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Yield stability and test location representativeness in foxtail millet [*Setaria italica* (L.) Beauv.] genotypes

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Abstract
Development of a crop variety with high grain yield and stability in test locations is an important part of crop breeding program. Thirteen foxtail millet genotypes were evaluated in randomized complete block design with three replications in Jumla and Dolakha, Nepal from April to August in three consecutive years 2017, 2018, and 2019. The objective of this study was to analyze grain yield stability and adaptability of foxtail millet genotypes applying genotype main effect plus genotype by environment interaction (GGE) biplot analysis. The results showed that grain yields were significantly ($P<0.05$) affected by the environment (E), genotype (G), and their interaction (G×E). The genotype HUMLA-163 had regression coefficient equal to unity ($b=1.01$), thus this genotype had average adaptation to all environments whereas HUMLA-213 ($b=1.18$) and HUMLA-252 ($b=1.19$) had regression coefficients greater than unity, thus these genotypes were more adapted to favorable environments. GGE biplot showed that HUMLA-163 was more stable and adaptive genotype. Thus, genotype HUMLA-163 is recommended for release as a variety to improve foxtail millet production in hilly region of Nepal.
Keywords: Foxtail millet, Genotypes, Environment, GGE biplot, Yield Parameters

Introduction

Foxtail millet (*Setaria italica* (L.) Beauv.) is a self-pollinating crop with chromosome numbers, 2n=18, classified under the Poaceae family and subfamily Panicoideae (Fedorov, 1974). It is one of the cultivated cereals and extensively cultivated in India, Nepal, Sri Lanka, Pakistan, Russia, Ukraine, the Middle East, Turkey, and Romania (Bala, 2004). It is hardy in nature and generally grows well on marginal lands having scarcity of irrigation as rain-fed crop (Dai et al., 2011a, b). It's cultivation was domesticated around 8000 years ago in the highlands of central China (Amgai et al., 2011; Lu et al., 2009). Now it's cultivation spread around 26 countries (Baker, 2003). Foxtail millet ranks second among the millets as for world production (Marathee, 1993; Bala, 2004). Millet is an important an important cereal crop in Nepal, cultivated on 271,183 ha with the production of 304,105 mt and productivity of 1,121 kg/ha (MoAD, 2016). It is also a good source of energy, fats, proteins, fatty acids, vitamins, minerals and dietary fiber (Jali et al., 2012).

Identification and release of promising variety of foxtail millet is the most promising and deliverable technology for increasing productivity through its utilization in crop improvement programs. Kandel et al. (2019) evaluated the performance of finger millet landraces over the different environments and which is necessary for plant breeder in selection and utilization in crop breeding programs (Dhami et al., 2019). Also, GGE biplot study of these landraces can be pivotal to identify stable and adaptive genotypes across the tested environments of Nepal.

The Eberhart and Russell (1966) model is widely used to identify and classify overall variations in genotype performance in predictable (regression) and unpredictable (deviation from the regression) components. This helps to select a specific site for a particular genotype and assess both yield (regression) and stability (deviation from the regression). Regression coefficients greater than 1 ($b \geq 1$) show superior and stable performance compared to the overall average of all genotypes tested in this model (Durovic et al., 2014). The objective of this study was to determine the interaction between genotype and environment on yield and yield components of foxtail millet genotypes and to identify stable foxtail millet varieties for general cultivation across the hilly region of Nepal.

Materials and methods

Experimental site and planting materials

The experiments were conducted at two different locations namely Kabre of Dolakha district and Bijayanagar of Jumla district from April to August in 2017, 2018 and 2019. The research field in Jumla was located at high hill region. It's climatic condition was cool temperate. The geographic coordinates for the research field in Jumla was 29°16′28″ N, 82°11′01″ E, and 2290 masl. The soil at Bijayanagar, Jumla was sandy, acidic to moderately alkaline, and moderately deep to very deep and moderately to poorly drained. The nitrogen content was low to medium, the available phosphorus was high to very high and the available potassium was medium to high. The organic carbon content ranged from low to high (Ghimire and Mandal, 2019).

The research field in Kabre was located in the mid-hill region and thus was characterized by cool temperate. The geographic coordinates for research field was $86^{0}9$' E longitude, $27^{0}38$'N latitude and 1740 m altitude. The soil of research filed at Kabre was sandy loam soil with pH from 4.5 to 6.2. i.e. slightly acidic (NARC, 2018). The climatic data during experiments was given in Table 1

Table 1. The climatic data during the experiments in Jumla and Dolakha in 2017, 2018 and 2019.

Years	Months	Dolakha			Jumla		
		Maximum Temp (^{0}C)	Minimum temp (^{0}C)	Total Rainfall (mm)	Maximum Temp (^{0}C)	Minimum temp (^{0}C)	Total Rainfall(mm)
2017	April	25	15	99	24.34	7.9	42.8
	May	25	16	289	25.42	15.48	180.1
	june	26	19	585	25.66	15.48	180.1
	July	25	19	497	24.1	16.4	280.1
	August	27	18	478.1	24.6	16.2	123.8
2018	April	26.5	12.5	73.6	22.1	6.1	40.3
	May	28.5	13.3	180.3	25.2	8.6	62.2
	june	28.8	17	181.3	27.3	14.4	65
	July	28	18.5	552.6	24.3	15.8	160.4
	August	27.5	19	378.4	24.1	16.3	225.4
2019	April	33	15	70.1	22.4	6.8	70.5
	May	28	18	190.1	24.2	7.6	31.5
	june	28	23	199	26.2	12.7	65.1
	July	26	20	510	23.88	16.17	252.6
	August	26	19	366	25.05	14.72	102.7

(Source: HRS, 2018, 2019, 2020; HCRP, 2018, 2019, 2020)

Experimental design, field layout, and cultural practices

The research plot was laid out in Randomized Complete Block Design (RCBD) with 13 foxtail millet accessions as treatments and three replications. The unit plot size was 4 m^2 and had 16 rows of crop sown at a distance of 25 cm between the rows. Interblock spacing of 1 m and inter plot spacing of 50 cm was maintained. Fertilizer application was done at the rate of 50:30:20 kg N:P:K per ha (HCRP, 2019). Half dose of N and full doses of P and K were applied as basal dose and remaining half of N was applied as side-dressing at the time of the tillering growth stage. The plots were kept free of weeds manually. The seeds were sown continuously at about (2.5-3) cm deep on rows with inter-row spacing of 25 cm. The panicles in each plot were harvested separately by cutting from the peduncle base and placed in paper envelops.

Research treatments

Thirteen foxtail millet genotypes were received from Hill Crops Research Program, Dolakha, Nepal for these experiments. The source of these foxtail millet genotypes was Nepal Agricultural Research Council, Hill Crops Research Program, Dolakha, Nepal. The foxtail millet genotypes namely CO1896, CO3474, CO3475, HUMLA-163, HUMLA-213, HUMLA-252, HUMLA-379, HUMLA-468, HUMLA-522, HUMLA-523, HUMLA-524, HUMLA-606 and HUMLA-631 were used in these experiments. All genotypes were lines and origin of genotypes was Nepal.

Data collection

Data on grain yield and yield attributing traits were recorded according to the protocol adapted by HCRP (2019). Each plot was harvested excluding border rows and grain moisture content for each plot was recorded and grain yield was adjusted to 12% moisture basis. The grain yield per plot was converted into ton/ha by using formula adapted by HCRP (2019).

Statistical analysis

The stability analysis was done using GEAR software Version 4.1 (Pacheco et al., 2015). The significant G × E was used for stability analysis using Eberhart and Russell model (1966). We used $P = 0.05$ as the statistical significance threshold (Gomez and Gomez, 1984; Shrestha, 2019).

Results and discussion

Genotype x environment effects

The genotypes were evaluated for grain yield and yield attributing.The genotypes showed the significant variation in days to heading, days to maturity, plant height, and grain yield. Stable genotypes HUMLA-163 produced significantly produce 1.35 t/ha, 1.85 t/ha and 0.81 t/ha during 2017, 2018, 2019 under Dolakha condition (Table 2). The genotype HUMLA-163 produced grain yield 1.39 t/ha, 1.26 t/ha and 1.35 t/ha during 2017, 2018 and 2019 under Jumla condition respectively (Table 3).The genotypes were significant for grain yield, plant height, and days to maturity in combined analysis (Table 4). The genotype x environment interaction was significant for grain yield, days to maturity, and plant height (Table 5). The stable genotypes Humla-163 produced significantly higher grain yield 1.46 t/ha (Table 5). This result was similar to the findings of Adhikari et al., (2018) and Jawale et al., (2017) who reported significant differences among millet varieties for grain yield. In combined analysis over year and location genotypes HUMLA-163 produced 1.37 t/ha in 2017, 1.55 t/ha in 2018, and 1.08 t/ha in 2019 under-tested locations (Table 4).Thus, HUMLA-163 which had 94 days to flowering, 142 days to maturity with plant height 171cm was recommended for release as a variety to improve foxtail millet production in these environments.

Table 2: Growth and yield performance of Foxtail millet genotypes in Dolakha in 2017, 2018 and 2019.

		2017				2018				2019			
SN	Genotypes	DTH	DTM	PH	GY	DTH	DTM	PH	GY	DTH	DTM	PH	GY
1	CO1896	78	115	118	1.21	91	131	141	1.14	90	138	149	0.71
2	CO3474	84	122	144	1.54	90	139	152	1.52	90	141	162	0.73
3	CO3475	73	114	150	1.16	73	113	118	1.25	62	116	119	0.38
4	HUMLA-163	87	121	167	1.35	90	139	164	1.85	90	143	182	0.81
5	HUMLA-213	76	116	169	1.31	89	119	155	1.25	83	119	165	0.77
6	HUMLA-252	87	122	138	1.16	76	113	164	1.41	64	114	177	0.64
7	HUMLA-379	85	122	148	0.98	88	128	154	1.29	90	126	171	0.58
8	HUMLA-468	87	123	133	1.16	76	116	172	1.20	76	113	181	0.54
9	HUMLA-522	76	115	139	1.44	82	115	135	0.65	77	117	138	0.30
10	HUMLA-523	72	121	161	1.45	83	109	156	1.21	78	112	175	0.55
11	HUMLA-524	73	114	156	1.26	79	108	160	1.48	73	111	175	0.68
12	HUMLA-606	80	121	147	1.65	82	127	149	0.69	79	130	153	0.28
13	HUMLA-631	76	114	144	1.57	61	107	136	1.13	50	107	141	0.45
	Grand Mean	125	118	147	1.32	81	120	150	1.23	77	122	161	0.57
	F test	*	*	*	*	*	*	*	*	*	*	*	ns
	CV(%)	23.50	10.40	14.90	26.32	12.29	6.39	10.00	30.33	16.02	7.79	10.93	25.99
	$LSD_{(0.05)}$	40.59	26.83	47.77	0.76	21.74	16.74	32.72	0.90	26.83	20.68	38.24	0.57

*DTH= 50% days to heading, DTM=80% day to maturity, PH=Plant height (cm), GY=Grain Yield (t/ha), *Significant at 0.05 probability level, ns= Non significant LSD = Least significant difference at 0.05 level,CV= Coefficient of variation in percentage*

Table 3: Growth and yield performance of Foxtail millet genotypes in Jumla in 2017, 2018 and 2019.

SN.	Genotypes	2017				2018				2019			
		DTH	DTM	PH	GY	DTH	DTM	PH	GY	DTH	DTM	PH	GY
1	CO1896	114	144	138	0.95	113	140	135	0.94	112	137	136	1.00
2	CO3474	127	165	148	0.57	123	158	143	0.63	114	141	138	0.87
3	CO3475	74	141	138	0.10	80	137	132	0.54	86	138	131	0.68
4	HUMLA-163	94	144	176	1.39	97	141	171	1.26	100	137	165	1.35
5	HUMLA-213	94	144	164	1.45	97	141	157	1.36	95	135	156	1.32
6	HUMLA-252	109	144	157	1.33	105	140	150	1.29	103	143	150	1.34
7	HUMLA-379	94	144	176	1.86	96	141	165	1.76	96	137	160	1.84
8	HUMLA-468	113	144	160	1.45	112	141	158	1.41	108	143	152	1.47
9	HUMLA-522	96	140	159	0.24	98	137	154	0.56	95	136	153	0.74
10	HUMLA-523	107	144	166	1.33	110	138	163	1.35	104	140	158	1.51
11	HUMLA-524	94	144	167	1.56	95	143	163	1.49	98	139	160	1.55
12	HUMLA-606	94	141	164	0.45	98	138	159	0.66	98	140	153	0.93
13	HUMLA-631	96	143	150	0.31	99	136	143	0.66	93	141	140	0.84
	Grand Mean	100	145	158	1.00	101	141	153	1.07	100	139	150	1.19
	F test	*	*	*	*	*	*	*	*	*	ns	*	*
	CV(%)	11.19	0.97	7.35	24.21	9.36	1.37	7.53	25.85	7.08	3.41	7.84	20.60
	$LSD_{(0.05)}$	24.46	3.05	25.37	0.74	20.68	4.19	25.14	0.60	15.42	10.32	25.60	0.53

*DTH= 50% days to heading, DTM=80% day to maturity, PH=Plant height (cm), GY=Grain Yield (t/ha), *Significant at 0.05 probability level, ns= Non significant, LSD = Least significant difference at 0.05 level, CV= Coefficient of variation (%)*

Table 4: Combined performance of Foxtail millet genotypes in Dolakha and Jumla in 2017, 2018 and 2019.

		2017				2018				2019			
SN	Genotypes	DTH	DTM	PH	GY	DTH	DTM	PH	GY	DTH	DTM	PH	GY
1	CO1896	96	129	128	1.08	102	136	138	1.04	101	138	143	0.85
2	CO3474	105	143	146	1.05	106	148	147	1.07	102	141	150	0.80
3	CO3475	73	127	144	0.63	77	125	125	0.89	74	127	125	0.53
4	HUMLA-163	91	133	171	1.37	93	140	168	1.55	95	140	173	1.08
5	HUMLA-213	85	130	166	1.38	93	130	156	1.31	89	127	161	1.04
6	HUMLA-252	98	133	147	1.24	90	126	157	1.35	83	128	163	0.99
7	HUMLA-379	89	133	162	1.42	92	135	160	1.52	93	132	166	1.21
8	HUMLA-468	100	134	146	1.31	94	129	165	1.31	92	128	166	1.00
9	HUMLA-522	86	128	149	0.84	90	126	145	0.61	86	127	145	0.52
10	HUMLA-523	89	133	164	1.39	96	123	160	1.28	91	126	166	1.03
11	HUMLA-524	83	129	161	1.41	87	125	162	1.49	85	125	168	1.11
12	HUMLA-606	87	131	155	1.05	90	132	154	0.67	88	135	153	0.60
13	HUMLA-631	86	128	147	0.94	80	122	140	0.89	71	124	141	0.64
	Grand Mean	90	132	153	1	91	130	152	1.15	88	130	155	0.88
	F test	*	*	*	*	*	ns	*	*	*	*	*	*
	CV(%)	17.35	5.69	11.13	25.27	10.83	3.88	8.77	28.09	11.55	5.60	9.39	23.30
	$LSD_{(0.05)}$	29.54	26.52	26.45	0.87	24.78	22.02	21.45	0.62	25.95	21.40	27.20	0.70

*DTH= 50% days to heading, DTM=80% day to maturity, PH=Plant height (cm), GY=Grain Yield (t/ha), *Significant at 0.05 probability level, LSD = Least significant difference at 0.05 level, ns= Non significant, CV= Coefficient of variation (%)*

Table 5: Combined Performance of the Foxtail millet genotypes over years (2017, 2018 and 2019) and locations (Dolakha and Jumla).

SN	Genotypes	DTF	DTM	PH	GY
1	CO1896	104	138	140	1
2	CO3474	108	151	148	0.9
3	CO3475	75	126	127	0.64
4	HUMLA-163	94	142	171	1.46
5	HUMLA-213	92	131	159	1.35
6	HUMLA-252	91	128	159	1.34
7	HUMLA-379	93	135	165	1.68
8	HUMLA-468	97	128	164	1.38
9	HUMLA-522	89	127	148	0.55
10	HUMLA-523	96	125	164	1.35
11	HUMLA-524	88	126	165	1.52
12	HUMLA-606	90	134	155	0.68
13	HUMLA-631	79	123	142	0.73
	Grand Mean	92	132	154	1.12
	F test (G)	*	*	*	*
	G × E	*	*	*	*
	CV(%)	12.64	5.06	11.50	29.55
	$LSD_{(0.05)}$	8.98	8.5	10.9	0.21

*DTH= 50% days to heading, DTM=80% day to maturity, PH=Plant height (cm), GY=Grain Yield (t/ha), *Significant at 0.05 probability level, G × E= Genotypes into environment interaction, LSD = Least significant difference at 0.05 level, CV= Coefficient of variation (%)*

GGE biplot and stability analysis

Stability in the yield performance is the major concern to the breeder and influenced mostly by genotype x environment interaction (Zobel et al., 1988). In the GGE biplot, the assessment of yield and stability of genotypes (Figure 1) was carried out using the average environment (tester) coordinate methods (Yan and Hunt, 2000). An ideal genotype should have an average environment (tester) coordinate, determined by the two-component results of PC1 and PC2 (Yan and Kang, 2003). An ideal genotype, which is located at the center of the concentric circle, is the one that has both high mean yield and high stability (Yan and Kang, 2003). Therefore, the results showed that genotype HUMLA-163 was stable (Figure 2).

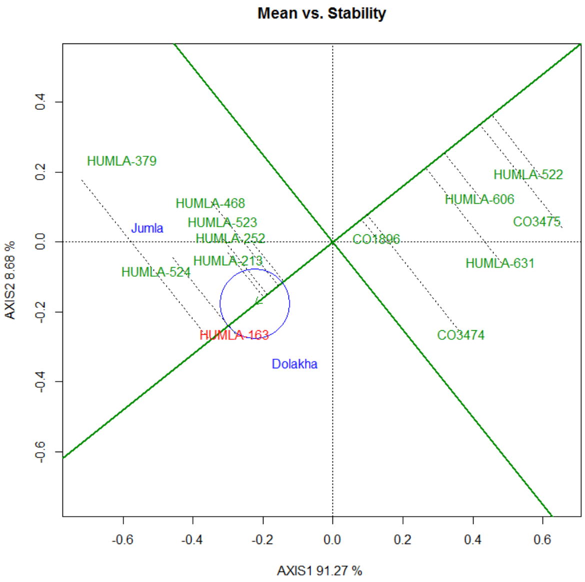

Figure 1: GGE biplot showing ranking of foxtail millet genotypes for mean yield and stability

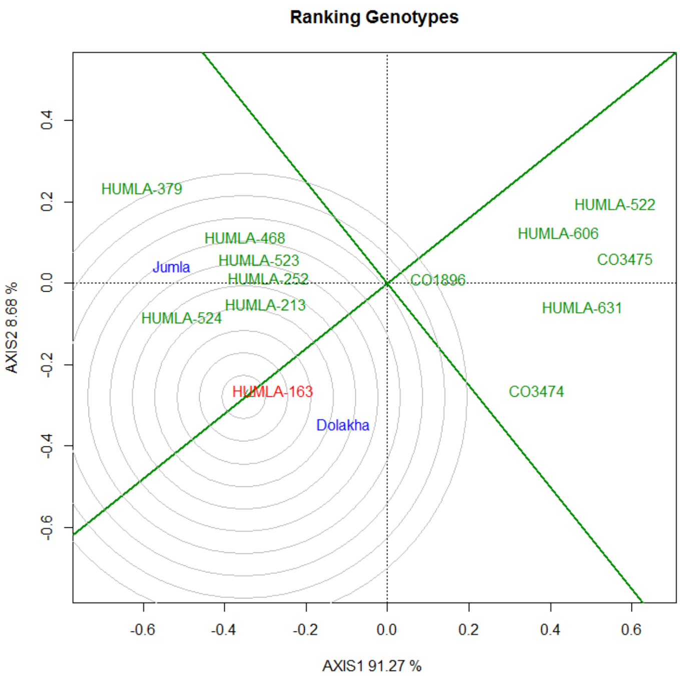

Figure 2. Comparison of foxtail millet genotypes with the ideal genotype.

In GGE biplot polygons (Figure 3), vertexes are furthest from the origin of the biplot, they should help locate some genotypes represented by positioning at the best or worst vertex in some or all environments. The vertex genotypes were HUMLA-379, HUMLA-522, HUMLA-163 and CO3474 which were supposed to be the most responsive to tested environment conditions. Vertex genotypes are more responsive to environments and they are considered as specially adapted genotypes for tested locations. The lines perpendicular to the polygon separate the mega-environment. A similar study carried out by Yan and Kang (2003).

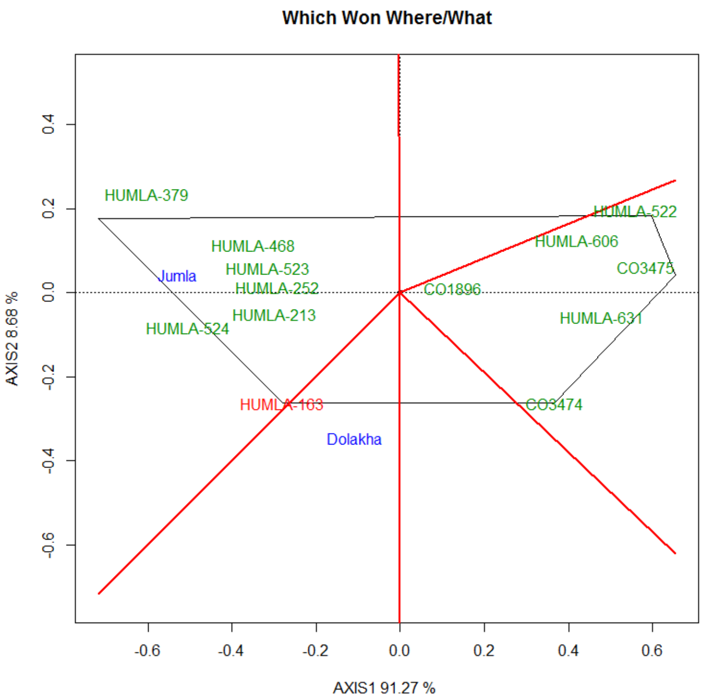

Figure 3. Polygon view of GGE biplot to the identification winning of foxtail millet genotypes and their related mega environments.

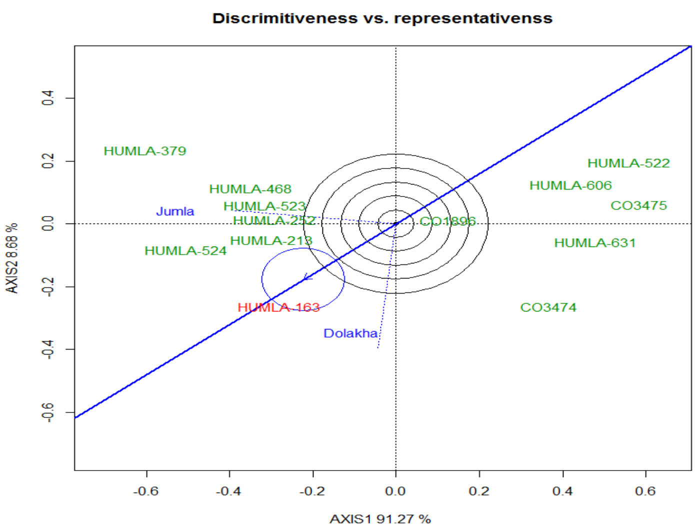

Figure 4. Biplot showing foxtail millet genotypes with respect to their environments

Genotype adaptability and stability are useful parameters for recommending genotypes for known cultivation conditions. Eberhart and Russell (1966) proposed an assessment of cultivar response to environmental changes using a linear regression coefficient and variances of regression deviations. Namely, cultivars that have regression coefficients greater than unity would be more adapted to favorable growing conditions, those with regression coefficients less than unity would be adapted to unfavorable environmental conditions, and those with regression coefficients equal to unity would have an average adaptation to all environments. The genotype HUMLA-163 had regression coefficient equal to unity (b=1.01), thus this genotype had average adaptation to all environment whereas HUMLA-213 (b=1.18) and HUMLA-252(b=1.19) had regression coefficients greater than unity, thus these genotypes was more adapted to stable genotype across the tested locations.

Table 6: Performance and stability parameters of foxtail millet genotypes in Jumla and Dolakha in 2017, 2018 and 2019.

		Stability parameters				
SN	Genotypes	Sd	CV(%)	bi	S^2di	R^2
1	CO1896	0.12	12.17	0.73	0.111**	0.97
2	CO3474	0.15	15.57	0.93	0.114**	0.99
3	CO3475	0.18	27.63	0.81	-0.077	0.47
4	HUMLA-163	0.14	17.85	1.01*	0.109*	0.99
5	HUMLA-213	0.17	14.19	1.18*	0.112**	0.96
6	HUMLA-252	0.18	15.55	1.19*	0.108*	0.90
7	HUMLA-379	0.15	11.51	0.92	-0.108	0.87
8	HUMLA-468	0.17	14.50	0.95**	-0.114	0.99
9	HUMLA-522	0.16	25.32	0.75	-0.09	0.54
10	HUMLA-523	0.18	15.00	0.99**	-0.110	0.93
11	HUMLA-524	0.19	14.69	0.88	-0.110	0.94
12	HUMLA-606	0.24	29.16	0.95	-0.041	0.40
13	HUMLA-631	0.15	19.43	1.21**	0.111	0.98

Sd = Standard deviation, CV= Coefficient of variation (%), bi = regression coefficient R^2 = coefficient of determination. (Eberhart and Russell 1966). *Significant at 0.01 probability level, S^2di= coefficient of stability, *Significant at 0.05 probability level*

Conclusion

The performance and yield stability across different environments varied among foxtail millet genotypes. The genotype HUMLA-163 had regression coefficient equal to unity (b=1.01), thus this genotype had an average adaptation to all environments whereas HUMLA-213 (b=1.18) and HUMLA-252(b=1.19) had regression coefficients greater than unity, thus these genotypes were more adapted to tested environments. Based on results, foxtail millet genotypes namely HUMLA-213 and HUMLA-252 produced the higher grain yield and showed the adaptability under favorable environment of Jumla. The genotype namely HUMLA-163 was identified as stable, high yielding, and adaptive genotype across the hilly region of Nepal. Thus, this genotype was recommended for possible release for wider adaptability across Jumla, Dolakha, and other areas with similar agro-ecology in the country.

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Conflict of interest

All authors declare that there is no conflicts of interest

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