Research Article:

SELECTION OF LENTIL GENOTYPES WITH STABLE YIELD AND PROTEIN CONTENT ACROSS DIVERSE ENVIRONMENTS

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ABSTRACT

Lentil (*Lens culinaris* Medik.) is a cool-season crop, rich in protein, dietary fiber, and micronutrients like iron, zinc and selenium with low fat. The effect of environment, genotypes and their interaction are important in determining yield and nutritional content of a crop. This study was designed to investigate the effects of genotype and environmental interaction on yield and grain protein stability in twelve lentil genotypes. Experiment was conducted at three diverse environments of Khajura (Banke), Khumaltar (Lalitpur) and Bijayanagar (Jumla) during winter season of 2020/21 using alpha lattice design with two replications. Data were recorded for days to flowering, days to maturity, plant height, number of pods per plant, number of seeds per pod, hundred seed weight, and grain yield. Protein content was analyzed by Kjeldahl method. The stability and genotype by environment interaction were examined with AMMI and GGE biplot methods. Results showed that yield and protein content are influenced by all of genotype, environment and genotype by environment interaction. Environment is identified as the leading factor in causing yield variation. Genotype X2011S-183-11 yielded (983 kg/ha) most stably of all among test environments in the panel of genotypes, although environment-specific adaptation of genotypes to could be noted owing to their higher marginal yield at certain environment. The highest protein content was observed in the genotype X2011S-223-6 (25.0%) with better specific adaptation to Vijayanagar, Jumla while most stable expression of grain protein was found in genotype X2011S-125-23 (23.6%) across test environments. The tested genotypes can serve as valuable resource, in lentil improvement program, to breed for high and stable yield and grain protein content.

Keywords: AMMI, environment, genotype, GGE biplot, grain protein content

INTRODUCTION

Lentil shares about 60% in area and 65% in production, of all grain legumes produced in Nepal. It is cultivated in area of 1,45,954 ha of land and the total production under the cultivated area was 1,52,936 MT (MoALD, 2025). Lentil is a versatile crop that can be cultivated under mono-, mixed-, inter-, and relay-cropping systems. It can fix atmospheric nitrogen if effectively nodulated. Under favorable conditions, it can fix about 49.20 kg ha-1 of atmospheric nitrogen in the soil in association with symbiotic bacteria (Gan et al., 2017). In semi-arid areas, they serve as important cover- as well as green manure-crop (Allen et. al, 2011). Lentil is rich in high dietary fiber content, low in fat content and has no cholesterol. Lentil seeds contain 1-2% fat, 24-26% protein, 56-58% carbohydrate, 2.1% minerals, and 3.2% fiber (USDA, 2026). For its dense nutritional property, lentil is consumed as dal with rice in Nepal. With increasing number of studies confirming health benefits of lentil consumption in terms of cardiovascular and cancer disease protection (Papandreou et al., 2019), the crop is gaining worldwide popularity as well as rise in demand.

Abiotic stresses like soil moisture, heat, and drought stress are major lentil limiting factors that affect lentil production the most (Venugopalan et al., 2021). Sehgal et.al (2017) reported that abiotic stress such as cold, drought reduces 20-45% in aboveground biomass. Likewise, Johansen et.al (1994) reported about 54% yield loss due to prolonged abiotic stress. The evaluation of genotypes is the key to utilization in breeding programs. Worldwide, legume research programs routinely test large number of accessions as well as introgression lines for their nutritional properties and adaptive traits. At a domestic level, researchers are also required to ensure stable performance of genotypes over a wide range of environments as large number of growers seek high production (Gauch et al., 2006) amid increasingly uncertain climatic scenarios.

Cold tolerance in lentils is an essential trait for their successful cultivation in regions with colder climates. To increase lentil yield and expand its cultivation to areas with challenging environmental conditions, it is essential to identify and breed for characteristics that are resistant to cold. Likewise, protein quality is a key factor in lentil production as it determines the nutritional value of the final product. High protein content lentil varieties can increase production and attract more consumers. The performance of a genotype is determined by three factors: genotypic main effect, environmental main effect and their interaction (Yan et al., 2007). Environmental factors include soil moisture, sowing time, fertility, temperature and day length, all of which have accumulated effect as plant progresses through various growth stages (Bull et al., 1992). Advanced breeding materials must be evaluated in multiple locations for selection and yield testing (Pobkhunthod et al., 2022). Multi-environment testing of genotypes for quantitative attributes, mainly yield and it’s component traits, helps to determine effects of genotype by environment interactions, and thus paints a picture of their performance stability when adopted later at a wider scale. Current study, consisting of replicated varietal trial at three sites, was carried out to investigate the effects of genotype and environmental interaction on grain yield and protein stability in twelve lentil genotypes.

RESEARCH METHODS

Plant materials: Twelve lentil genotypes named X2011 S-123-3, X2011S-183-11, X2013-266-2, X2011S-243-12, X2011-213-6, X2011-115-23, X2011 S-226-5, X2011S-196-18, X2011S-33-9, ILL 10690, ILL-10947 and Khajura Musuro-3 (check) were used in this experiment. All genotypes were obtained from Grain Legumes Research Program, Khajura, Banke.

Experiment sites: Experiments were conducted in the fields of National Plant Breeding and Genetics Research Center, Nepal Agricultural Research Council (NARC), Khumaltar, Lalitpur (E3); Grain Legumes Research Program (GRLP), Khajura, Banke (E2); and Agriculture Research Station (ARS), Vijayanagar, Jumla (E1), respectively. Khumaltar, Lalitpur is at an altitude of 1,368 masl with 27º40’ N Latitude and 85º20’ E Longitude, Khajura, Banke is at the altitude of 181 masl with 28º06′ North latitude and 81º37′ East longitude and likewise Vijayanagar, Jumla is at the altitude of 2300 masl with 29º 17’ North latitude and 82º10’ East longitude.

Experiment design: The experiment was laid out in an alpha lattice design (block size: 4; number of blocks: 3) with 12 treatments, arranged in 4 blocks per replication and 3 plots per block, with two replications. A plot size of (2 × 1.5) m^2 was utilized for the experiment with 0.25m row spacing and continuous plant-to-plant spacing. The field was prepared for cultivation with tillage on 19th November 2020 in Khumaltar, 16th October, 2020 in Khajura and in 30th November, 2020 in Vijayanagar.

Cultural practices: The recommended dose of inorganic fertilizers @ 20:40:20 ($N:P_2O_5: K_2O$) kg/ha was applied as basal. The entire amount of phosphorus (DAP), potassic fertilizer (MOP), and nitrogenous fertilizer (Urea) were applied at the final land preparation. All other practices were performed on requirement basis as recommended for the cultivation of Lentil.

Observed traits: During in-season growth, observations were taken for early stand, final plant stand, days to flowering, and days to maturity, plant height and number of pods per plants. Plot yield, number of seeds per pod and thousand kernel weight were recorded upon harvest and shelling of the pods. Descriptors were recorded based on suggestions by IBPGR (1985).

Protein analysis

Seed protein content was analyzed by Kjeldahl method (Bremner, 1960) in Animal Nutrition Lab, Agriculture and Forestry University. Proximate analysis with Kjeldahl method involves two distinct steps: digestion, distillation and filtration. Digestion apparatus consist of heating units, round-bottom flasks, filter paper, dry sample, K_2SO_4 (5gm/gm sample), $CuSO_4$ (0.25 gm/sample), conc. H_2SO_4 (15-20 ml), volumetric flask, and distilled water. Likewise, distillation system consist of flasks, digested volume, indicator (Red + Blue) 0.5ml, conical flask, NaOH solution (95%) 50 ml, Boric acid (2%) 100 ml. Finally, filtration system consists of H_2SO_4 solution (0.01 N) and burette stand. At first, 1 g of the dry sample was taken in filter paper and put in a digestion flask. Then, 5 g of K_2SO_4, 0.25 gm of $CuSO_4$ and 20 ml of conc. H_2SO_4 was added to the flask and was kept in an inclined position in the digestion assembly until floating ceased. Acid boils vigorously and is digested in about 2-3 hours. The digested sample was then transferred to a volumetric flask and final volume was made up to 250 ml by adding distilled water. After that, 50 ml of digested volume along with 50 ml of 95% NaOH was then kept in a distillation flask of capacity of 250 ml. The distillate was then received (condensed by NH3) in a conical flask filled with 100 ml of 2% boric acid. For this, the apparatus was immediately airtightly closed and heated. Afterward, 150 ml of distillate (boric acid + ammonia) was taken in a conical flask and titrated against 0.01 N H_2SO_4 until the final color appears to be green. At this point, titrate value was recorded.

Statistical analysis

Aggregate statistics like mean, standard deviation, coefficient of variation, standard error, heritability and genetic advance were computed for important traits. All statistical analyses were conducted using R statistical software version 4.1.1. Initially, a combined analysis of variance (ANOVA) was employed to assess the existence of genotype by environment interaction (GEI) using metan R package (Olivoto et al., 2020). Subsequently, multivariate stability and GEI were examined through the application of the Additive Main Effects and Multiplicative Interaction (AMMI) (Equation 1) and Genotype Main Effects plus Genotype-Environment Interaction (GGE) biplot methods. AMMI model was formulated to comprehensively accommodate all factors that may be of relevance, including genotype, environment and genotype x environment, to enable prudent partitioning of variance components. This is to account for the fact that environment, in comparison to genotype or interaction components, could constitute a significant source of variation. Moreover, Interaction Principal Component (IPC) weights of the AMMI model hold greater validity in predictive scenarios were interaction component is thought to influential (Sa'diyah et al., 2016). The GGE biplots were generated based on multi-environment trial data of yield and protein content to create visual representations of various models. These methods draw upon the foundational concepts of GGE introduced by Yan and Kang (2003), and Yan et al. (2007), with a specific focus on mega-environment assessment.

$$Y_{ger} = \mu + \alpha_g + \beta_e + \sum_{n=1}^{N} \lambda_n \gamma_{gn} \delta_{en} + \rho_{ij} + \varepsilon_{ger} \text{Equation (1)}$$

Where:

- Y_{ger} : Yield of genotype *g* in environment *e* for replication *r*.
- μ: Grand mean.
- α_g: Mean deviation of genotype *g* (genotypic main effect).
- β_e: Mean deviation of environment *e* (environment main effect).
- λ_n: Singular value for the *n*-th Interaction Principal Component (IPC) axis
- γ_{gn}: Genotype eigenvector (IPC score) for axis *n*.
- δ_{en}: Environment eigenvector (IPC score) for axis *n*.
- ρ_{ij}: Residual noise.
- ε_{ger}: Error term.

RESULTS AND DISCUSSION

Morphological and quality traits

The pooled mean performance of lentil genotypes across three environments are shown in Table 1. The number of flowering days ranged from 108 to 124 with an average of 117.5 days across all environments. Except for genotype X2011S-226-5, all other genotypes recorded the longest flowering days than the check genotype, Khajura-Musuro-3. Maturity days ranged from 156 to 173 with an average of 167. All the genotypes recorded the longest maturity days than the check genotype. Plant height varied from 30.0 to 37.3 cm with a mean of 34.1 cm across all environments. All other genotypes recorded the lowest plant height than the check genotype, except for genotype X2011S-226-5. Number of pods per plant had a high degree of variability from 24 to 40 with a mean of 29. Check genotype, Khajura Musuro-3 showed the highest number of pods per plant than the rest of the genotypes. There was no significant variation of number of seeds per pod for the lentil genotype across environments. The observed average hundred seed weight was 2.7 g ranging from 2.3 to 3.3 g. All the genotypes recorded as higher hundred seed weights than the check genotype, Khajura-Musuro-3. The grain yield showed a wide range of variability (367.9 to 1338.8 kg), with a mean of 668.6 kg. Check genotype, Khajura-Musuro-3 recorded the highest grain yield of the rest of the genotypes. The previous studies conducted at different date and places also suggested a large and exploitable variation in different lentil germplasm (Hussain et al., 2022; Gleridou et al., 2022; Vanave et al. 2019, Neupane et al., 2020). The crude protein percentage ranged from 21.7 % to 25.0 % across the environments, with an average of 23.4%. All the genotypes recorded higher percentage of crude protein than the check genotype Khajura-Musuro-3 except X2011S-226-5. The variation of protein content in this study was also supported by the experiment result of Subedi et. al (2022).

Table 1. Pooled mean performance of lentil genotypes across three environments of Vijayanagar, Khajura and Khumaltar, Lalitpur

Genotypes	DF (days)	DM (days)	PH (cm)	PP	SP	HSW (g)	YP (kg)	GY (kg/ ha)	CP (%)
X2011S-123-36	113	167	35.7	28	2	2.9	0.2	605.8	22.7
ILL 10947	124	171	33.9	27	2	2.7	0.2	490.2	22.9
X2011S-183-11	110	161	34.2	33	2	2.4	0.3	983.4	24.0
X2013-266-2	119	168	31.7	28	2	2.9	0.1	390.2	23.1
X2011S-243-12	123	170	32.0	24	2	2.3	0.1	367.9	23.0
X2011S-223-6	122	170	32.4	30	2	3.2	0.2	489.1	25.0
X2011S-125-23	118	168	34.3	26	2	3.3	0.2	591.6	23.6
X2011S-226-5	108	163	37.3	28	2	2.6	0.2	797.6	21.7
X2011S-196-18	122	173	35.1	31	2	3.1	0.2	572.9	23.9
ILL10690	124	170	35.6	29	2	2.4	0.1	452.9	23.8
X2011S-33-9	120	170	30.0	25	2	2.5	0.3	942.2	24.3
Khajura Musuro -3	108	156	36.4	40	2	2.3	0.4	1338.8	22.6
Min	108	156	30.0	24	2	2.3	0.1	367.9	21.7
Max	124	173	37.3	40	2	3.3	0.4	1338.8	25.0
Mean	117.5	167	34.1	29	2	2.7	0.2	668.6	23.4
CV (%)	3.2	0.9	9.3	11.0	13	30.8	15.7	15.7	0.09
$LSD_{(0.05)}$	4.0	5.3	8.7	3.5	4	1.3	0.2	187.1	1.2
p-value	<0.01	<0.01	NS	<0.01	NS	NS	<0.01	<0.01	<0.01

***: Significant at 0.01 of significance level and *: Significant at 0.05 of significance level, DF = Days to Flowering, DM = Days to Maturity, PH = Plant Height, PP = Number of pods per plant, SP= Number of seeds per pod, HSW = Hundred seed weight, YP = Yield plot, GY = Grain Yield, CP = Crude Protein, Mean, CV = Coefficient of Variation; NS (in p-value)=Non Significant at 5% level.*

Performance of mean yield of 12 lentil genotypes at three location are shown in Table 2.There was significant variation ($p < 0.01$) among genotypes for grain yield at three locations (Khajura, Banke, Vijayanagar, Jumla, and Khumaltar, Lalitpur), suggesting substantial genetic variability and differential adaptation. At Khajura, Banke, grain yield ranged from 506.0 to 2335.0 kg ha^{-1}, with a mean yield of 962.4 kg ha^{-1}. The highest yielding genotype was Khajura Musuro-3 (2124.0 kg ha^{-1}), followed by X2011S-183-11 (1481.0 kg ha^{-1}) and X2011S-226-5 (1317.5 kg ha^{-1}). At Vijayanagar, Jumla, yield ranged from 196.7 to 1580.0 kg ha^{-1}, with an average of 554.4 kg ha^{-1}. The genotype X2011S-33-9 produced the highest grain yield (1548.3 kg ha^{-1}), followed by X2011S-183-11 (735.0 kg ha^{-1}) and X2011S-125-23 (673.3 kg ha^{-1}). Similarly, at Khumaltar, Lalitpur, grain yield varied from 99.0 to 1766.0 kg ha^{-1}, with a mean of 489.0 kg ha^{-1}. The check genotype Khajura Musuro-3 recorded the highest yield (1592.3 kg ha^{-1}), followed by X2011S-226-5 (792.0 kg ha^{-1}) and X2011S-183-11 (734.3 kg ha^{-1}). Across locations, genotypes X2011S-183-11, X2011S-226-5, and Khajura Musuro-3 consistently performed well, suggesting broader adaptability and superior yield potential. In contrast, some genotypes such as X2013-266-2 and X2011S-243-12 showed lower yields across environments, indicating poorer adaptation or lower yield potential. Overall, the significant genotype differences across locations demonstrate the importance of multi-environment testing for identifying stable and high-yielding lentil genotypes suitable for diverse agro-ecological conditions of Nepal. Previous studies conducted at different date and places also suggested a large and exploitable variation in different lentil germplasm (Sharma et al., 2022; Hussain et al., 2022; Gleridou et al., 2022; Vanave et al. 2019, Neupane et al., 2020).

Table 2. Mean performance of lentil genotypes for grain yield and crude protein at different three environments of Vijayanagar, Khajura and Khumaltar, Lalitpur

Genotypes	Grain Yield (kg/ha)			Crude Protein (%)		
	E1	E2	E3	E1	E2	E3
X2011S-123-36	633.3	903.5	280.5	18.83	25.49	24.47
ILL 10947	620.0	685.5	165.0	21.11	26.23	24.02
X2011S-183-11	735.0	1481.0	734.3	19.03	25.19	23.77
X2013-266-2	293.3	638.0	239.3	19.21	25.43	24.02
X2011S-243-12	351.7	537.5	214.5	20.43	26.29	24.37
X2011S-223-6	386.7	759.0	321.8	20.21	26.03	25.52
X2011S-125-23	673.3	870.5	231.0	20.63	26.79	24.77
X2011S-226-5	283.3	1317.5	792.0	23.91	27.13	23.82
X2011S-196-18	505.0	743.5	470.3	17.53	25.19	23.37
ILL10690	323.3	713.5	321.8	18.81	25.63	24.92
X2011S-33-9	1548.3	775.0	503.3	21.53	26.79	24.67
Khajura Musuro -3	300.0	2124.0	1592.3	18.31	24.93	24.72
Min	196.7	506.0	99.0	17.3	24.6	23
Max	1580.0	2335.0	1766.0	24.3	27.5	25.7
Mean	554.4	962.4	489.0	20.0	25.9	24.4
CV (%)	14.7	17.4	25.0	0.53	2.2	0.4
$LSD_{(0.05)}$	187.0	384.9	279.9	0.23	1.25	0.21
p-value	<0.01	<0.01	<0.01	<0.01	<0.05	<0.01

AMMI model based variance estimates

Stability analysis using AMMI model first fits the additive effects for the genotypes and the growing environments, followed by the multiplicative term for genotype-environment (GE) interactions. The AMMI analysis of variance indicated highly significant ($p < 0.01$) effects of genotype, environment, and interaction for almost all traits as shown in Table 3.

Table 3. AMMI analysis of variance for different morpho-physiological and quality traits of lentil genotypes

Source	DF	FD MSS	MD MSS	PH MSS	PP MSS	SP MSS	HSW MSS	YP MSS	GY MSS	CP MSS
ENV	2	3984.5**	11331.7**	430.2**	6699.7**	4.6**	18.1*	0.1**	1579905**	293**
GEN	11	212.5*	140**	27.8	115.3*	0.2	0.7	0**	511234**	3.1**
GEN: ENV	22	238.9*	29.2*	26.6	122.5*	0.2	0.5	0*	240751.3*	3.6**
PC1	12	425.9**	44.7*	41.1	204.2*	0.3	0.9	0**	422967.2**	3.3**
PC2	10	14.4	10.5	9.3	24.5	0.1	0	0	22092.2	0
Residual	3	13.8	2.2	9.9	10.2	0	0.6	0	10975.4	0.0
Total	93	225.9	275.1	32.1	234.8	0.2	0.8	0	214741	5.9

***: Significant at 0.01 of significance level and *: Significant at 0.05 of significance level, DF = Degree of Freedom, FD = Flowering date, MD = Maturity date, PH = Plant height, PP = Number of pods per plant, SP= Number of seeds per pod, HSW = Hundred seed weight, YP = Yield plot, GY = Grain yield, CP = Crude protein, ENV = Environment, GEN=Genotype*

Biplot analysis of grain yield

The GGE biplot for grain yield (Fig. 1) showed high PCA1 and PCA2 scores for the grain yield plotted on X- and Y-axis. The genotypes X2013-266-2, X2011S-223-6, and ILL10690 were found to be non-sensitive to environmental interaction forces because they were proximal to the origin, however, the rest of the genotypes were shown to be very responsive to environmental interaction forces, because they were far off the origin. E1 (Vijayanagar) had almost zero scores on the first PCA1, while E2 (Khajura) and E3 (Khumaltar) had high scores on the first and second PCAs for grain yield. For grain yield, it was observed that genotypes X2011S-183-11 and Environments E2 (Khajura) and E3 (Khumaltar) had a significant effect on the genotype by environment interaction. Genotype X2011S-33-9 exhibited the best adaptation in E1 (Vijayanagar), whereas X2011S-183-11 and the check genotype Khajura Musuro-3 were best adapted to E2 (Khajura) and E3 (Khumaltar), respectively.

The concentric circles on the biplot aid in visualizing the length of the environment vectors, which is proportional to the standard deviation within the individual environments and is a measure of the discriminating ability of environments. E1 (Vijayanagar) and E2 (Khajura) were the most discriminative environments among the three because they had the longest vector length, whereas E3 (Khumaltar) was the least discriminating. Non-discriminatory (non-informative) test environments provide minimal information about genotypes and should not be used for testing. For the representativeness of test environments, an average environmental axis (AEA) is drawn from the center. The environment with the smaller angle with AEA is more representative of the test environments. Although E1 (Vijayanagar) is highly discriminating but non-representative of all test environments, E2 (Khajura), which is only next to former in discriminativeness but most representative is ideal for selecting generally adapted genotypes. Likewise, mean versus stability based on genotype based SVP indicates that genotype G2011S-183-11 is the most stable of all while also securing third position in terms yield on genotypic main effect basis.

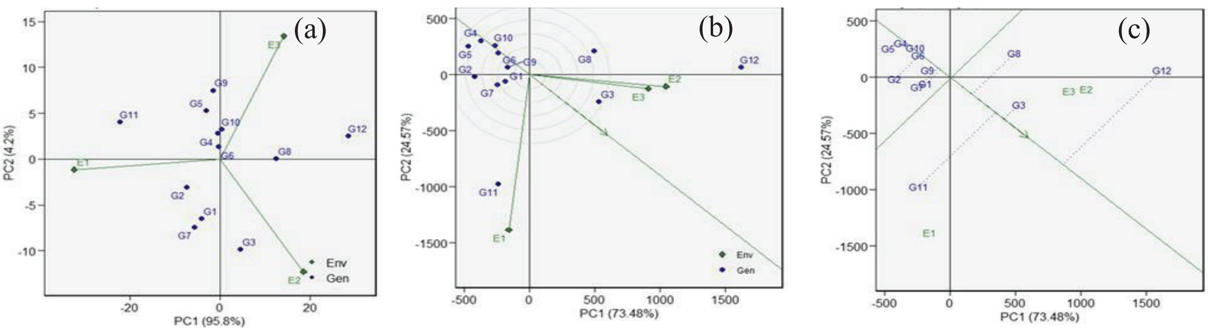

Fig. 1. GGE biplot (a), discriminativeness vs representativeness biplot and (b) mean vs stability (c) for grain yield of lentil genotypes.

Note: E1 Environment 1 (Vijayanagar), E2: Environment 2 (Khajura), E3: Environment 3 (Khumaltar), G1: X2011S-123-36, G2: ILL 10947, G3: X2011S-183-11, G4: X2013-266-2, G5: X2011S-243-12, G6: X2011S-223-6, G7: X2011S-125-23, G8: X2011S-226-5, G9: X2011S-196-18, G10: ILL10690, G11: X2011S-33-9, G12: Khajura Musuro-3

Biplot analysis for crude protein

The joint ANOVA model for crude protein data (Table 2) suggests significant role of Genotype x Environment interaction in protein content determination. In extension of that, the data was subject to GGE model (Genotype + Genotype x Environment) biplot analysis with environment centering, and environment- and genotype-based singular value partitioning (SVP). Resulting biplots are shown in Fig. 2. The biplot model explains a total of 98.43% of variance in crude protein through first two principal component axes. Genotypes X2011S-125-23, X2011S-33-9, X2011S-123-36, ILL 10947 and X2013-266-2, owing to their close proximity to the origin, are the least responsive genotypes with respect to environmental forces, while genotype X2011S-183-11, X2011S-226-5 and X2011S-223-6 are the most influenced genotypes. Khajura (as seen from Fig. 1) was noted to the most representative environment for testing genotypes, but in terms of discriminativeness all environments appear to be have proper discriminating qualities. Hence, no test environments are redundant subsets. Multi-environment assessing of lentil genotypes for seed micronutrient (Fe and Zn) composition, although comprising a different germplasm set from ours, by Darai et al. (2020) remark on good discriminating property of Khajura environment, corroborating our results on the property of environment. Among the test genotypes, genotype X2011S-125-23 was found to the most stably performing, noted as having near zero projection to AEA (Fig. 2), in terms of crude protein content. Although, genotypes X2011S-33-9 and X2011S-196-18 are also promising with relatively stable but exceptionally higher grain protein content as compared to most stably performing one.

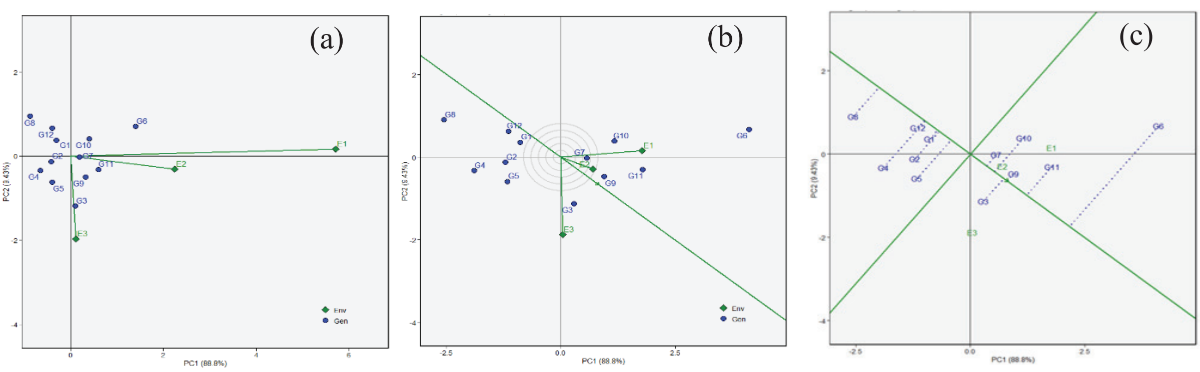

Fig. 2. GGE biplot (a), discriminativeness vs representativeness biplot (b) and mean vs stability (c) for grain protein content of lentil genotypes.

Note: E1 Environment 1 (Vijayanagar), E2: Environment 2 (Khajura), E3: Environment 3 (Khumaltar), G1: X2011S-123-36, G2: ILL 10947, G3: X2011S-183-11, G4: X2013-266-2, G5: X2011S-243-12, G6: X2011S-223-6, G7: X2011S-125-23, G8: X2011S-226-5, G9: X2011S-196-18, G10: ILL10690, G11: X2011S-33-9, G12: Khajura Musuro-3

CONCLUSION

High variability was observed among all lentil genotypes for grain yield, its component traits, and protein content suggesting that there is a huge scope for germplasm improvement through selection. Genotype X2011S-183-11 was found to be the most stably yielding genotype across environments, thus can be recommended in all environments. Check genotype Khajura Masuro-3 was found to be specifically better performing in Khajura and Khumaltar environments and genotype X2011S-33-9 was found to be better in Vijayanagar. With respect to stable crude protein content, genotype X2011S-183-11 was found suited for cultivation across all test locations. Likewise, since huge variability in yield and protein content arise also due to environment, screening for broadly adapted germplasm from a different panel of genotypes need to strategically account for the component by including a larger yet more representative set of environment, or its constituent factor combination.

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AUTHOR CONTRIBUTIONS

KHD: Conceptualization, Writing – review & editing, Supervision; **MP:** Investigation, Data curation, Formal analysis, Writing – original draft; **DD:** Formal analysis, Visualization, Writing – original draft, Writing – review & editing; **SS:** Investigation, Formal analysis, Writing – review & editing; **RD:** Conceptualization, Resources, Writing – review & editing.

CONFLICT OF INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

ETHICAL APPROVAL AND PERMITS

Author ensures that research submitted complies with relevant ethical standards and legal requirements

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