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Research Paper

Genotype-based testing for aluminium tolerance in the pea (*Pisum sativum*)

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ABSTRACT

Aluminium (Al) is detrimental for the growth of pea under acidic soil condition with poor growth and low yield. To enhance the production, tolerant genotype is very important; therefore, we aimed our study to screen pea genotypes for Al tolerance in acid soil. The screening of 25 pea genotypes was carried out in a naturally ventilated polyhouse with 3 levels of Al (control, 12 ppm and 24 ppm) and replicated thrice. The screening was done using growth and yield parameters. The parameters were significantly reduced due to Al treatment in genotypes except in some. K-mean clustering was carried out to categorize genotypes into tolerant, intermediate and susceptible. Based on clustering at a higher level of Al (24 ppm), Kashi Samrath, Kashi Samridhi and EC9485 were classified as tolerant whereas 'Matar Ageta-7', 'Pb-89', 'AP-3', 'Lincoln', 'Arkel', 'Kashi Ageti', 'Kashi Shakti', 'VRPE-29', 'CHFGP-7', 'CHFGP-15' as susceptible genotypes. These genotypes have potential to improve yield in acid soil affected regions of India and assist in further breeding of pea genotypes for Al tolerance.

Key words: Acidic soil, Aluminium toxicity, K-mean clustering, *Pisum sativum*

Pea (*Pisum sativum* L.) is an important legume crop grown all over India and it provides important dietary protein to millions of people (Chandel *et al*., 2022). Many abiotic stresses affect the production of pea (Nasreen and Farid, 2003). Out of which, Aluminium (Al) toxicity in acidic soil is a major constraint for pea growth and physiology. The productivity of pea is very low in acid soil affected states such as Arunachal Pradesh, Meghalaya, Assam, Uttarakhand, Mizoram, Nagaland, Sikkim and Meghalaya. It shows considerable variability in physiological properties against Al toxicity (Kichigina *et al*., 2017). The primary effect of phytotoxic Al is the inhibition of root growth in pea and injury to root tips making it hard and subtle (Motoda *et al*., 2010). Plants have a mechanism to defend Al toxicity through various methods. Therefore, for expansion of its cultivation in acidic soil predominant area, there is an urgent need to evaluate the new germplasm of pea to select high yielding and aluminium tolerant genotypes that can be adopted for commercial production. Further, it will also add in opening scope for preliminary multi-location testing that can be incorporated in the future breeding programmes for the improvement of yield and quality traits having resistance to diseases, especially powdery mildew. Currently, continuous emphasis and interest have been given for inclusion of vegetable legumes in improved cropping systems on the acid soils (Kushwaha *et al.,* 2017). Hence, the successful inclusion of garden pea will depend on the mitigation of the Al toxicity constraint. The selection of varieties with genetic potential for tolerance to the Al stress associated with acid soils will be one of the low input approaches to solving this problem.

Fast and reliable screening technique for Al toxicity is one of the most vital tools essential to efficiently develop Al-tolerant cultivars. Optimum Al concentration is a prime requisite for efficient screening among the genotypes. Therefore, the present experiment was designed to screen important genotypes of garden pea under greenhouse in pots containing Al added soil.

MATERIALS AND METHOD

The pot experiment was carried out at the poly-house complex of College of Horticulture and Forestry, CAU, Pasighat, Arunachal Pradesh during 2019–2020 during *rabi* season. The experiment was designed in two factorial CRD with three replications and the experiment was repeated twice. The first factor comprised of 25 pea genotypes (Table 3) and the second factor comprised of 3 levels of Al (control, 12 ppm and 24 ppm). Plastic pots (30 cm

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× 30 cm) were filled with 7 kg soil and the treatment was imposed using $AlCl_3.7H_2O$. The soil had *p*H (6.00), EC (0.01 d S/m), organic carbon (1.5 %), available N (100.8 mg/kg), available P (19 mg/kg), available K (120 mg/kg), Exchangeable Ca (8 mg/kg), Exchangeable Mg (2.4 mg/kg), available B (0.3 mg/kg) and exchangeable Al (KCl) (0.2 ppm) levels prior to sowing.

Screening parameters

For screening of genotypes biomass, length, dry matter of root and shoot was recorded at 20 days after sowing. Plants were uprooted and separated into root and shoot and biomass was recorded using precision balance. Length of root and shoot was also recorded and the samples were kept in hot air oven (60 °C, 48 hours) for drying and dry matter was recorded. At harvesting pod length, pod weight, number of pods plant^{-1}, number of seed pod^{-1} and yield (kg ha^{-1}) were taken for screening.

K-Mean Clustering

Using K-mean clustering analysis all the genotypes were grouped into three clusters. K-mean clustering was done for each character using the difference value obtained by subtracting the control value with the value obtained under Al stress were ranked as tolerant for the highest score, intermediate for medium score and susceptible for lowest score based upon 95% confidence interval (Bitencourt *et al*., 2011).

Statistical analysis

The ANOVA was carried out by procedure outlined by Gomez and Gomez (1984). K-mean cluster analysis was carried out by using SPSS software (Version 21).

RESULTS AND DISCUSSION

Growth characteristics

In terms of growth genotypes reacted in numerous ways to the aluminum treatments. There was significant variation among treatments in biomass, length, dry weight of seedling showing that roots were shorter and thicker in Al stressed conditions.

Root and shoot Biomass

Averaged across genotypes, Al treatment significantly decreased root biomass by nearly 20% (p<0.05) at 12 ppm Al and 26% (p<0.05) at 24 ppm Al level. At 24 ppm Al level, the highest significant reduction was recorded in 'CHFGP6' followed by CHFGP1, 'Arka Priya', and 'Kashi Shakti' (Table 1). However, root biomass of genotypes including Kashi Samridhi, 'AP3', 'Arkel', 'EC9485', 'Matar Ageta-7', 'Pb89', 'Lincoln', 'P.S.M3', 'Kashi Ageti', 'VRP5', 'EC 9485', 'CHFGP-14', 'CHFGP-55', Priya was not affected by the higher level of Al (24 ppm). It might be attributable to the capacity of certain genotypes to express normal biomass even at stress conditions as opined by Kushwaha *et al*. (2017). Kichigina *et al*. (2017) also observed similar results, in which root biomass of all pea genotypes decreased except few genotypes which they classified as tolerant.

Averaged across genotypes Al treatment significantly decreased shoot biomass by nearly 18% (P<0.05) 12 ppm Al and 27% (P<0.05) at 12 and 24 ppm Al level compared to control (Table 1). Interaction between Al treatment and genotypes was found significant shoot biomass and it *at par* with control for 'Kashi Ageti', 'EC–9485', 'Priya', 'AP–3', 'Arkel', 'Kashi Samrath', 'Lincoln', 'PSM–3', 'Arka Apoorva', 'Kashi Samridhi', 'NO–17', 'CHFGP–55', 'Priya', 'KK–10' genotypes at 24 ppm Al level.

Root and shoot length

Averaged across genotypes significant reduction of nearly 9% at 12 ppm and 15% at 24 ppm Al treatment in root length was observed compared to control. Application of 12 ppm Al showed a reduction in root length only in 'CHFGP15', 'Arkel' and 'Kashi Samridhi' suggesting that lower concentration had a less negative effect on root length. At 24 ppm Al level, the highest significant reduction in root length was observed in CHFGP–15 followed by 'VRPE–29', 'CHFGP–7', 'CHFGP–1', 'Kashi Ageti', 'NO–17' at 24 ppm Al level with respect to control (Fig. 1). Root length inhibition is the most typical symptom of Al toxicity and is known to show rapid growth retardation even within minutes of exposure. The promptness of the root growth inhibition upon exposure to Al indicates that Al quickly disrupts root cell expansion and elongation, before inhibiting cell division (Frantzios *et al.,* 2001). As a result, root length inhibition caused by aluminium toxicity is the most studied parameter and has been extensively evaluated in an array of plant species.

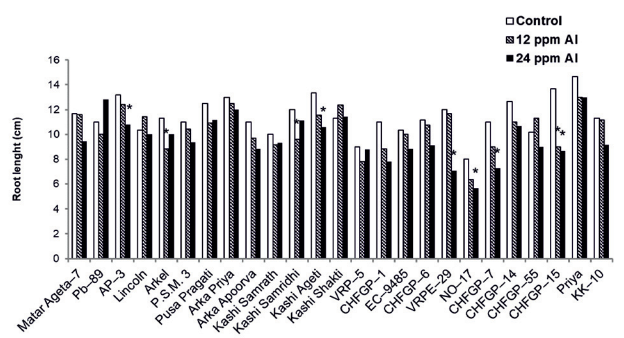

Fig. 1. Influence of Al treatment on root length of pea genotypes (20 days after treatment), C.D for factor (G)=1.30, Factor (Al)=0.46 and factor (G×Al)=2.29, * indicates significant difference from control)

Table 1. Morphological screening characters of pea genotypes at seedling stage (20 days after treatment)

Genotypes	Root biomass (g/plant)			Shoot biomass (g/plant)			Root dry matter (g/plant)			Shoot dry matter (g/plant)		
	Control	12 ppm	24 ppm	Control	12 ppm	24 ppm	Control	12 ppm	24 ppm	Control	12 ppm	24 ppm Al
Matar Ageta–7’	0.150	0.173	0.137	1.350	1.237	0.877	0.083	0.089	0.08	0.184	0.158	0.126
‘Pb–89’	0.167	0.150	0.137	0.813	0.617	0.513	0.074	0.057	0.073	0.102	0.111	0.111
‘AP–3’	0.193	0.117	0.200	1.067	1.227	1.013	0.076	0.038	0.062	0.163	0.146	0.118
‘Lincoln’	0.207	0.153	0.180	0.963	0.790	0.810	0.051	0.065	0.05	0.131	0.190	0.227
‘Arkel’	0.143	0.133	0.140	0.737	0.843	0.673	0.051	0.048	0.048	0.097	0.123	0.100
‘P.S.M. 3’	0.075	0.123	0.050	0.853	0.750	0.717	0.039	0.065	0.038	0.131	0.093	0.146
‘Pusa Pragati’	0.183	0.160	0.130	0.950	0.763	0.643	0.080	0.059	0.046	0.182	0.129	0.112
‘Arka Priya’	0.170	0.130	0.080	0.477	0.297	0.237	0.063	0.059	0.035	0.112	0.075	0.065
‘Arka Apoorva’	0.220	0.180	0.160	0.450	0.377	0.310	0.095	0.053	0.064	0.102	0.068	0.066
‘Kashi Samrath’	0.060	0.045	0.040	0.650	0.570	0.550	0.025	0.016	0.021	0.091	0.076	0.068
‘Kashi Samridhi’	0.110	0.049	0.120	0.540	0.370	0.340	0.055	0.020	0.053	0.082	0.079	0.129
‘Kashi Ageti’	0.227	0.123	0.190	0.430	0.277	0.697	0.116	0.070	0.080	0.248	0.162	0.111
‘Kashi Shakti’	0.167	0.110	0.083	1.460	0.733	1.033	0.080	0.060	0.044	0.210	0.187	0.090
‘VRP–5’	0.190	0.157	0.160	0.910	0.647	0.443	0.103	0.088	0.092	0.183	0.157	0.127
‘CHFGP–1’	0.190	0.150	0.100	0.683	0.523	0.443	0.086	0.065	0.042	0.118	0.102	0.078
‘EC–9485’	0.070	0.047	0.062	0.333	0.180	0.317	0.042	0.027	0.031	0.080	0.050	0.061
‘CHFGP–6’	0.240	0.170	0.147	0.700	0.577	0.390	0.090	0.074	0.054	0.130	0.105	0.094
‘VRPE–29’	0.160	0.100	0.090	0.870	0.807	0.507	0.084	0.056	0.049	0.183	0.170	0.074
‘NO–17’	0.113	0.070	0.032	0.423	0.493	0.29	0.057	0.034	0.016	0.078	0.096	0.056
‘CHFGP–7’	0.130	0.080	0.065	0.890	0.683	0.643	0.054	0.035	0.036	0.188	0.167	0.138
‘CHFGP–14’	0.183	0.167	0.153	0.600	0.453	0.350	0.078	0.06	0.061	0.115	0.098	0.071
‘CHFGP–55’	0.157	0.150	0.140	0.650	0.540	0.48	0.048	0.043	0.039	0.148	0.117	0.100
‘CHFGP–15’	0.183	0.167	0.140	0.813	0.610	0.473	0.090	0.065	0.051	0.183	0.155	0.104
‘Priya’	0.115	0.123	0.103	0.483	0.610	0.447	0.078	0.088	0.076	0.127	0.110	0.102
‘KK–10’	0.113	0.092	0.050	0.533	0.357	0.340	0.064	0.054	0.040	0.097	0.119	0.089
CD (G X Al)	0.039	0.02	0.014	0.221	0.111	0.079	0.021	0.011	0.008	0.034	0.017	0.012

The shoot length of the pea genotypes varied significantly among themselves. Al treatment had a significant effect on the shoot length of 20 days old pea plants. Due to Al treatment significant reduction of 13% at 12 ppm and 18.6% at 24 ppm Al treatment in shoot length was observed at and 24 ppm Al treatment, as compared to control (Table 3). The findings of shoot growth inhibition are in agreement with the outcomes of Yang *et al*. (2009) in soybean.

The interaction effect was found significant for shoot length in 20 days old seedlings. At 24 ppm Al level, shoot length of 'CHFGP6', 'Kashi Samrath', 'VRP–5', 'VRPE–29', 'EC–9485', 'Kashi Samridhi' and 'Lincoln' was found significantly *at par* with control (Table 3). Legesse *et al*. (2017) also reported a substantial reduction in plant height with Al treatment in *Phaseolus vulgaris*.

Root and shoot dry matter

Mean shoot dry matter of pea seedling across Al concentration was found significantly different. Averaged across genotypes, shoot dry matter was significantly less than the control at both levels of Al. Interaction between Al and genotype was found significant. At 24 ppm Al level, shoot dry matter of 'Pb–89', 'Arkel', 'P.S.M.3', 'Kashi Samrath', 'EC–9485', 'NO–17', 'Priya' and 'KK–10' was recorded *at par* with control (Table 1).

A significant difference was recorded in mean root dry matter across Al concentration among different genotypes of pea at the seedling stage. 'VRP–5' recorded the highest root dry matter which was *at par* with 'Kashi Ageti' and 'Matar Ageta–7' (Table 1). Averaged across genotypes root dry matter significant reduced at 12 and 24 ppm Al level.

Interaction between genotypes and aluminium treatment was found significant. At 24 ppm Al level, root dry matter of 'Matar Ageta–7', 'Pb–89', 'AP–3', 'Lincoln', 'Arkel', 'P.S.M. 3', 'Kashi Samrath', 'Kashi Samridhi', 'VRP–5', 'EC–9485', 'CHFGP–7', 'CHFGP–14', 'CHFGP–55' and 'Priya' was significantly *at par* with control (Table 1). Ansari *et al*. (2019) observed a decrease in dry matter of *Dolichos* bean in susceptible genotypes but was not affected in tolerant genotypes. Similarly, Vieira *et al.* (2008) reported a significant decrease in dry matter in the Dolichos bean.

Screening based on yield and yield contributing characters

Yield is the most important factor which is taken for screening purposes of Al tolerance. Screening based on morphology is fast but less reliable; therefore the yield of the plant has to be taken into account for the screening of genotype. Pea genotypes with externally added Al resulted in a marked reduction in yield, number of pod per plant and pod characters.

A significant variation was observed among 25 genotypes of pea for pod length and pod weight due to Al treatment both pod length and pod weight was significantly (Table 2). 'CHFGP-7', 'Arka Priya', 'Pusa Pragati', 'Kashi Shakti', 'Kashi Samrath' were superior for pod length. At the lower level of Al (12 ppm), pod length was affected in few genotypes only and at 24 ppm Al level, pod length decreased in pea genotypes except in 'Arka Priya', 'Arka Apoorva', 'Kashi Samrath', 'Kashi Samridhi', 'Kashi Ageti', 'VRP-5', 'EC9485', 'CHFGP-6', 'VRPE-29', 'NO-17', 'CHFGP-7', 'CHFGP-14' and 'CHFGP55' (Table 2). Similarly, due to Al treatment pod weight also reduce in pea genotypes except for 'Arka Priya', 'Arka Apoorva', 'Kashi Samrath', 'Kashi Samridhi', 'CHFGP-1', 'EC-9485', 'CHFGP-6', 'NO-17', 'CHFGP-7', 'CHFGP-14', 'CHFGP-55', 'CHFGP15', and 'KK-10' which were found *at par* with control (Table 2). Similarly, Legesse *et al.* (2017) reported a substantial decrease in the pod length and yield of *Phalseolus vulgaris* in response to the addition of a higher concentration of Al (100 mg Al/kg soil). The result is in conformity with the findings of Ansari *et al*. (2019) where pod length and weight were affected in susceptible *Dolichos* bean genotypes.

A significant difference was observed for mean yield across Al concentration in 25 different pea genotypes. Averaged across genotypes significant reduction of 18% ($p<0.05$) and 33% ($p<0.05$) in yield was observed in 12 and 24 ppm Al levels, respectively compared to control. 'Kashi Samrath', 'Arka Priya', 'CHFGP-14', 'CHFGP7', 'CHFGP1', 'CHFGP55', 'Kashi Samridhi' and 'Arka Apoorva' were found superior for yield. From the present result, it was clear that the higher level of Al caused a marked negative effect on yield. The addition of Al (24 ppm) decreased the yield of genotypes significantly except for 'Pusa Pragati', 'Arka Priya', 'Arka Apoorva', 'Kashi Samrath', 'Kashi Samridhi', 'EC9485', 'CHFGP6' and 'KK10' (Table 3) suggesting that these genotypes can tolerate Al and perform better in toxic condition. Valle *et al*. (2009) reported that toxic concentration of Al in acid soils inhibited root growth and caused a considerable decline in yields of Alsensitive crops.

A significant reduction in the number of pods/plant was recorded in Al treatment in both levels (Table 2). The different genotypes of pea showed a significant difference in the number of seeds/pod. Significant reduction in the number of seeds/pod was recorded in Al treated plants, at 12 ppm Al 19% ($p<0.05$) and at 24 ppm Al 27% ($p<0.05$) reduction was obtained as compared to control.

Interaction between Al treatment and genotypes was found significant. 'CHFGP-7', 'Arka Apoorva', 'Arka Priya', 'Kashi Samrath' and 'Kashi Samridhi' were found

Table 2. Effect of Al on yield contributing character

Genotypes	Pod weight (g plant^{-1})			No. of pod plant^{-1}			Pod length (cm)			No. of seed pod^{-1}		
	Control	12 ppm	24 ppm	Control	12 ppm	24 ppm	Control	12 ppm	24 ppm	Control	12 ppm	24 ppm
Matar Ageta–7’	2.98	2.93	2.07	6.33	5.00	3.00	6.00	5.50	4.33	3.50	3.00	1.33
‘Pb–89’	4.27	4.00	3.33	7.67	5.67	3.67	7.83	5.67	5.33	5.67	3.00	3.00
‘AP–3’	3.60	3.03	2.80	7.00	5.67	4.00	5.83	5.33	4.00	3.33	2.67	2.33
‘Lincoln’	4.07	3.40	2.80	6.33	6.00	3.00	5.93	5.67	4.00	4.50	3.50	2.50
‘Arkel’	3.08	2.73	2.70	10.67	6.67	3.67	6.83	5.93	5.67	4.33	2.67	2.67
‘P.S.M. 3’	3.48	3.20	3.00	5.67	5.33	3.33	5.83	5.67	4.67	3.67	2.67	1.67
‘Pusa Pragati’	4.03	3.60	3.33	6.33	5.33	4.00	9.00	7.33	6.33	6.33	4.00	3.00
‘Arka Priya’	4.37	4.30	4.40	8.33	8.67	7.33	8.17	8.33	7.67	5.67	5.67	5.33
‘Arka Apoorva’	3.33	3.40	3.23	7.00	6.33	7.00	6.83	6.00	6.33	6.00	6.33	5.33
‘Kashi Samrath’	4.73	4.68	4.77	8.33	8.00	7.33	7.20	6.33	7.17	5.33	5.00	5.67
‘Kashi Samridhi’	2.51	2.53	2.37	10.00	9.67	10.33	5.17	5.83	5.50	5.33	4.67	6.00
‘Kashi Ageti’	2.92	2.23	1.97	6.33	4.33	3.67	5.83	5.33	5.33	3.67	2.33	1.67
‘Kashi Shakti’	3.34	3.42	2.87	6.33	4.33	3.67	8.00	6.33	6.50	4.67	4.33	2.67
‘VRP–5’	2.69	2.50	2.34	6.33	5.33	4.33	5.50	5.67	4.83	3.33	2.33	2.00
‘CHFGP–1’	4.08	3.97	3.90	8.33	6.67	6.33	7.33	6.67	6.33	5.33	4.33	4.00
‘EC–9485’	1.84	1.80	1.70	11.00	10.67	8.67	5.33	4.83	4.50	5.00	4.67	4.33
‘CHFGP–6’	2.13	2.13	2.13	10.00	6.33	8.67	5.67	5.33	5.50	5.33	5.00	5.00
‘VRPE–29’	4.00	3.30	3.43	7.00	6.00	5.00	6.33	5.83	5.83	4.33	2.33	3.00
‘NO–17’	2.40	2.40	2.40	10.00	8.67	7.67	4.90	5.00	5.50	5.00	5.00	5.00
‘CHFGP–7’	3.53	3.17	3.53	10.33	8.00	7.33	8.83	7.17	8.67	7.00	6.00	5.67
‘CHFGP–14’	4.10	4.03	4.20	9.33	7.33	6.33	6.67	6.67	6.33	4.67	4.00	5.00
‘CHFGP–55’	3.36	3.07	3.10	8.33	9.33	7.33	6.00	6.17	5.33	5.33	3.67	3.33
‘CHFGP–15’	3.30	2.97	3.00	6.00	6.00	4.67	7.33	5.67	5.67	5.33	4.33	3.67
‘Priya’	3.62	3.50	3.10	5.33	4.33	3.33	7.83	6.00	4.67	5.67	3.67	2.67
‘KK–10’	3.07	3.63	3.40	5.00	4.33	3.67	8.00	5.67	5.50	6.00	5.33	4.00
CD (G X Al)	0.331			1.358			0.935			1.161		

Table 3. Source of genotypes, screening characters and categorizing of genotypes based on multivariate analysis (K-mean clustering)

Genotypes	Source of collection	Shoot length (cm)			Yield (kg ha^{-1})			K-mean clustering	Ranking
		Control	12 ppm	24 ppm	Control	12 ppm	24 ppm		
Matar Ageta–7’	PAU, Ludhiana	18.33	17.22	14.44	4,222	3,259	1,415	21	Susceptible
‘Pb–89’	PAU, Ludhiana	11.94	9.44	9.83	7,333	5,037	2,593	19	Susceptible
‘AP–3’	CSAUA&T, Kanpur	16.22	14.78	11.22	5,630	3,822	2,489	20	Susceptible
‘Lincoln’	ICAR-IARI, Katrain	9.77	8.55	7.93	5,704	4,933	2,156	22	Susceptible
‘Arkel’	ICAR-IARI	14.11	11.44	11.11	7,037	4,067	2,178	22	Susceptible
‘P.S.M. 3’	GBPUAT, Pant Nagar	14.99	13.00	11.78	4,370	3,793	2,222	24	Intermediate
‘Pusa Pragati’	ICAR-IARI	13.74	12.83	11.00	5,704	4,844	5,022	18	Susceptible
‘Arka Priya’	ICAR-IIHR	13.50	11.33	11.50	8,074	8,259	7,185	25	Intermediate
‘Arka Apoorva’	ICAR-IIHR	14.00	12.33	11.33	5,926	4,844	5,022	24	Intermediate
‘Kashi Samrath’	ICAR-IIVR	12.33	10.67	11.43	8,741	8,341	7,852	29	Tolerant
‘Kashi Samridhi’	ICAR-IIVR	13.21	11.00	11.55	5,556	5,481	5,481	31	Tolerant
‘Kashi Ageti’	ICAR-IIVR	13.77	11.28	8.89	4,111	2,222	1,704	19	Susceptible
‘Kashi Shakti’	ICAR-IIVR	12.77	10.55	10.22	4,741	3,519	2,444	19	Susceptible
‘VRP–5’	ICAR-IIVR	11.55	11.16	10.22	3,593	3,044	2,378	23	Intermediate
‘CHFGP–1’	Heirok, Thoubal, Manipur	17.33	15.67	14.67	7,556	6,000	5,533	20	Susceptible
‘EC–9485’	ICAR-IIVR	17.18	14.67	15.66	4,444	4,511	3,533	28	Tolerant
‘CHFGP–6’	Imphal East, Manipur	17.11	17.33	17.33	4,926	3,156	4,281	25	Intermediate
‘VRPE–29’	ICAR-IIVR	13.17	12.16	11.78	6,222	4,496	3,889	21	Susceptible
‘NO–17’	ICAR-IIVR	14.87	11.00	9.83	5,333	4,696	4,133	24	Intermediate
‘CHFGP–7’	Imphal East, Manipur	19.67	18.00	17.00	8,111	5,867	5,652	22	Susceptible
‘CHFGP–14’	Imphal East, Manipur	16.33	14.33	14.33	8,726	6,593	6,015	25	Intermediate
‘CHFGP–55’	Landrace, Sikkim, Gangtok	19.67	15.67	15.00	6,740	6,296	5,111	24	Intermediate
‘CHFGP–15’	Imphal East, Manipur	19.67	17.00	14.33	4,244	4,074	3,185	19	Susceptible
‘Priya’	Rajdhani Seeds., New Delhi	10.61	9.83	7.94	4,296	3,481	2,407	22	Intermediate
‘KK–10’	KK Beej Bhandar, , Assam	12.44	9.55	9.44	3,407	3,570	3,185	23	Intermediate
CD (G X Al)		1.92			961				

good for the number of seeds per pod (Table 2). Similarly, Legesse *et al.* (2017) reported significant reductions in the pod length and yield of common bean in response to applying the higher level of Al (100 mg Al/kg soil), however at 12.5 mg Al/kg soil, they observed no significant difference for all the yield components compared to the control.

Clustering of genotypes

Al tolerance among pea genotypes was evaluated in this study using Kmean cluster analysis of the data for morphological and yield traits. The advantage of using multivariate analysis in the evaluation of Al tolerance is that it permits simultaneous analysis of several characters to increase the accuracy of the genotype ranking. The tolerance level of the genotype is done by overall performance but not only based on a single character which may prove unreliable.

Based on the K-clustering score sum of all the studied characters 'Kashi Samrath', 'Kashi Samridhi' and 'EC-9485' were classified as tolerant at 24 ppm Al level (Table 3). 'Matar Ageta-7', 'Pb-89', 'AP-3', 'Lincoln', 'Arkel', 'Kashi Ageti', 'Kashi Shakti', 'CHFGP-7' and 'CHFGP-15', 'VRPE-29' were classified as susceptible genotypes and the remaining was intermediate performing (Table 3). Kichigina *et al*. (2017) classified pea genotypes into tolerant and susceptible using clustering using the Ward method based on morphological and economic traits. The results are in agreement with Kumar *et al.* (2016) where they used Hydro and aeroponic technique for rapid drought tolerance screening in maize.

These genotypes have potential to improve yield in acid soil affected regions of India and assist in further breeding of pea genotypes for Al tolerance.

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