Genotype x Environment Interaction and Stability for Grain Yield of Buckwheat (*Fagopyrum Tataricum* Geartn)

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Abstract

Stability analysis is an important step in developing cultivars. Seven buckwheat genotypes were evaluated at hilly regions of Nepal namely Dolakha, Ramechhap, Solukhumbu, Kaski, Dailekh, Surkhet, Jumla and Doti districts during winter seasons of 2017 and 2018 using randomized complete block design with three replications to identify stable and high yielding genotypes. The genotype × environment interaction for grain yield was significant ($P \leq 0.05$). The genotypes ACC#2227-1 (1.62 t/ha) and ACC#2223-1 (1.52 t/ha) were found higher sensitive to environment and produced higher mean grain yield across the locations. Joint regression analysis showed that genotypes ACC#2227-1 and ACC# 2223-1 had regression coefficient of 1.41 and 1.33, respectively. The coefficient of determination (R^2) for genotypes, ACC#2227-1 and ACC#2223-1 were higher. The GGE biplot analysis showed that ACC#2227-1 and ACC#2223-1 were more stable and adaptive across the locations; therefore, they can be taken for general cultivation.

Keywords: Buckwheat, G×E interaction, Stability, Grain yield

Introduction:

In Nepal, buckwheat is a sixth staple food crop after rice, wheat, maize, finger millet, and barley (MoALD, 2016/17 and Nepali *et al.*, 2019). It is considered as poor man's crop and is an alternate cereal that represents an important food supply in remote places of Himalayas. Both species of buckwheat species namely *Fagopyrum esculentum* Moench and *F. Tataricum* Geartn are grown in Nepal. It is staple food crop in high hills where it is grown as the major summer crop. In colder areas Tataricum type is more common where common buckwheat cannot be cultivated (Uprety, 1995). The total area of buckwheat cultivation was 11070 ha of land and total production and productivity was 1207 mt and 1.09 t/ha respectively (MoALD, 2016/17).

Common buckwheat (*Fagopyrum esculentum*) is grown throughout the country, whereas bitter buckwheat (*Fagopyrum tatricum*) is grown in the hilly area of Nepal. Hill Crops Research Program (HCRP), Dolakha, Nepal has 474 accessions of buckwheat where characterization and evaluation that includes common and Tataricum type from local and exotic sources (Uprety,1995).

Relatively wide adaptability has been observed in Tataricum type than in common buckwheat. It is the best crop in higher altitude in terms of adaptation to different climatic variables and easily fitted to different cropping patterns due to short duration. It is cultivated in marginal land in 61 out of 75 districts of Nepal from some 60 m to 4500 m above sea level, especially hilly and mountain districts like Rukum, Rolpa, Jajarkot, Dolpa, Humla, Jumla, Kalikot, Kavre, Dolakha, and Okhaldhunga, Mustang, Solukhumbu, and Taplejung districts regularly since time immemorial (Luitel *et al.,* 2017). Recently it has been grown in some Terai districts like Chitwan, Jhapa, and Nawalparasi for commercial purposes especially for green vegetable which has very high demand due to rutin chemical contents which is importance for control blood presser and sugar. Every family grows Tartary buckwheat in upper Mustang and Dolpa districts and diversity of buckwheat is very high in Manang, Dolpa, Mustang, Jumla, and Solukhumbu (Luitel *et al.,* 2017 and Joshi, 2008).

Buckwheat is a multipurpose crop and is grown for use as basic food, animal feed, vegetable, soup, beverage and medicine (Luitel *et al.,* 2017; Dhakal, 2015). All parts of buckwheat plants are used in various ways. The rutin produced by leaf is an important pharmaceutical product used to brew tea for the treatment of hypertonia. About a month, blooming flowers produce high-quality nectar forhoney; grains are the basic food; hulls of grains are used to make pillows; straw is a good source for livestock; green plants are used as green fertilizers (Luitel *et al.,*2017) and (Gondola *et al.*, 2010). In Nepal there is a list of 34 dishes prepared with buckwheat, such as dhindo (thick porridge), roti (bread), momo (Chinese pancake), lagar (very thick bread), dheshu (thicker than lagar), fresh vegetables, dried vegetables, Kancho pitho (raw flour), chhyang or jaand (local beer), raksi (alcohol), salad (leaves), pickle (fresh and dry leaves), soup, ryale roti, Noodle, sel roti, bhat (rice), sausage, dorpa dal, tea, vinegar, jam, macaroni, biscuit, cakes, mithai (sweet), haluwa, puri, puwa, bhuteko Phapar (roasted grain), satu, phuraula, porridge, and pakauda. Nepalese people from mountain region prefer dhind otha nother items due to their specific taste (Luitel *et al.,* 2017 and Joshi, 2008). Buckwheat can be used as a staple diet in Nepal by substituting highly polished rice. Buckwheat higher nutritional value and medicinal value acts as a food guard in the food security of Nepal. It has a multiple use thus providing hub for agro based industry. It is grown in marginal lands with harsh environmental conditions thus being friendlier with farmers. But its cultivation is decreasing, and its landraces are deteriorated due to various factors. Preserving germplasm planting local and races helps for long term sustainable agriculture in Nepal. It has an allelopathy effect thus we do not have to deal with weed problems like in other crops. It can easily cope with changing climate. Buckwheat flowers are very fragrant and are attractive to bees thus they can be used to produce special, strong, dark honey (Up, 2018). Buckwheat can be served as an alternative to rice. Raw buckwheat groats are rich source of lipid, protein and sterol in comparison to roasted buckwheat groats (Dziedzic *et al.,* 2015). Buckwheat contains high level of starch similar to many cereal grains (Qin *et al*. 2010). Components responsible for technological product may be concentrated or regulated to obtain a desired product (Skrabanja *et al.,* 2004). It grows well in areas with less fertile soil and little rainfall. Leaves and shoots of common buckwheat are leafy vegetable in Himalayan region (Arora *et al.,* 1995). Emphasis has to be given on conservation and utilization of various genetic resources of this multipurpose crop for economic and food security (Arora *et al.,* 1995).

The performance of a variety is linked to its capacity to adjust to the fluctuating edaphic and climatic situations. Significant interaction of G × E suggested that buckwheat germplasm should be tested through different years and locations. Several researchers have reported that the G × E and G × E × Y interactions are more important than G × Y interaction for yield in different crops like mungbean (Ullah *et al.*, 2011). It is generally felt that the improved varieties cater to only one climatic zone of hill. Therefore, the success of a variety depends not only on its high performance in a given environment but also on its ability to perform consistently well in ever changing environment. Thus, the phenotypic stability of varieties over a wide range of environment has received considerable attention in recent past. Tartary buckwheat (*F. Tataricum*) varieties suited to high hill condition rarely do well even under mid hill conditions. On the contrary, common buckwheat (*F. esculentum*) varieties adapted to mid hill conditions, do not perform well in high hills. The objectives of this study were to: (i) determine the magnitude of genotype by environment interaction for yield of buckwheat genotypes under hilly regions of Nepal; (ii) determine yield stability for buckwheat genotypes and (iii) to identify genotypes that are widely adapted (stable) and specifically adapted (with narrow adaptation) for the yield.

Materials and Methods

Seven buckwheat genotypes including Farmer's variety were evaluated for seven traits at eight locations namely Kaski, Ramechhap, Solukhumbu, Surkhet, Dolakha, Jumla, Doti, Dailekh during winter seasons of 2017 and 2018. Each trial was laid out in randomized block design with three replications. The field was prepared and moisture level was maintained through the irrigation before sowing. Well decomposed compost @ 5 t/ha and NPK @ 30:30:0 kg/ha as basal dose were applied for better yield. Full dose of P_2O_5 and K_2O and half dose of N were applied as basal dose and remaining 50% nitrogenous fertilizer was further split into two parts. First half dose at tillering stage and second half at the booting stage. Seed rate was 50-60kg/ha. Sowing was done manually at depth of 3-4 cm.The plot size for genotypes was 3×2 cm consisting of 12 rows. Row to row spacing was 25 cm and plant to plant was continous respectively. Thinning is practiced after 10-15 days of sowing to maintain the optimum plant population. A light irrigation was given at flowering stages. Observation on plant height (cm), number of primary branch, Number of flower cluster was recorded from 10 randomly selected plants from each replication. Observation on plant stand was recorded from 1 m^2 from each replication. The days to 50% flowering, days to maturity and grain yield were recorded on plot basis. The genotypes were evaluated based on measurement of grain yield. The grain yield was calculated using below formula (MoALD, 2016/17);

$$\text{Grain yield} \left(\frac{\text{kg}}{\text{ha}}\right) = \frac{(100 - \text{M}) \times \text{Plot yield (kg)} \times 10000\text{m}^2}{(100 - 12) \times \text{Net plot area } (\text{m}^2)}$$

Where,
M is the moisture content in percentage of the grains.
Net plot area = 6 m^2

Statistical analysis

Data from each location were subjected to Analysis of Variance (ANOVA) individually to explore differences among entries for grain yield trait and pooled across locations to determine G x E interaction. The significant G × E were used for stability analysis of Eberhart and Russell model (1966). A genotype with unit regression coefficient (bi=1) and deviation not significantly different from zero ($Sd^2i=0$) was taken to be a stable genotype with unit response.

Analysis of variance (ANOVA) was carried out on the data to assess the genotypic effects and mean comparisons among treatment means were estimated by the least significant difference (LSD) test at 5% levels of significance. The ANOVA was performed using RCBD to derive variance components using

GenStat statistical package (12th edition) (Payne *et al.*, 2009). The stability analysis was done using GEAR software Version 4.1 (Pacheco *et al.*, 2015).

Results and Discussion:

Genotypes × Environment Interaction:

Variation due to genotypes × environment interaction was significant for days to flowering, days to maturity, plant height and grain yield, which indicated variable response of genotypes across locations over years indicating the environment influence on these characters (Table 1). The locations differed greatly in altitude, temperature and rainfall variation that affected performance. Huang *et al.* (2017) reported that climatic and soil factor of different location influenced the grain yield. Aliu and Fetahu, (2010) have reported that various morphological and biochemical traits were highly influenced by the genotype × environment interactions. Results of the study were similar to the findings of Dhiman *et al.* (2002), who reported significant G x E interaction for different traits in buckwheat.

Table 1. Statistical analysis of days to 50% flowering, days to maturity, plant height and grain yield across eight locations and two years (2017 and 2018) for 7 buckwheat genotypes.

SN	Genotypes	Days to flowering (50%)	Days to maturity (75%)	Plant height (cm)	Grain yield (t/ha)
1	Sample-9	46	83	91	1.23
2	ACC#2223-1	45	77	83	1.52
3	Sample-6-1	47	79	86	1.15
4	ACC#2201-2	48	79	89	1.28
5	Kabre Bitter	44	79	84	1.16
6	ACC#2227-1	44	77	85	1.62
7	Farmer 's local check variety	45	76	92	1.09
	Grand Mean	45	78	87	1.29
	P-value	0.08	0.15	0.02	0.00
	Gen x Env	0.00	0.00	0.00	0.00
	Env	0.12	0.12	0.98	0.47
	CV (%)	5.53	4.77	5.30	10.63
	LSD0.05	3.00	5.00	6.00	0.14

Significant interaction of G × E suggested that buckwheat germplasm should be tested through different years and locations. Several researchers have reported that the G × E and G × E × Y interactions are more important than G × Y interaction for yield in wheat (Saeed *et al.*, 2016). Significant G × E (L) interactions indicated that these genotypes tended to rank differently for majority of the traits at different locations (Table 1). Varied response of genotypes was observed at different locations for days to flowering with range of 44 to 48 days with mean of 45 days (Table 1). The variation in days to flowering indicated the response of buckwheat to changing climate and also signifies exploration of its potential for changing environment. Results of this study were similar to the finding of Debnath *et al.*, *(*2008). The genotypes exhibited inconsistent response for days to maturity (Table 1). 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 75% maturity across locations and over years, the genotypes ACC#2227-1, ACC#2223-1 and farmer's variety matured early. Similarly range of diversity for maturity of across the locations and over the years was 73 to 90 days and similar findings in Tatary buckwheat was reported by Zhou and Arora (1995). All genotypes showed high variation across locations and over the years in plant height and it ranged from 92 to 83 cm with mean value of 87 cm. Similar finding on buckwheat varied 5 to 102 cm in india,63 to 149 cm in Korea and 25 to 116 cm in Nepal (Baniya *et al.*, 1995 and Debnath *et al.*, 2008). Mean grain yield of buckwheat genotypes ranged from 1.09 t/ha to 1.62

t/ha. Buckwheat genotypes ACC#2227-1(1.62 t/ha) was top ranking grain yield fallowed by genotypes ACC#2223-1 (1.52 t/ha) across location over the year. These results were similar to the finding of Joshi (2004) who reported low mean grain yield in buckwheat genotypes which was 0.709 to 1.26 t/ha and Halbrecq *et al*., (2004) who recorded 2 to 2.5 t/ha.

Stability analysis:

An ideal genotype gives the highest yield across tested environments and is suitable in its performance. For broad selection, the ideal genotypes are those that have both high mean yield and high stability. An "ideal" view was drawn (Figure 1) that showed ACC#2223-1 and ACC#2227-1 were the closest to the ideal genotype. A genotype closer to the "ideal" genotype was more desirable. The genotypes would be more suitable when they are close to the performance line.

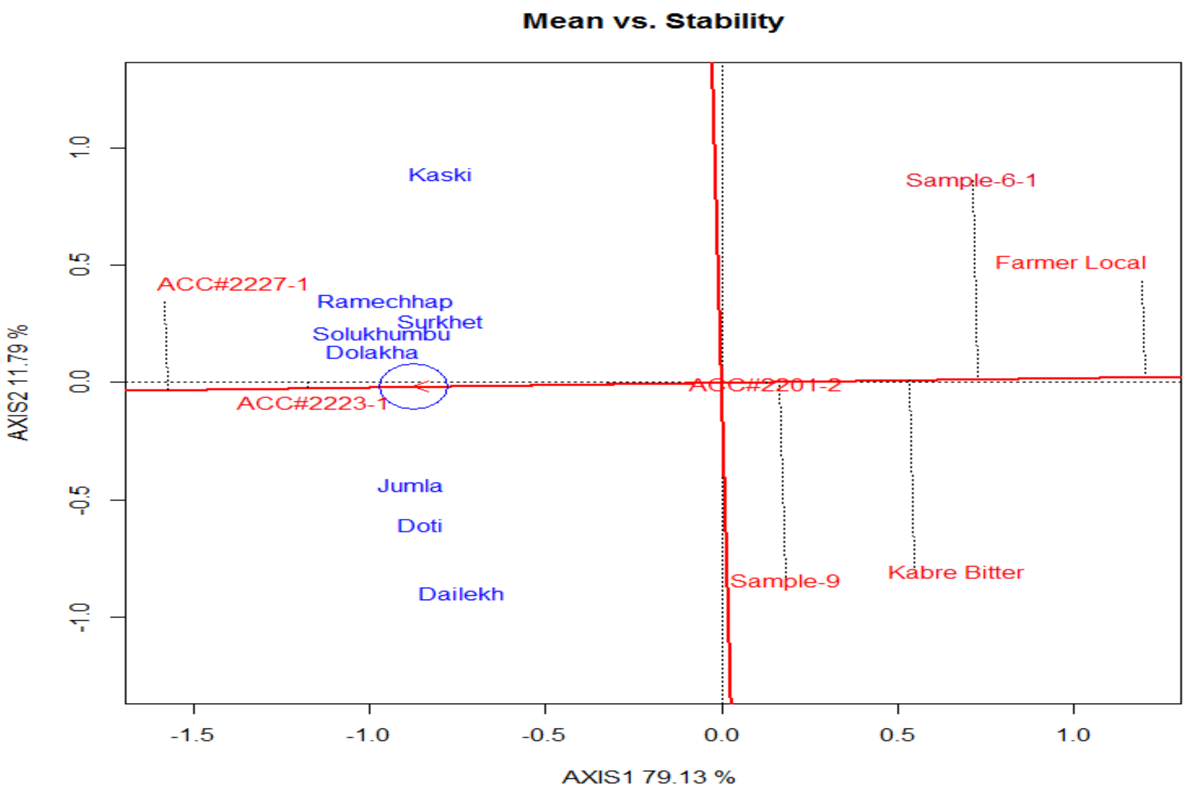

Figure 1. GGE biplot of 7 Buckwheat genotypes for mean yield and stability across 8 locations and two years

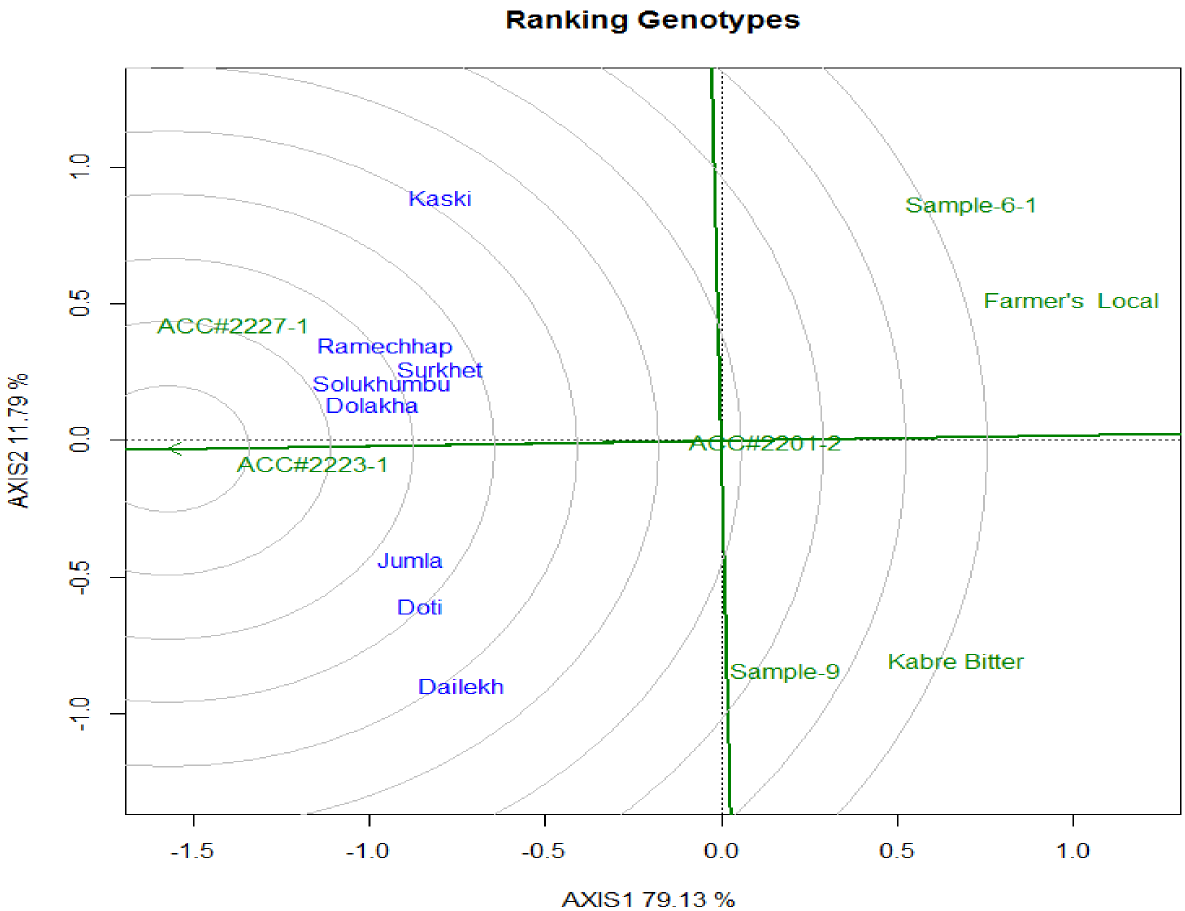

Figure 2. Comparison of 7 Buckwheat genotypes with the ideal genotype.

Figure 2 showed that the buckwheat genotype ACC#2227-1 and ACC#2223-1 that most suitable than other genotypes because they were near to ideal genotype, these two genotypes consisted of the smallest concentric ring indicating more stability. The biplot (Figure 3) represented a polygon indicating that the vertex genotypes were ACC#2223-1, ACC#2227-1, Kabre bitter, ACC#2201-2, Sample-9, Sample-6-1and farmer's variety. The genotypes positioned on the vertexes have the longest distance from the biplot origin; they were supposed to be the most responsive either best or the poorest at one or every environment. The allocation of potential mega-environments was shown by "which won where" graph. The lines perpendicular to the polygon separated the mega-environments. The buckwheat genotypes ACC#2227-1 and ACC#2223-1 were suitable for all testing locations.

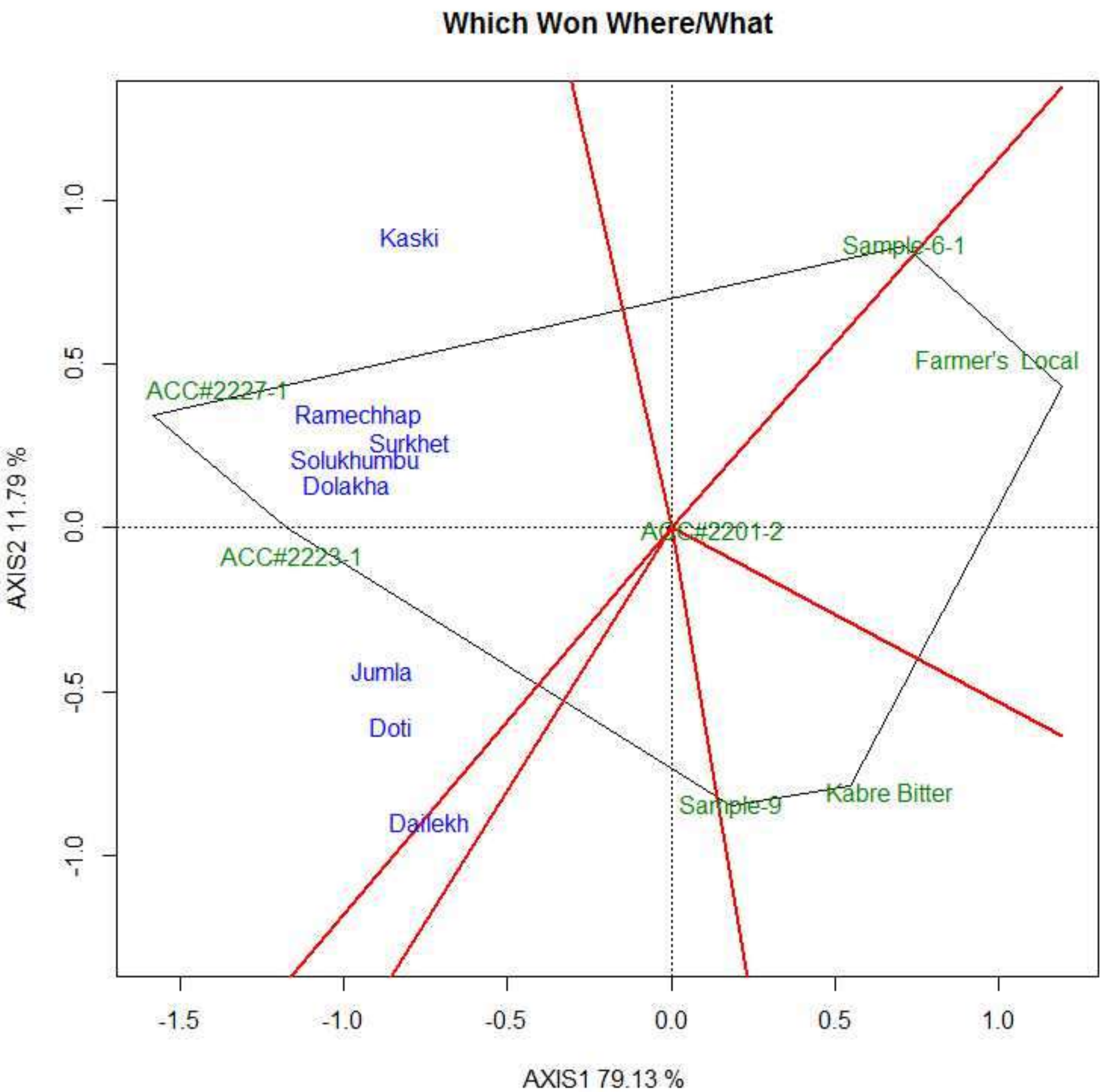

Figure 3. Polygon view of GGE biplot to the identification winning of buckwheat genotypes and their related mega environments

Table 2. Mean grain yield values (t/ha) and stability parameters for seven buckwheat genotypes across eight environments and two years 2017/18

S.N.	Genotypes	Grand Mean	Sd	CV(%)	bi	S^2di	R^2
1	Sample-9	1.23	0.18	14.27	1.33	0.01	59.97
2	ACC#2223-1	1.52	0.19	12.71	1.13	0.00	69.03
3	Sample-6-1	1.15	0.14	12.21	0.49	0.01	18.04
4	ACC#2201-2	1.27	0.18	13.79	1.17	0.00	64.42
5	Kabre Bitter	1.16	0.07	5.79	0.25	-0.01	19.89
6	ACC#2227-1	1.62	0.25	15.14	1.11	0.01	70.45
7	Farmer 's local check variety	1.08	0.13	12.28	0.92	0.00	68.71
	Total	**1.29**					

bi = regression coefficient, Sd = Standard deviation, R^2 = coefficient of determination. (Eberhart and Russell, 1966).

Previously, various stability measurements have been used by different workers. Eberhart and Russel (1966) stressed the need to consider both linear and nonlinear components in Genotype x Environmental Interaction in evaluating the stability of the genotypes. The coefficient of regression (bi) explained the adaptiveness of the tested genotypes over the evaluated environments. The varieties with b-value near to unity and highest mean grain yield show the more average stability. The Figure 3 showed that ACC#2227-1 and ACC#2223-1 were the highest grain yield and were suitable genotypes. Their means of grain yield were 1.62 t/ha and 1.52 t/ha and bi value were 1.11 and 1.13 respectively (Table 2). Therefore, these genotypes were more desirable because of their its mean yields were higher with greater coefficient of determination (R^2=0.70,0.69) respectively.

Conclusion:

Identification of stable superior buckwheat genotypes is the most important task in buckwheat development program. The significant genetic variability was observed among buckwheat genotypes for agronomical traits. The results indicated that yield performance of buckwheat genotypes was influenced by GE interaction effect, the environments and genotypes as well. Thus, the highly significant G × E effects suggest that genotypes may be selected for adaptation to specific environment. Grain yield is a complex trait that is affected by a number of component characters along with the environment directly or indirectly. GGE biplot analysis showed that stable genotypes ACC#2227-1 and ACC#2223-1 were more stable and adaptive across the tested environment of Dailekh, Surkhet, Ramechhap, Solukhumbu, Kaski, Jumla, Doti and Dolakha respectively. Thus, these genotypes were found promising and could be released and recommended to farmers for general cultivation in hilly region of Nepal.

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Conflict of interest:

The authors declare no conflicts of interest regarding publication of this manuscript.

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Annex 1. Statistical analysis of grain yield across eight locations and two years (2017 and 2018) for 7 buckwheat genotypes.

SN	Genotypes	Dolakha	Ramechhap	Solu	Surkhet	Kaski	Jumla	Dailekha	Doti
	Year 1(2017)	**GY (t/ha)**	**GY(t/ha)**	**GY(t/ha)**	**GY(t/ha)**	**GY (t/ha)**	**GY(t/ha)**	**GY (t/ha)**	**GY(t/ha)**
1	ACC#2227-1	1.73	2.045	1.62	1.50	1.60	1.50	1.23	1.50
2	ACC#2223-1	1.69	1.765	1.56	1.40	1.52	1.40	1.25	1.40
3	Sample-9	1.41	1.24	1.20	1.15	1.20	1.15	1.15	1.15
4	ACC#2201-2	1.58	1.23	1.15	0.99	1.40	0.99	1.18	1.0
5	Kabre Bitter	1.38	1.13	1.12	1.01	1.02	1.01	1.21	1.0
6	Farmer's variety	1.24	1.04	1.00	0.97	1.26	0.97	0.97	0.97
7	Sample-6-1	1.37	1.17	1.17	1.11	1.23	1.11	0.96	1.20
	P value	0.00	0.00	0.00	0.00	0.00	0.00	0.165	0.00
	$LSD_{0.05}$	0.19	0.35	0.17	0.11	0.06	0.11	0.27	0.11
	Year 2(2018)								
1	ACC#2227-1	1.31	1.86	1.62	1.71	1.63	1.57	1.12	1.71
2	ACC#2223-1	1.27	1.76	1.51	1.61	1.47	1.51	1.14	1.61
3	Sample-9	0.96	1.06	1.02	1.36	1.23	1.5	1.05	1.20
4	ACC#2201-2	1.28	1.23	1.15	1.20	1.36	1.73	1.11	1.36
5	Kabre Bitter	1.08	1.05	1.15	1.22	1.28	1.26	1.11	1.24
6	Farmer's variety	0.88	1.04	0.94	1.18	1.31	1.20	0.87	1.16
7	Sample-6-1	1.12	1.16	1.85	1.32	1.48	1.4	0.86	1.22
	P value	0.06	0.00	0.00	0.00	0.02	0.02	0.24	0.00
	$LSD_{0.05}$	0.28	0.28	0.20	0.11	0.20	0.73	0.32	0.11

التفاعل الوراثي البيئي وثباتية الغلة الحبية في الحنطة السوداء (*Fagopyrum Tataricum* Geartn)

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الملخص

يعتبر تحليل الثباتية خطوة هامة في تحسين الأصناف. تم تقويم سبعة أصناف من الحنطة السوداء في مناطق تلال نيبال وهي: دولاكا، ورامیتشاب، وسولوكومبو، وكاسكي، وديليكا، وسوركيت، وجوملا، ودوتي، وذلك خلال شتاء موسمي 2017 و2018 وفق تصميم القطاعات الكاملة العشوائية وبثلاثة مكررات، من أجل تحديد الأصناف التي تتميز بالثباتية والغلة المرتفعة. بينت النتائج معنوية التفاعل الوراثي البيئي ($P \leq 0.05$)، وقد أظهر الصنفان ACC#2227-1 (1.62 طن/هكتار) وACC#222-1 (1.52 طن/هكتار) أكثرها حساسية للظروف البيئية والأعلى في الغلة الحبية على مستوى كافة المواقع، كما بلغت قيم معامل الانحدار 1.41 و1.33 للصنفين على التوالي، وقد كانت قيم معامل التحديد لهما أيضاً مرتفعة. وأظهر التحليل GGE biplot ثباتية هذان الصنفان عبر مواقع الدراسة، وبالتالي يمكن اعتماد هذان الصنفان للزراعة في كافة المواقع.

الكلمات المفتاحية: الحنطة السوداء، التفاعل الوراثي البيئي، الثباتية، الغلة الحبية.