Core Ideas
• Genotype × environment interaction among 11 genotypes was highly significant over three different locations.
• Genotype NL 96475A was most stable for all environments.
• Genotype NL 96680 was suitable for low-performing environments.

ABSTRACT
The assessment and measurement of yield stability of a genotype over environments is an important component of a certain breeding program. Ten elite genotypes of lentil (*Lens culinaris* Medik) and one check variety were evaluated for their adaptability at three different locations of Punjab Province, viz.—Nuclear Institute for Agriculture and Biology (NIAB), Faisalabad; Barani Agricultural Research Institute (BARI), Chakwal; and Arid Zone Research Institute (AZRI), Bhakar. Trials were conducted during two consecutive years (2013–2014). Genotype × environment interactions (of crossover nature) among 11 genotypes and 3 environments were observed to be highly significant. Mean seed yield was found maximum for NL 56-1 (718 kg ha⁻¹) followed by NL 96475A (709 kg ha⁻¹) during 2013. However, NL 96475A had shown stable performance at different locations and was better responsive to favorable conditions having high regression coefficients. NL 96680 also appeared to be a stable genotype for low-performing environments, as it had a regression coefficient less than unity. In the year 2014, the same genotypes, NL 96475A and NL 96680, had shown stable performance. NL 96475A was found suitable for all environments, and NL 96680 was suited to a low-performing environment. On the basis of these observations, it has been concluded that NL 96475A was the most stable genotype with mean yield greater than the grand mean, nonsignificant estimates of unit regression coefficient, and deviation from regression.

Abbreviations: AZRI, Arid Zone Research Institute; b, regression coefficient; BARI, Barani Agricultural Research Institute; G × E, genotype × environment; NAIB, Nuclear Institute for Agriculture and Biology; $S^2d$, deviation from regression.

Lentil (*Lens culinaris* Medik) is the second most important winter pulse crop after chickpea (*Cicer arretinum* L.) in Pakistan. It has 25% protein (Kahraman, 2016) in its seed, and thus plays an important role to meet the protein requirements of the people of Pakistan. In Pakistan, it is grown on an area of 13.8 thousand ha with an annual production of 6.7 thousand Mg (Anonymous, 2017–2018). It is mainly grown in districts of Narrowal, Sialkot, Jhelum, Rawalpindi, Chakwal, and Gujrat. Average yield is low in Pakistan as compared to other countries of the world due to non-availability of high-yielding and stable genotypes and weed infestation. The seed yield is ultimately the result of favorable interaction of genotype with the environment. Stable performance over different environments is a desirable feature, which depends on the magnitude of genotype × environment (G × E) interactions (Sadiq et al., 2001).

The assessment of stability and adaptability of the genotypes is an important component of any breeding program. Various environmental factors affect plant growth at different stages of plant development (Bull et al., 1992; Oladosu et al., 2017). A stable genotype can be identified by considering the regression coefficient (b) and deviation from regression ($S^2d$) simultaneously. A genotype having $b < 1.0$ is considered to be more stable for low-performing environments, and a cultivar with $b > 1.0$ has below-average stability that is suitable for high-performing environments. A cultivar with $b = 1.0$ has average stability and is well or poorly adapted to all environments with high or low mean performance. Hence, a cultivar with $b = 1.0$ and $S^2d = 0.00$ can be defined as a stable one (Eberhart and Russell, 1966). Exploitation of G × E interactions is important for the identification of stable varieties.
Table 1. Locations of research institutes where the experiments were conducted.

<table>
<thead>
<tr>
<th>Sr. no.</th>
<th>Research institutes</th>
<th>Location in the country</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Nuclear Institute For Agriculture and Biology (NIAB), Faisalabad</td>
<td>Central Punjab</td>
</tr>
<tr>
<td>2</td>
<td>Arid Zone Research Institute (AZRI), Bhakhar</td>
<td>Southern Punjab</td>
</tr>
<tr>
<td>3</td>
<td>Barani Agriculture Research Institute (BARI), Chakwal</td>
<td>Upper Punjab</td>
</tr>
</tbody>
</table>

The G × E interaction in various crops was studied by different research workers (Ashraf et al., 2001; Zubair and Ghafoor, 2001). For measuring phenotypic stability in grain legumes, stability parameters have also been studied (Bakhsh et al., 1995; Sharif et al., 1998, Qureshi, 2001).

The present study was conducted at the Nuclear Institute for Agriculture and Biology (NIAB), Faisalabad (Pakistan) and other two locations of the Punjab Province to assess the performance of different lentil genotypes and their interaction with the environment at different locations along with stability parameters for the identification of high-yielding and stable varieties with wider adaptability over environments.

**MATERIALS AND METHODS**

Ten selected elite lines of lentil (i.e., NL 56-1, NL 96, NL 9710, NL 9727, NL 96475A, NL 96617, NL 96625, NL 96635, NL 96639, and NL 96680), developed through hybridization at NIAB, Faisalabad, and standard check Masoor-93, were evaluated at three different locations of Punjab Province, i.e., NIAB Faisalabad, Barani Agricultural Research Institute (BARI), Chakwal and Arid Zone Research Institute (AZRI), Bhakhar in 2013 (Table 1). The genotypes were sown in a triplicated randomized complete block design. The plot size was 7.2 m² and row-to-row and plant-to-plant distances were 30 and 10 cm, respectively. The experiment was repeated in 2014 at the same locations. Data on seed yield (kg ha⁻¹) from different locations were collected and subjected to the analysis of variance (Steel and Torrie, 1997). Different stability parameters were estimated by using the regression method following the Eberhart and Russell (1966) model. Two years of data were analyzed separately to check whether these genotypes were performing similarly in both years at given locations or not.

**RESULTS AND DISCUSSION**

Pooled analysis of variance showed highly significant differences (P ≤ 0.01) among genotypes and among environments. The G × E interaction was also significant (P ≤ 0.05) in both years (Table 2). This clearly indicates that the genotypes were genetically different and thus exhibited variable responses to variable environments.

Table 2. Mean squares from the analyses of variance for seed yield of lentil genotypes.

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>d.f.</th>
<th>First year Mean squares</th>
<th>F value</th>
<th>Second year Mean squares</th>
<th>F value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Replication</td>
<td>2</td>
<td>7,037.37</td>
<td>1.30 ns†</td>
<td>5,745.01 ns</td>
<td>2.66 ns</td>
</tr>
<tr>
<td>Genotypes</td>
<td>10</td>
<td>45,565.25</td>
<td>8.44**</td>
<td>77,425.77</td>
<td>35.90**</td>
</tr>
<tr>
<td>Environments</td>
<td>2</td>
<td>3,946,294.95</td>
<td>730.95**</td>
<td>1,807,275.16</td>
<td>837.86**</td>
</tr>
<tr>
<td>G × E interaction</td>
<td>20</td>
<td>55,538.28</td>
<td>10.29**</td>
<td>141,509.75</td>
<td>65.60**</td>
</tr>
<tr>
<td>Error</td>
<td>64</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Significant at the 0.01 level.
† ns, not significant.

Genotype × environment (G × E) interactions may be either crossover in nature, in which a significant change takes place from one environment to another (Matus et al., 1997), or it may be non-crossover in nature if the ranking of genotypes across environments remains constant and the interaction is significant because of change in the magnitude of response (Baker, 1988; Blum, 1983). In the present study the G × E interaction was of crossover in nature.

Highly significant differences for seed yield were observed among the genotypes in both the years (Table 3), which indicated the presence of genetic variability among the genotypes. During first year (2013), all the genotypes produced higher seed yield compared with the check (Masoor-93) except NL 96635 and NL 96639. NL 56-1 produced maximum seed yield (718 kg ha⁻¹) followed by NL 96475-A (709 kg ha⁻¹). In the second year (2014), again all the genotypes produced higher seed yield compared with the check Masoor-93 except NL 56-1. The genotypes NL 96, NL 96475A, NL 96617, and NL 96625 produced maximum seed yield of 475, 464, 437, and 467 kg ha⁻¹, respectively. The low yield of NL 56-1 may be due to the attack of disease in the second year. Fernandez et al. (1989) observed high-yielding mungbean (Vigna radiata var. radiata) cultivars to be less stable across environments due to a high positive linear relationship between the regression coefficient and the average yield of cultivars.

Genotype × environment interaction was highly significant (P ≤ 0.01) and was crossover in nature during both the years. In the first year (2013) NL 96475 showed stable performance at different locations having nonsignificant estimates of unit regression co-efficient and deviation from regression. A genotype with above-average regression value and nonsignificant standard deviation from regression may perform better in favorable environments as studied by Zubair and Ghafoor (2001). NL 96680 was also found to be a stable genotype, but yield was quite low. NL 96475A was found to be more responsive to favorable conditions due to high regression coefficient from unity, whereas NL 96680 was more responsive to low-performing environments by having regression coefficient lesser than unity. Grand mean of seed yield over all locations was 613 kg ha⁻¹. NL 56-1, NL 96, NL 9727, and NL 96617 produced above-average yield but were not stable, either due to the significant regression coefficient or significant deviation from regression. The remaining genotypes viz, NL 9710, NL 96625, NL 96635, NL 96639, and Masoor 93 (check) had below-average yield. Stability in the seed yield had been previously reported by Saleem et al. (2002), Swamy and Reddy (2004), and Sarkar and Kundagrami (2017) in mungbean; Bakhsh et al. (2006) and Prakash (2006) in chickpea; Thakare et al., (2016) in rajmash (Phaseolus vulgaris L.); Karimizadeh et al., (2012) in lentil; and Temesgen et al., (2015) in faba bean (Vicia faba L.).

The genotype NL96475A again showed stable performance over varying environmental conditions during the year 2014 and it...
was responsive to all environments (b value close to unity), whereas NL96680 was also a stable one but yield was lower than grand mean. The lines NL56-1 and NL9710 had negative regression coefficient, which might be an indicator of a genotype’s positive response to a poor environment. However, both lines showed lower seed yield compared with standard check (Masoor 93).

The level of response of different genotypes toward stability parameters was different. Genotypes having stable performance under different environmental conditions may be released as a commercial variety or used in a breeding program for the evolution of high-yielding and stable lentil varieties. Yearly performance of different lentil genotypes under varying environmental conditions clearly indicated that NL96475A was a most stable genotype (having nonsignificant estimates of unit regression coefficient and deviation from regression), which showed more seed yield compared with the grand mean. Hence, it has been concluded that the line NL96475A is most suitable for general cultivation in the Punjab Province after its approval as a commercial variety.

**ACKNOWLEDGMENTS**

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**REFERENCES**


