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MORPHOLOGICAL CHARACTERIZATION AND ESTIMATION OF GENOTYPE × ENVIRONMENT INTERACTION OF INDIGENOUS BUCKWHEAT GERMPLASM COLLECTED FROM GILGIT BALTISTAN PAKISTAN

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Abstract

A two-year study (2011 and 2012) was conducted at two locations (Skardu and Ghanche) of Gilgit Baltistan, Pakistan to characterize and estimate genotype by environment interaction (GEI) for 20 buckwheat genotypes collected from 18 locations of Gilgit - Baltistan, Pakistan. The GE interaction was studied using a set of six quantitative descriptors. Wide range of variations was recorded for flowering, maturity, plant height, 1000 grain weight, grains plant^{-1} and grain yield ha^{-1}. Significant differences in locations for all traits were recorded. Years × locations interactions was also significant ($p \leq 0.05$) for all traits except grains plant^{-1} and grain yield ha^{-1}. Similarly, genotype × location × year interaction existed for most of the traits except plant height, grains plant^{-1} and grain yield ha^{-1}. The genotype Sh-914 (29.91 g) excelled in 1000-grain weight, followed by Rd-915 (27.04 g). Maximum grains plant^{-1} were produced by Sh-914 (323.62) followed by the genotype Gh-918 (229.16). Maximum grain yield of 2010.27 kg ha^{-1} was produced by genotype Sh-914, followed by the genotype Gh-918 (1910.40 kg ha^{-1}). Days to flowering, days to maturity, and 1000 grain weight were the major contributors towards genetic divergence among the buckwheat genotypes. Moderate to high estimates of broad-sense heritability and selection response were observed for traits at two test locations.

Cluster analysis based on morphological and yield related traits classified buckwheat genotypes of two species (*Fagopyrum esculentum* and *F. tataricum)* into three main groups. The clustering pattern revealed that genotypes collected from the same location were grouped into different clusters. Data obtained on the basis of Dendrogram showed differences for various phenological and yield traits among buckwheat genotypes. Buckwheat genotypes Sh-914 and Gh-918 performed well at Skardu and Sh-914 and Rd-915 at Ghanche .The information on the existing genetic variability for morphological and yield component traits would serve as basis for genetic improvement in Buckwheat breeding programs.

Key words: Buckwheat, Morphological characterization, GE interaction, Gilgit - Baltistan

Introduction

Buckwheat belongs to the family Polygonaceae and is grown as a minor crop in Gilgit-Baltistan, Pakistan. Buckwheat is believed to be cultivated first in the Himalayan region of India, from where it spread to China and other parts of the world (Krotov, 1960). Buckwheat provides food security to traditional poor resource farmers under subsistence farming but its cultivation and utilization in Pakistan is limited. Both Common (*Fagopyrum esculentum* L.) and Tartary buckwheat (*F. tataricum* L.) are cultivated as a summer crop in valleys of Karakoram and Hindukush, Pakistan. In Baltistan, Common buckwheat is called "*jawas*", while Tartary buckwheat is called "*brow*". In Balti language Tartary buckwheat is also known as *Kho-brow* (bitter), Common buckwheat is known as *Sta-Brow* / *Gevas* and wild one is known as *Khi-Brow*. In the upper Hunza area the word "*Bali*" is commonly used for buckwheat. In Gilgit - Baltistan, buckwheat is cultivated as summer crop in July and harvested in October at above 2500 m altitude, and also as autumn crop in August and harvested in November at 1000-2000 m. Buckwheat is sown on an area of 585.24 hectare with the average production of 1151.25 MT (NAAS,2014) (Table 1).

Due to the lack of improved varieties and any systematic breeding program, buckwheat cultivation is diminishing day by day in Pakistan and has become an endangered species. Although several landraces are grown by local farmers in Himalayan regions of Pakistan, information regarding genetic diversity of buckwheat germplasm is not documented yet, which is a primary requisite for designing of any breeding program. Genetic diversity analysis helps to choose desirable parents for establishing new breeding population. Better knowledge on genetic diversity could help in maintaining long term selection gain (Chowdhary *et al.*, 2002). Knowledge of genetic diversity among existing cultivars of any crop is essential for long term success of breeding programs and maximizes the exploitation of the germplasm resources (Belaj *et al*., 2002). Collection and characterization of landrace identification has attained great importance in the national and international seed programs as it is the basic source of variation for any crop. This characterization must also be carried out across locations, to assess the genotype by environment interaction, which is important criteria for selection in breeding programs.

The short duration buckwheat crop is suitable for single cropping areas in extreme north of Pakistan. The crop is grown only in subsistence farming and is now considered to be endangered species in Pakistan. The climatic conditions and geography of Gilgit - Baltistan favors buckwheat cultivation because it is a crop of cool, moist, temperate regions and is sensitive to high temperatures and hot dry winds especially when moisture is scarce. The present study was thus designed to characterize the indigenous germplasm of buckwheat for identification of suitable indigenous germplasm for cultivation and future buckwheat improvement programs under two environments.

Materials and Methods

A set of 20 buckwheat genotypes was collected from 18 locations of three districts (Skardu, Gilgit and Ghanche) of Gilgit Baltistan, Pakistan (Fig. 1). Based on seed color and shape, the 20 indigenous genotypes were visually divided into two species of *Fagopyrum*, i.e., *F. esculentum* L. (13 genotypes) and *F. tataricum* L. (07 genotypes). These 20 genotypes were grown at the experimental field of the Department of Agriculture Skardu and Ghanche during 2011 and 2012 (Table 2). The locations were chosen on the basis of differences in temperature and moisture, to which buckwheat is sensitive. Distance between Skardu and Ghanche is about 120 km. Mean weather data of the sites are given in Table 3.

The genetic material was sown on July 05 and 22, 2011 at Research Farms at Skardu and Ghanche, respectively. In 2012, the same experiments were repeated with sowing on July 08 at Skardu and July 26 at Ghanche. The experiments were laid out in a randomized complete block design with three replications at each location. The field was prepared and the moisture level was maintained through irrigation before sowing. A light dose of urea fertilizer was applied while preparing the land. Sowing was done manually at depth of 5 - 6 cm. The unit plot size for a genotypes was 4 × 1.25 m consisting of four rows. Row to row and plant to plant spacing were kept 30 cm and 25 cm, respectively. Two seeds per hill were planted and thinning was done to maintain optimum plant population. Irrigation was provided at both locations as and when needed to avoid moisture stress.

Days to first flower initiation, maturity and yield was recorded on plot basis. For data on plant height, 1000-grain weight (g), grains plant^{-1}, 10 plants were selected at random from each plot.

Data were analyzed across years and locations using mixed effects model via the Proc GLM (Generalize Linear Model Procedure) in Statistical Analysis System (Anon., 2000). Within the model, locations were considered as fixed effect while years, genotypes and replications as random effects (Steel & Torrie, 1980). Ali & Zahid (2007) used General Linear Model (GLM) for analysis of variance of yield data to examine the total variation in genotypes, environments and genotype x environment interaction to identify high yielding lentil genotypes grown at 11 locations for 2 years in Pakistan.

Table 1. District wise area, seed requirement, production and utilization of Buckwheat.

Districts	Area (ha.)	Seed required (MT)	Production (MT)	Consumption (MT)	Marketed (MT)
Gilgit	0.51	0.61	0.81	0.81	0.00
Hunza	14.10	4.32	15.82	15.82	0.00
Nagar	17.15	4.80	19.21	19.21	0.00
Ghizer	8.07	1.08	8.60	2.15	6.45
Skardu	305.17	112.21	498.97	363.77	135.20
Shigar	122.84	46.26	372.44	220.85	151.59
Kharmang	2.70	0.81	3.77	3.77	0.00
Ghanche	112.15	27.58	227.60	179.53	48.07
Astore	0.39	0.31	1.25	1.25	0.00
Diamer	2.16	0.35	2.76	2.76	0.00
Total	**585.24**	**198.32**	**1151.25**	**809.94**	**341.31**

Source: Northern Areas Agriculture Statistics, 2014.

Table 2. Indigenous buckwheat genotypes collected from different locations of Gilgit - Baltistan, Pakistan.

Identification number	Type of species	Collection district	Collection point
Gh-901	Tartary	*Ghanche	Saltoro
Gh-902	Tartary	*Gilgit	Gilgit
Sh-903	Tartary	*Skardu	Baha
Rd-904	Tartary	Skardu	Daso
Gh-905	Tartary	Ghanche	Ghomo
Rd-906	Tartary	Skardu	Bilamik
Rd-907	Tartary	Skardu	Thowar
Sh-908	Tartary	Skardu	Daso Shiger
Sk-909	Common	Skardu	Manthal
Rd-910	Common	Skardu	Baghicha
Gh-911	Common	Ghanche	Thalay
Rd-912	Common	Skardu	Stak
Sh-913	Common	Skardu	Zill
Sh-914	Common	Skardu	Tistey
Rd-915	Common	Skardu	Tormik
Gh-916	Common	Ghanche	Haricon
Gh-917	Common	Ghanche	Balghar
Gh-918	Common	Ghanche	Tallis
Rd-919	Common	Skardu	Baha
Rd-920	Common	Skardu	Daso

*Districts of Gilgit – Baltistan, Pakistan

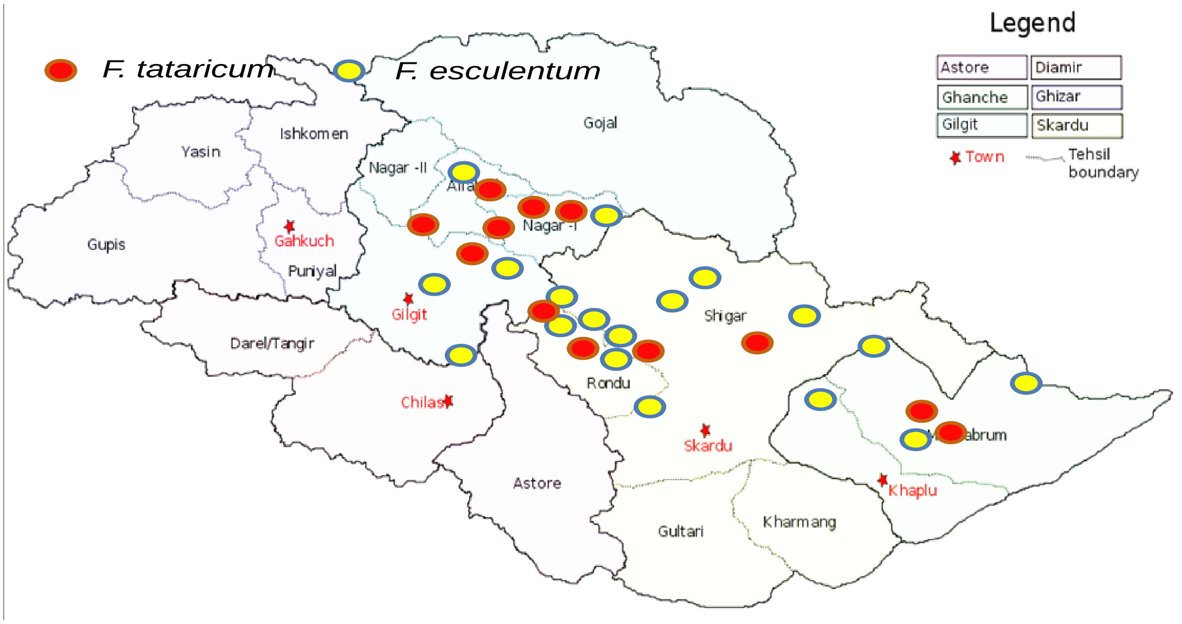

Fig. 1. Sampling locations of buckwheat germplasm in Gilgit - Baltistan province of Pakistan. The red circles represents the collection locations.

Table 3. Mean temperature (°C) and rainfall (mm) at experimental sites (Skardu and Ghanche) during growing period of buckwheat (July–October 2011-12).

Months	Mean temperature (°C) at Skardu		Mean temperature (°C) at Ghanche		Rainfall (mm)
	Maximum	Minimum	Maximum	Minimum	
July	32.5	13.8	28.3	11.4	19
August	33.2	15.5	30.8	13.6	24
September	25.6	9.2	24.2	8.6	13
October	20.4	4.8	17.1	3.7	12

Source: Meteorological Department Skardu Baltistan Pakistan

Estimation of variance components: The variances due to genetic and environment were estimated for all the traits of 20 genotypes under each environment independently by using the PROG VAR COMP option in SAS. For estimation of broad-sense heritability (h^2_{BS}), genetic (Vg), genotype × year (Vgy) and error variances (Ve) at each location were estimated according to Rowe and Brink (1993) technique. Using 20% selection intensity, expected response (Re) to selection for each trait at each location (Skardu and Ghanche) was calculated according to the procedure outlined by Falconer & Mackay (1996).

Cluster analyses: Data recorded on all parameters was also analyzed by numerical taxonomic techniques using cluster analyses (Sneath & Sokal, 1973). Means of each character were standardized prior to cluster analyses to avoid effects due to scaling differences. Estimates of Euclidean distance coefficients were made for all pairs of genotypes to check the genetic relationship between collected genotypes on the basis of dissimilarity coefficient matrices using NTSYS-pc, Version 2.2 package (Rohlf, 2005).

Results and Discussion

Present results revealed high genetic variability for flowering, maturity, plant height, 1000 grain weight, grains plant^{-1} and grain yield ha^{-1}in the 20 indigenous buckwheat germplasm tested across two locations of Gilgit - Baltistan over two years along with a significant GE interaction.

Genotype × Environment interaction: Characterization of buckwheat indicated significant ($p\leq0.05$) differences among the genotypes for all traits. Variation due to genotype × environment interaction were significant for all traits except grains plant^{-1} and grain yield, which indicated variable response of genotypes in both environments. Variance due to locations was also significant for all the traits indicating the environment influence on these characters (Table 4). Aliu & Fetahu, (2010) have reported that various morphological and biochemical traits were highly influenced by the genotype × environment interactions. Results of the current study are also in accordance with the findings of Dhiman *et al.* (2002), who reported significant G x E interaction for different traits in buckwheat. They considered phenotypic characters to classify the genotypes. Similarly, Majid *et al*. (2007) also observed significant variation for most of the quantitative traits in wheat. Arain *et al*. (2011) studied GE interaction and grain yield performance in twelve wheat genotypes at various locations having different agro-climatic conditions in Sindh Pakistan for two years and reported that pool analysis of variance revealed highly significant ($p<0.01$) difference for genotypes, environments and genotype x environment (G × E) interaction.

Table 4. Mean squares for days to flowering, days to maturity, plant height, 1000-grain weight, grain number plant^{-1}, grain yield ha^{-1} of buckwheat evaluated for two years (2011 – 2012) at two locations.

Source	d.f	Days to flowering	Days to maturity	Plant height	1000 grain weight	Grain number plant^{-1}	Grain yield ha^{-1}
Y	1	1.5 ns	98.8**	255.3**	298.8**	27573.9**	178084.2 **
L	1	266.7**	976**	1123.8**	355.7**	22486.6**	137932.9 *
Y*L	1	92.5**	3.2 *	551.6**	167.1**	593.7 ns	13380.2 ns
Rep(Y*L)	8	2.2 ns	1.7 *	5.7 ns	1.9 ns	4367.1**	74538.7**
G	19	199.8**	48.9**	2084.8**	96.7**	6537.4**	147183.2**
G*Y	19	0.98 ns	10.2**	100.7**	15.1**	913.3 ns	25021.0 ns
G*L	19	2.4**	23.2**	496.7**	25.0**	1298.8 ns	32598.4 ns
Y*G*L	19	5.5**	17.7**	43.5**	;15.4**	1011.3 ns	34531.0 ns
Error	152	0.6	0.51	6.7	0.84	988.8	16031.3

** = Significant at p≤0.01, * = Significant at p≤0.05, ns = Not significant

Morphological parameters for identification and classification of buckwheat cultivars have been efficiently used by Hirose *et al*. (1991). Likewise, Ujihara (1983) differentiated three genotypes based on flowering time in Common buckwheat. In the current study, significant variations for location (L), year (Y), L × Y, G × Y and G × L suggested inconsistency in the performance of genotypes of two species across the environments. Therefore, it was imperative to evaluate the performance of these genotypes of both species in order to identify genotypes having superior attributes.

In present investigation, the genotypes were easily and distinctly classified through different morphological traits. Analysis of mean squares showed that the effect of location was more important than that of year for flowering, maturity, plant height, 1000 grain weight, grains plant^{-1} and grain yield (Table 4). Significant interaction of Y × L suggested that buckwheat germplasm should be tested through different years and locations. Several researcher have reported that the G × L and G × L × Y interactions are more important than G × Y interaction for yield in different crops like sorghum (Hovny *et al*., 2005), mungbean (Ullah *et al*., 2011) and wheat (Saeed *et al*., 2016). Significant G × L interactions indicated that these genotypes tended to rank differently for majority of the traits at different locations (Table 4).

Present results also revealed that genotypes Gh-918, Gh-916 and Gh-917 and Rd-915, Rd-910, Rd-919 and Rd-920 collected from similar locations did not exhibit similar morphological characteristics like flowering, maturity, plant height, 1000 grain weight, grains plant^{-1} and grain yield (data not shown). It suggests that morphological divergence observed cannot solely be attributed to environmental variations but possibly to genetic make-up of the populations. However, to test this hypothesis, it would be necessary to collect extensive morphological data and evaluate that for the distribution of variability. Although morphological traits always provided base for classification of accessions, yet some researcher do not agree with this opinion. Dias *et al*. (1993) classified the Portuguese cabbage and Galega kale population on the basis of geographical origin rather on morphological differences. Same findings were also reported by Padilla *et al*. (2005) who classified collections of *B. rapa* on geographical origin. Similarly, Cartea *et al*. (2002) also investigated the strong relationship of genotypes with geographical origin rather than with morphological differences in Kale. During the present study we also observed that there were significant differences for mean values of studied traits which denoted a range of diversity of the collected genotypes. Since these genotypes were collected from different valleys with diverse ecology, the significant differences further strengthen the variability among these genotypes as reported earlier (Yan, 2001).

Varied response of genotypes was observed at different locations for flowering with a diversified range of 20.67-34.67 days (Tatary) and 23.00 to 26.33 days (Common) at Skardu (Table 5). At Ghanche, Tatary ranged from 32.67 to 35.67 days and Common ranged from 23.33 to 29.33 days (Table 5). Most of the genotypes initiated early flowers at Skardu as compared to Ghanche. The variation in days to flowering indicated the response of buckwheat to the changing climate and also signifies exploitation of its potential for changing environments. A variable response of 25.80 to 28.50 days to flowering at different locations has been also observed by Debnath *et al*. (2008), while Rana (1998) noticed maximum of (37) days to flowering. The magnitude of heritability for days to flowering was relatively high at Skardu (0.95) than Ghanche (0.89). Similarly the expected selection response was also higher (5.67 days) at Skardu than Ghanche (5.15 days (Table 6). Similar higher heritability estimates for days to heading in wheat are also reported by Dhonde *et al*. (2000).

The genotypes exhibited inconsistent response for days to maturity (Table 5). Generally, farmers prefer to cultivate early maturing genotypes which can escape frost at maturity. It is also an important trait for selection in buckwheat germplasm. Considering the location effects, buckwheat genotypes matured early at Skardu than Ghanche. Among the genotypes, Sh-908 was the earliest in maturity, while Gh-911 was late maturing (87.67). The locations also played a significant role in maturity as observed during the present investigation. Maturity ranged from 74.67 to 82.67 days (Tatary) and 75.34 to 87.67 (Common) at Skardu while at Ghanche Tatary ranged from 82.34 to 90.67 and Common ranged from 77 to 87.33 days (Table 5). Similar range of diversity for maturity of Common buckwheat (60 to78 days) and Tatary (80 to 105 days) buckwheat is reported earlier by Zhou & Arora (1995). According to Table 6, the magnitude of heritability for maturity was greater at Skardu (0.83) than Ghanche (0.13) which might be due to higher environmental influence of Skardu. The expected selection response was low (0.58) under Ghanche than Skardu (3.13) (Table 6).

Table 5. Ranges and means for various traits of Buckwheat genotypes at two locations of Baltistan during 2011 and 2012.

Traits	Sites	Skardu						Ghanche					
	Species	Tartary			Common			Tartary			Common		
	Years	2011	2012	Mean	2011	2012	Mean	2011	2012	Mean	2011	2012	Mean
Days to flower initiation	Ranges	32.33-33.67	30.67-34.67		24.33-26.33	23.00-25.00		32.67-35.67	33.67-35.67		23.33-27.67	26.33-29.33	
	Means	33.12	32.62	32.85	25.30	23.41	25.36	34.66	34.66	34.66	25.79	27.46	26.62
Days to maturity	Ranges	80.00-82.33	74.67-82.67		77.67-87.67	75.34-87.00		82.34-88.67	87.33-90.67		82.67-87.33	77.00-85.33	
	Means	80.84	78.53	79.67	82.04	80.92	81.48	85.17	88.90	87.05	85.52	81.90	83.71
Plant height (cm)	Ranges	75.57-94.80	62.33-94.60		81.93-114.20	67.50-124.33		72.50-76.97	81.07-87.90		82.20-102.43	87.63-108.43	
	Means	81.57	80.16	80.87	103.31	102.58	102.95	73.66	83.59	78.62	96.25	98.74	97.50
1000 grains weight (g)	Ranges	19.11-25.83	21.64-25.77		19.80-34.27	17.70-29.67		18.27-25.34	17.68-24.48		20.29-29.56	16.49-20.97	
	Means	22.52	22.51	22.52	25.51	24.65	25.08	22.09	19.88	20.99	24.56	19.41	21.99
Grains plant $^{-1}$(g)	Ranges	247.37-327.93	222.83-304.13		222.33-320.10	244.50-320.10		237.23-299.33	192.80-257.27		238.93-317.37	226.97-306.23	
	Means	292.81	265.44	279.13	281.20	281.20	287.90	264.01	218.47	241.24	285.16	271.86	278.51
Grain yield ha $^{-1}$ (Kg)	Ranges	1478.4-1834.7	1651.2-1867.2		1687.47-1945.07	1571.2-1990.93		1547.73-1821.33	1505.6-1813.87		1547.73-2054.93	1709.87-2105.07	
	Means	1655.09	1721.98	1688.54	1747.22	1756.66	1747.94	1657.75	1615.16	1636.46	1788.88	1892.96	1840.92

Table 6. Genetic (Vg), genotype × year (Vgy), environmental (Ve) and phenotypic (Vp), variances, heritability (h^2_{BS}) and selection response (Re) for various traits in buckwheat.

Traits	Location	Vg	Vgy	Ve	Vp	h^2_{BS}	Re
Days to flowering	Skardu	17.36	0.51	0.50	18.37	0.95	5.67
	Ghanche	15.26	1.27	0.63	17.16	0.89	5.15
Days to maturity	Skardu	6.04	0.65	0.55	7.24	0.83	3.13
	Ghanche	1.33	8.33	0.48	10.13	0.13	0.58
Plant height	Skardu	309.26	18.35	9.04	336.65	0.92	23.59
	Ghanche	96.94	25.26	4.40	126.60	0.77	12.06
Thousand grain weight	Skardu	17.27	0.14	0.82	18.23	0.95	5.66
	Ghanche	2.08	9.51	0.86	8.29	0.25	1.01
Grain number plant^{-1}	Skardu	584.60	-293.64	1542.40	1833.36	0.32	19.11
	Ghanche	400.66	275.98	435.26	1111.91	0.36	16.82
Grain yield hectare^{-1}	Skardu	7643.60	-88.71	14220.00	21774.89	0.35	72.52
	Ghanche	12394.70	9251.90	17842.70	39489.30	0.31	86.21

All genotypes showed high variation across two locations for plant height. Range for Tatary was 62.33-94.80 cm and for Common was 67.50-124.33 cm at Skardu. At Ghanche range for Tatary was 72.50-87.90 cm and for Common was 82.20-108.43 cm (Table 5). Genotype Gh-917 was the tallest while Rd-904 was the shortest at both locations. According to Baniya *et al*. (1995), the range for plant height varied from 5 to 102 cm in India, 63 to 149 cm in Korea and 25 to 116 cm in Nepal while 66.29 to 84.57 in Bangladesh (Debnath *et al*., 2008). As mentioned in Table 6, high heritability for plant height was observed at Skardu (0.92) than Ghanche (0.77). Similarly, the selection response under Skardu was also higher (23.59) than Ghanche (12.06) (Table 6). Subhani & Alam (1998) reported greater magnitude of broad sense heritability and expected genetic advances in a population derived from wheat crosses.

Significant variation was observed for 1000-grain weight among buckwheat genotypes (Table 4). Genotype (Sh-914) with more grain weight also produced higher grain yield indicating positive effect of grain weight on total grain yield. Range for Tatary was 19.11-25.83 g and for Common was 17.70-34.27 g at Skardu, while at Ghanche, the range for Tatary was 17.68-25.34 g and for Common was 16.49-29.56 g (Table 5). Xiaoling (1995) reported 11.0 - 49.5 g for 1000-grain weight in Common buckwheat and 14.5 - 23.7 g in tartary buckwheat. Similarly, Rana (2004) observed a range of 13.6-38.0 g for 1000-grain weight. High heritability and selection response were exhibited at Skardu for the 1000 grain weight but at Ghanche the heritability and selection response was low (Table 6).

Grain number plant^{-1} is one of the most relevant yield contributing trait in buckwheat but is highly influenced by environmental stresses. Means and ranges for grains plant^{-1} are given in Table 5. At Skardu a range of 222.83-327.93 for Tatary, 222.33-320.10 for Common was recorded, while at Ghanche the range was 192.8-299.33 for Tatary and 226.97-317.37 for Common was recorded. Baniya *et al*. (1995) also reported similar range of 238-472 grains plant^{-1} in buckwheat. As shown in Table 6, low heritability for grains plant^{-1} was recorded both at Skardu (0.32) and Ghanche (0.36). The expected selection response was high both at Skardu (19.11) and Ghanche (16.82) (Table 6). Low heritability (0.23) for grain number spike^{-1} was also obtained in a study conducted by Al-Marakby *et al*. (1994).

Grain yield of buckwheat genotypes ranged from 1478.40 to 1867.2 kg ha^{-1} (Tatary) and 1571.2-1990.93 kg ha^{-1} (Common) at Skardu, while 1505.6-1821.33 kg ha^{-1} (Tatary) and 1547.73-2105.07 kg ha^{-1} (Common) at Ghanche (Table 5). Buckwheat genotype Sh-914 was top ranking grain yield followed by genotypes Sh-913 and Gh-918 (data not shown). Joshi (2004) have reported low mean yield in buckwheat genotypes (790 to 1267.25 kg ha^{-1}), however Halbrecq *et al*. (2004) have reported grain yield of 2000-2500 kg ha^{-1} in buckwheat. Likewise, Rana (1998) and Senthilkumaran *et al*. (2008) reported genetic diversity on basis of yield and characterized buckwheat cultivars in India. According to their investigations, the diversity for grain yield in buckwheat ranged from 1540 to 2300 kg ha^{-1}. Low magnitude of heritability for grain yield was observed at both locations (0.31and 0.35). Using 20% selection intensity, expected selection response for grain yield at Skardu was 72.52 kg ha^{-1} and 86, 21 kg ha^{-1} at Ghanche (Table 6).

Cluster analysis: Cluster analysis divided all genotypes of two buckwheat species (*F. esculentum* and *F. tataricum)* into various groups and sub groups (Fig. 2). The genotypes clustered into three main groups. Group-I had two main clusters. Cluster - I had two sub-clusters; sub-cluster - I comprised of four genotypes i.e., Gh-901, Sh-903 Rd-904, Rd-906 which were collected from Saltoro Ghanche, Baha Shiger, Daso Rondu and Bilamik Rondu, respectively while sub-cluster - II also comprised of four genotypes viz., Gh-902, Gh-905, Sk-909 and Rd-912 which were collected from Gilgit, Ghomo Ghanche, Manthal Skardu, Stak Rondu and Tistey Shiger, respectively.

Cluster II had only one genotype (Sh-914) collected from Tistey Shiger. Six genotypes viz. Gh-901, Gh-902, Sh-903, Rd-904, Rd-904 and Rd-906 forming group I were from Tartary species, while three genotypes viz. Sk-909, Rd-912 and Sh-914 were for Common species. The genotypes in group II were sub-divided into three clusters. Cluster one possessed six genotypes (Rd-907, Sh-913, Gh-918, Gh-916, Rd-919 and Rd-920). Genotypes in cluster I were collected from Thowar Rondu, Zill Shiger, Tallis Ghanche, Haricon Ghanche, Baha Rondu and Daso. Cluster II possessed only one genotype (Gh-917) collected from Balghar Ghanche, while cluster III had three genotypes (Sh-908, Rd-915 and Rd-920) collected from Daso Shiger, Tormik Rondu and Baghicha, respectively. Group III had one cluster and one genotype (Skd-911) collected from Thalay Ghanche (Table 7).

Table 7. Distribution of 20 buckwheat genotypes in three different groups/clusters.

Groups/ clusters	Number of genotypes	Genotypes	Species
I	9	Gh-901, Gh-902, Sh-903, Rd-904, Gh-905, Rd-906	Tartary
		Sk-909, Rd-912 and Sh-914	Common
II	10	Rd-907	Tartary
		Sh-913, Gh-918, Gh-916, Rd-919, Rd-920, Gh-917, Sh-908, Rd-915 and Rd-910	Common
III	1	Gh-911	Common

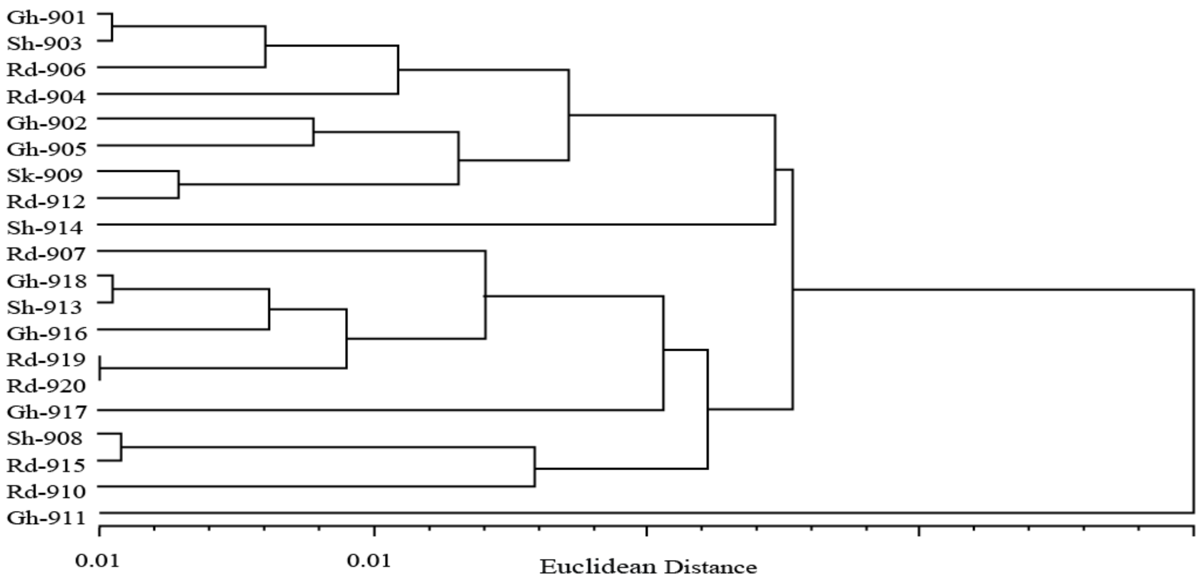

Fig. 2. Dendrogram presenting the genetic relationship among buckwheat genotypes used in the study.

It was apparent from the clustering pattern that the genotypes collected from the same valley were grouped into different groups. For instance the genotypes collected from Rondu appeared in three groups in spite of collection from the same valley and district which showed low genetic diversity based on geography. Our findings are in conformity with the investigation made by Debnath *et al*. (2008), who also found that genotypes collected from the same place did not form single cluster. They categorized 21 buckwheat genoty;pes collected from Bangladesh into five clusters on the basis of traits rather geography. Similarly, Masud *et al*. (1995) noticed same pattern in the genetic diversity of pumpkin.

Conclusions

A significant level of genetic variability was observed among different buckwheat landraces for traits of economic significance. The genotypes collected from different geographical locations of the country had close relationship which shows less variation in genetic diversity. Estimates of heritability were higher for flowering at both locations. However, maturity, plant height and 1000 grain weight had high heritability at Skardu only. High selection response was recorded for grain yield ha^{-1} and at both locations, however plant height and grain number plant^{-1} had more response to selection at Skardu. It can be concluded further that different valleys of Gilgit - Baltistan have a good source of genetic variability of buckwheat. This genetic diversity could be exploited for developing and tailoring cultivars for important traits like early maturity, higher yield and lodging resistance. Based on this studies genotypes collected from Thalay (Gh-911), Zill (Sh-913), Tistey (Sh-914), Haricon (Gh-916) and Tallis (Gh-918) had more diversity than the remaining genotypes. The genotypes collected from other geographical locations had close relationship among themselves showed narrow genetic diversity. The indigenous buckwheat landraces are further recommended for testing across high and mid valleys for GE interaction for stability along with hybridization efforts to broaden the genetic base.

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