is higher than 1, the genotype is adapted to high yielding environment and if the regression is lower than 1, the genotype is adapted to low yielding environments. Genotypes with regression coefficient equal or close to 1 and yield above average were considered more stable and adapted to all environments.

### RESULTS

Phenological characteristics such as days to heading and maturity as well as plant height are important adaptive traits in the harsh environment of the mountain agro-ecosystems. ANOVA was conducted for days to heading and maturity, plant height and grain yield of 8 tested landraces at all 5 sites as well as combined over locations. Highly significant differences were observed among tested landraces for days to heading at all sites except at Jugu (Table 3). Similarly, highly significant difference ( $p < 0.001$ ) was observed among tested landraces for days to maturity at Ghanpokhara, Hanku and Khumaltar but non-significant at Jugu and Chhipra (Table 3). Long maturity period in Hanku and Chhipra was observed due to prolonged snowfall during the early vegetative stage of the crop. Plant height is a trait correlated with the straw yield which is one of the important selection traits for farmers raising livestock. Genotypes differed significantly for plant height at Ghanpokhara, Hanku and Khumaltar but the difference was not significant at Jugu and Chhipra (Table 4). The difference among the landraces for grain yield was highly significant ( $p < 0.001$ ) at Khumaltar and significant at Hanku but not significant at Ghanpokhara, Jugu and Chhipra (Table 4). The highest grain yield was obtained at Khumaltar whereas the lowest yield was at Jugu (Table 4).

Combined over locations data showed significant differences for heading ( $P < 0.001$ ), maturity ( $P < 0.001$ ) (Table 3), plant height ( $P < 0.001$ ) and grain yield ( $P < 0.05$ ) (Table 4). Landrace NGRC02327 was found the earliest for heading and maturity while combined over locations whereas NGRC04901 was the latest for heading and maturity. NGRC02306 was the highest yielding landrace followed by NGRC04902 and NGRC04894 (Table 4). Two out of eight tested landraces yielded above overall mean at Chhipra, two out of eight landraces produced higher grain yield than overall mean at Hanku and five out of eight tested landraces gave better yield than the overall mean at Khumaltar (Table 4), suggested that environment and management was favorable and high yielding compared to other sites.

Genotype  $\times$  Environment (G $\times$ E) interaction was highly significant for days to heading, days to maturity (Table 3) and plant height (Table 4) but only significant difference was observed for grain yield (Table 4). Individual regression coefficients ( $b_i$ ) ranged from 0.686 to 1.492 (Figure 2), whereas coefficient of determination ( $R^2$ ) ranged from 54% to 95% which suggested the model fit well and explained good proportion of variation. Overall mean yield was 1905 kg/ha with minimum of 1355 kg/ha and maximum of 2294 kg/ha (Table 4).

Similarly, the regression coefficient ( $b_i$ ) and mean yield of individual landrace were plotted in the scatter plot in Figure 3 to select the stable and high yielding landrace. If regression coefficient is higher than 1, the genotype is adapted to high yielding environment and if the regression is lower than 1, the genotype is adapted to low yielding environments. Genotypes with regression coefficient equal or close to 1 and yield above average were considered more stable and adapted to all environments (Bilbro and Ray, 1976). We found NGRC04894 was the most stable landrace ( $b=1.033$ ) adapted to all locations (Figure 3). Similarly, two landraces NGRC02306 and NGRC04902 were better adapted to

high yielding environments like Khumaltar but they are very sensitive to environmental change, producing very low yield in less favorable environment and even better yields when subjected to the high yielding environments. In contrast, NGRC04901 was a stable genotype ( $b=0.874$ ) better adapted to low yielding environments (Figure 3).

**Table 3. Mean days to heading and maturity of naked barley landraces across five locations**

Accession	Days to heading (day)						Days to maturity (day)					
	Chhipra	Hanku	Ghanpo khara	Jugu	Khumal	Mean±SE	Chhipra	Hanku	Ghanpo khara	Jugu	Khumal	Mean±SE
NGRC04003	124	152	107	106	113	121±5.1	172	195	156	149	146	164±5.6
NGRC02327	114	143	91	91	92	107±6.2	164	190	146	140	130	154±6.5
NGRC04894	135	157	112	115	115	127±5.3	171	199	167	160	145	169±5.7
NGRC02306	135	159	103	107	105	122±7.1	176	200	153	155	145	166±6.4
NGRC04903	135	141	95	101	101	114±5.9	169	190	154	152	137	160±6.0
NGRC04902	137	144	109	105	105	120±5.2	176	196	157	155	146	166±5.8
NGRC04901	136	164	115	121	120	131±5.6	175	201	167	162	151	172±5.5
NGRC01137	139	162	109	105	107	125±6.8	177	202	156	153	146	167±6.5
Overall mean	132	153	105	106	107	121	173	197	157	153	143	165
F-test:						***						***
Location	-	-	-	-	-		-	-	-	-	-	
Genotypes	***	***	***	ns	***	***	ns	***	***	ns	***	***
Loc×Genotypes	-	-	-	-	-	***	-	-	-	-	-	**
CV (%)	6.47	5.78	8.10	10.9	8.15	16.1	8.50	4.63	4.43	9.70	4.97	13.1
LSD ( $\alpha=0.05$ )	5.51	3.56	7.79	-	6.86	5.86	-	3.69	3.50	-	8.67	7.71

\*Significant ( $P<0.05$ ); \*\*Highly significant ( $P<0.01$ ); \*\*\*Very highly significant ( $P<0.001$ ); <sup>ns</sup>Non-significant

**Table 4. Mean plant height (cm) and grain yield (kg/ha) of naked barley landraces across five locations**

Accession	Plant height (cm)						Grain yield (kg/ha)					
	Chhipra	Hanku	Ghanpo khara	Jugu	Khumal	Mean±SE	Chhipra	Hanku	Ghanpo khara	Jugu	Khumal	Mean±SE
NGRC04003	86	77	107	95	110	96±5.6	2500	995	2205	720	3041	1935±337
NGRC02327	83	79	114	96	100	95±5.3	1167	1167	2456	1557	2622	1860±293
NGRC04894	73	68	92	75	99	83±5.2	2500	2017	2155	1345	2432	2116±279
NGRC02306	83	68	101	61	91	82±5.3	1834	2328	2493	1255	3062	2294±342
NGRC04903	81	86	125	89	110	100±5.9	1584	1461	1775	1414	2451	1773±290
NGRC04902	86	82	113	78	119	98±5.9	1750	1892	2153	1250	3807	2274±345
NGRC04901	83	75	114	75	113	94±6.3	1667	817	1195	639	2322	1355±217
NGRC01137	82	75	111	73	110	92±6.2	1000	1267	1540	802	3056	1630±304
Overall mean	82	76	110	80	107	93	1750	1493	1997	1123	2849	1905
F-test:						***						***
Location	-	-	-	-	-		-	-	-	-	-	
Genotypes	ns	**	***	ns	***	**	ns	*	ns	ns	***	*
Loc×Genotypes	-	-	-	-	-	**	-	-	-	-	-	*
CV (%)	13.7	10.9	8.5	14.1	9.2	22.7	32.7	24.7	31.6	30.7	17.0	37.7
LSD ( $\alpha=0.05$ )	-	8.8	8.7	-	8.2	14.9	-	1150	-	-	249.8	923

\*Significant ( $P<0.05$ ); \*\*Highly significant ( $P<0.01$ ); \*\*\*Very highly significant ( $P<0.001$ ); <sup>ns</sup>Non-significant

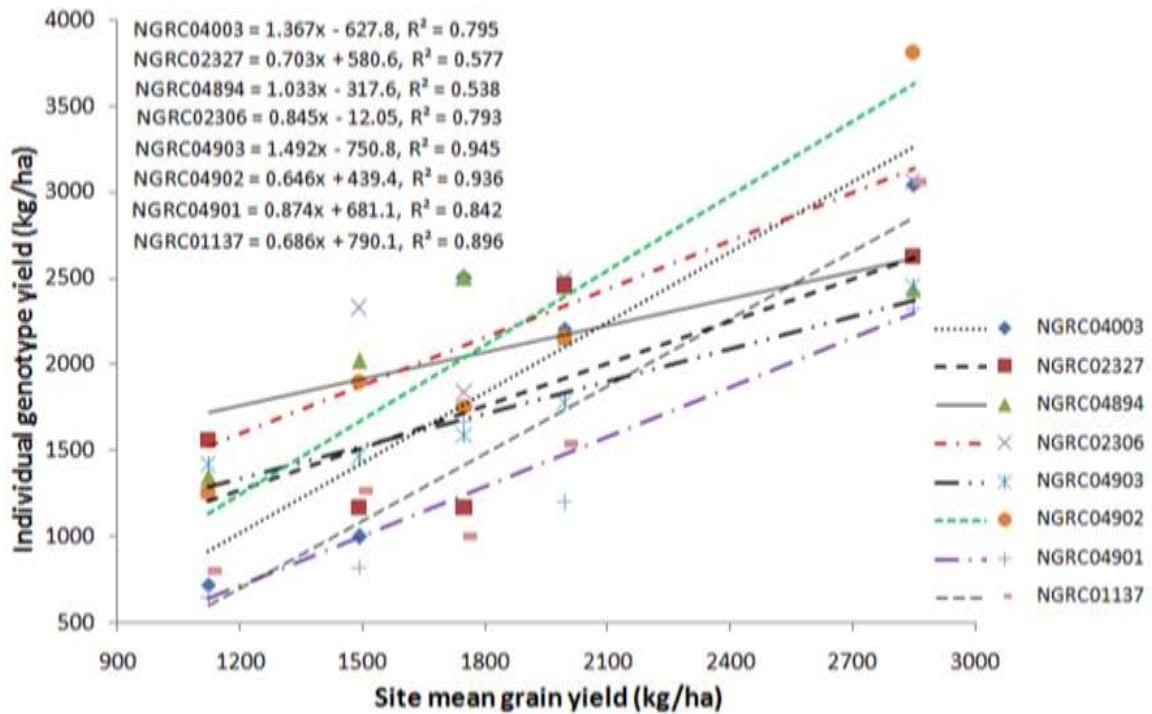


Figure 2. Regression lines showing the relationship between individual genotype yield and site mean yield of naked barley landraces

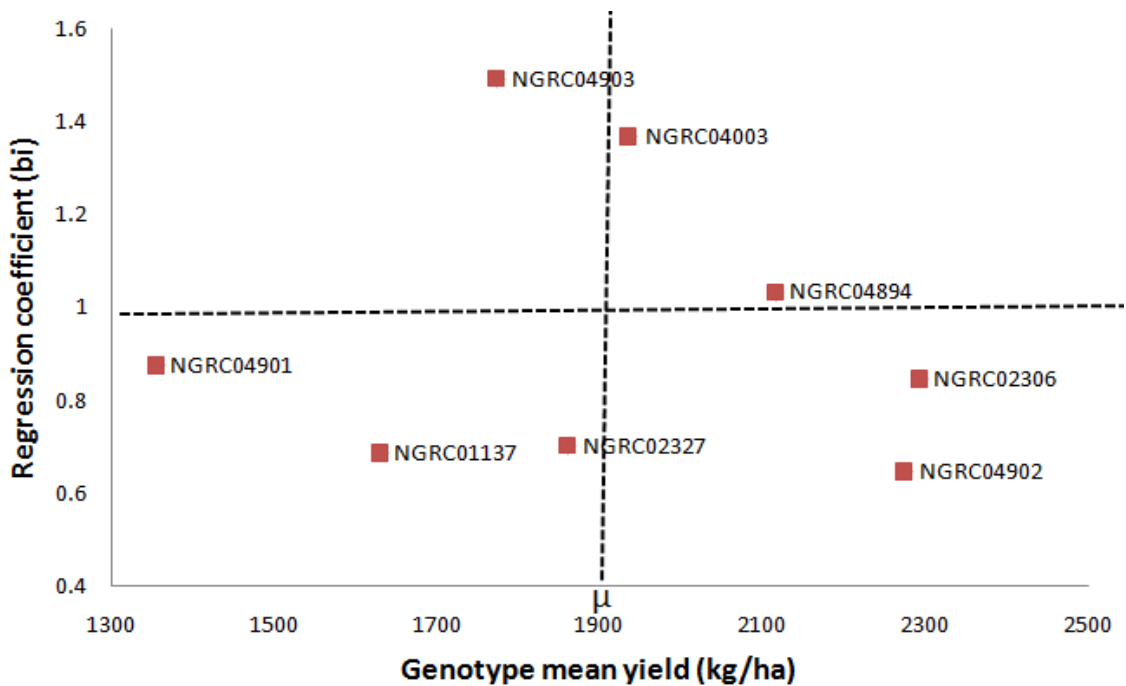


Figure 3. Relationship of genotype adaptation or regression coefficient (bi) with genotype mean yield of tested landraces ( $\mu$  = population mean).

## **DISCUSSION**

Landraces are populations that farmers select based on their functional traits, manage over time through a sequence of cropping seasons and become adapted to their local environments (Bajracharya et al 2012). Testing genotypes at more locations is considered important rather than testing in more years at the same location for stability studies (Saeed et al., 1984). Stability and adaptability studies are useful for recommending and releasing a genotype to cultivate in wide as well as specific environments (Witcombe 1975, Witcombe and Gilani 1979, Murphy and Witcombe 1982, Murphy et al 1982, Murphy and Witcombe 1986, Witcombe et al 2016, Pandey et al 2006). Those landraces could be further verified and multiplied in farmers' field for wider promotion. Evaluation of landraces across mountain environments showed significant differences in functional traits like grain yield, maturity and plant height. The results demonstrate high GxE interaction suggesting need of more localized varietal assessment. This study increased the opportunity to select genotypes adapted across locations and the high and low yielding environments. The application of this study will be used to distribute a set of Informal Research and Development (IRD) kits ie half kg seed per HH and 500 to 1000 kits (Joshi and Sthapit 1991, Sthapit et al 2017, Witcombe et al 2016) for deploying new diversity and provide farmers for participatory selection for their needs.

Diversity in landraces of traditional crops including naked barley has shrinking in mountainous region (Parajuli et al 2017, Palikhey et al 2017) as well as other parts of Nepal. In the crops like naked barley, farmers have few varietal selection options because there is only one variety officially released (NARC 2012, SQCC 2016). Genetic diversity of naked barley from mountain areas exists in the collection of National Genebank or in farmers' fields but they are not easily accessible to majority of farmers. Agro-morphological diversity among Nepalese naked barley landraces was assessed by Yadav et al (2018) and found these landraces superior in terms of agronomical traits and suggested to utilize in breeding program. Apart from screening naked barley landraces, crosses between covered and naked barley would release the genetic variability between these two forms. Farmers of mountain areas prefer varieties that have set of traits such as higher yield, earliness and high biomass. After on-farm trials in wider scale, these better performing varieties need to be released or registered so that the process would be mainstreamed and farmers' choices in this neglected crop would be increased.

## **CONCLUSION**

Naked barley is an important winter crop in mountain region of Nepal but production area and genetic diversity is shrinking fast due to various challenges including very limited varietal options. Identification of stable superior naked barley genotypes is the most important task in variety development program. We found that NGRC04894 was the most stable genotype which can be grown in all environments. The genotypes namely NGRC02306 and NGRC04902 were suitable to be grown in Khumaltar. There was high genotype by environment (GxE) interaction suggesting the need of more localized varietal assessment. In mountain region such as Jumla and Humla, farmers can prefer even the lower yielding but early maturing genotype i.e. NGRC02327 as it fits better in the rice based cropping system. These candidate genotypes need to be deployed to farmers' fields in wider areas followed by release or registration which would help to diversify the genetic portfolio of naked barley landraces in the mountain region.

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