The Effect of Two Different Agro-Climatic Conditions on Growth and Yield Performance of Sugarcane Genotypes

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Abstract Sixteen (16) Sugarcane genotypes response were studied in an experiment “genotype x location interactions” in two different agro-ecological zones (Mardan and Harichand) of Khyber Pakhtunkhwa, Peshawar-Pakistan during 2011-12 and 2012-13. The experiment was laid out in triplicate Randomized Complete Block (RCB), design with plot size of 67 m² (10 m × 6.7 m). Combined analysis of variance was used to identify the presence of genotype x location interactions from replicated multi-environment trials. The data revealed significant variations among the genotypes for percentage germination, tillers, plant height, nodes plant-1, internode length and cane yield at 1% probability level. It was observed that none of the genotypes could show superiority with respect to all attributes. However, the mean performance over locations and years indicated that the check genotype Mardan-93 remained superior by showing maximum buds germination of 42.26%. The maximum number of tillers (259.17), plant height (189.41 cm), nodes plant-1 (22.23), internode length (16.97 cm), cane diameter (23.29 mm), cane yield (68.42 t/ha), millable canes (87.83), sugar recovery (10.57%) and sugar yield (7.07 t/ha) was recorded for genotypes MS91CP238, MS99HO391, Hoth127, MS94CP15, S97CP288, MS99HO317, MS92CP979, MS91CP272, MS99HO93, MS99HO93, MS99HO93 and MS99HO317, respectively against check genotypes. It was concluded that genotypes MS99HO317, MS99HO93, MS92CP979 and MS91CP238 were superior at SCRI, Mardan (test location-I) based on tillering ability, millable canes, cane yield, sugar recovery and sugar yield. Sugarcane Seed Multiplication Farm (SSMF), Harichand-Charsadda. (test location-II), the cultivars MS91CP272, MS99HO391, MS94CP15 and MS99HO391 were superior based on tillers, millable canes, sugar recovery and sugar yield compared to other genotypes. The combined over years and locations performance exhibited the genotypes MS99HO317, MS91CP238, MS92CP979 and CP98831 were superior in terms of percentage germination, tillers, cane yield, number of millable canes, sugar recovery and sugar yield.

Keywords Sugarcane genotypes; Genotype x location interactions; ANOVA; Growth and yield performance

Background Crop cultivars are released for commercial production based on their relative worth to produce high yields (food, feed, fiber, or fuel) and other essential agronomic characteristics. The yield performance of crop cultivars is under the control of genetic and environmental influences accompanied with selection attempts to exploit the genetic basis of the attributes so that released cultivars can continually produce high yields. However, due to the quantitative nature of the trait (controlled by many genes), genes vary in their expression and contribution to yield as environmental conditions change. This introduces a degree of uncertainty when evaluating genotype performance in specific environments, as the actual contribution due to genotype may be influenced (either positively or negatively) by environmental conditions. Consequently, there is uncertainty of the repeatability of genotypic performance in different environments. This is the basis of Genotype x environment interactions, which has been a constraint to crop improvements from selection for decades (Ramburan, 2012).
Genotype x environment interactions occur when two or more genotypes are compared across different environments and their relative performance (responses to the environment) is different. Due to effect of this interaction, the association between phenotype and genotype is reduced. This raises the important issue of adaptation because a breeder’s selection in one environment of superior performers may not hold true in another environment. By measuring the $G \times E$ interactions, the breeder is usually better equipped to determine the best breeding strategy to use and develop the genotype that is most adapted to the target region (Acquaah, 2007).

Development of cultivars or varieties, which can be adapted to a wide range of diversified environments, is the ultimate goal of plant breeders in crop improvement programs. The adaptability of a variety over diverse environments is usually tested by the degree of its interactions with different environments under which it is planted. A variety or genotype is considered to be more adaptive or stable one if it has a high mean yield but a low degree of fluctuation in yielding ability when grown over diverse environments. $G \times E$ interactions become important when the rank of breeding lines changes in different environments. This change in rank has been defined as crossover $G \times E$ interaction (Baker, 1988). $G \times E$ interactions in general, and $G \times E$ interactions of crossover type in particular, are considered to have a negative impact on the success of breeding programs, because breeders search for a few widely adapted cultivars. Whilst this is probably the best strategy in the case of breeding programs in developed countries targeted to favorable environments, Stroup et al. (1993) suggested that, in case of unfavorable environments, breeders may look at $G \times E$ interactions in a different way. Measuring $G \times E$ is important in order to determine an optimum strategy for selecting genotypes with adaptation to target environments (Annicchiarico, 1997). In plant breeding programs, potential genotypes are usually evaluated in different environments (locations and years) before selecting desirable genotypes. For quantitative traits such as yield, the relative performance of different cultivars often varies from one environment to another. Such statistical interaction results from changes in the relative ranking of the genotypes or changes in the magnitudes of differences between genotypes from one environment to another. Changes in ranking make it difficult for the plant breeder to decide which genotype should be selected (Nguyen et al., 1980). The importance of $G \times E$ interactions in sugarcane selection is widely recognized (Milligan et al., 1990). Environmental effects on sugarcane yields may be due to differing nutrient deficiencies (Anderson et al., 1995), disease pressures or climatic differences among locations (Magarey and Mewing, 1994). However, the vast majority of studies addressing the effects of location on sugarcane yields have focused on the interaction of genotype x environment. Numerous studies have reported significant $G \times E$ interactions and recommended sugarcane selection in differing environments (Bissessur et al., 2010).

The objectives of the present research work to evaluate promising genotypes of sugarcane for their yield and associated parameters under two different agro-climatic conditions of Khyber Pakhtunkhwa (KP) Province of Pakistan and to determine the magnitude of yield differences in both locations.

1 Results and Discussion
Multi-location testing is desired in crop improvement program as elite breeding lines are normally tested across several locations over many years before the best one to be released to growers. The aim of this study was to check the performance of elite sugarcane genotypes under the two different agro-ecological conditions of the Khyber Pakhtunkhwa, Pakistan. The variations in varietal performance under the influence of different environmental conditions is defined as genotype by environment ($G \times E$) interactions.

1.1 Estimation of genetic variability for various morphological traits
1.1.1 Germination
It is considered the most indispensable physiological phase as without it there is no plant to obtain production. In the present studies, the combined analysis of variance revealed highly significant differences ($p \leq 0.01$) among the genotypes for percentage germination. Genetic makeup and diverse nature of origin suggest differences in the genotype (Thippleswamy et al., 2003). Tahir et al. (2013) reported identical results for the same parameter while studying genetic divergence in elite sugar genotypes. Similarly, years, locations and genotype x year interactions
were also highly significant (p≤0.01) for this trait. However, the interactions of years x location, genotype x year and genotype x year x location were non-significant (Table 1).

Mean results exhibited that germination in sugarcane genotypes ranged from 27.11 to 46.61% at SCRI, Mardan vs. 19.09 to 48.75% at Harichand (Table 2). About 81.25% of the total sugarcane genotypes showed maximum buds germination at SCRI, Mardan than at Harichand. At SCRI, Mardan, check genotype Mardan-93 showed the maximum germination of 46.61% while genotype S96SP1215 showed the minimum (27.11%). Similarly, at Harichand, the maximum buds sprouting (48.75%) was recorded for genotype CP89831 while the minimum (19.09%) for genotype MS99HO93. Averaged over 16 sugarcane genotypes, germination at SCRI, Mardan and Harichand were 38.27 and 32.80%, respectively.

1.1.2 Number of tillers
Number of tillers is directly related to cane yield and therefore, play a key role in enhancing the final yield of sugarcane. Highly significant differences (p≤0.01) were recorded for number of tillers among the genotypes across years and locations (Table 1). These results are in good agreement with the findings of Tahir et al. (2013) wherein they also got significant differences for number of tillers. Highly significant (p≤0.01) differences were also recorded for locations and years x location interactions for this attribute. Similarly, interactions of genotype x year and genotype x year x location exhibited significant (p≤0.05) differences. However, non-significant differences were recorded for years and genotype x location interactions for this parameter.

Means for number of tillers of sugarcane genotypes ranged from 121.25 and 279.83 at SCRI, Mardan vs. 66.67 and 238.50 at Harichand (Table 2). About 68.75% of the sugarcane genotypes produced maximum number of tillers at SCRI, Mardan than at Harichand. At SCRI, Mardan, the maximum number of tillers (279.83) were produced by genotype MS91CP238 while the minimum (121.25) by genotype S96SP1215. Similarly, at Harichand, the maximum number of tillers (238.50) were produced by genotype MS91CP238 whereas the minimum (66.67) by genotype MS99HO93. Averaged over 16 sugarcane genotypes, number of tillers at SCRI, Mardan and Harichand were 181.55 and 165.62, respectively.

1.1.3 Plant height
Combined mean square results over two years and locations for plant height exhibited highly significant (p≤0.01) variations among the genotypes (Table 1). Our results are in line with those of Tahir et al. (2013) who reported identical results for the same trait. Similarly, years, locations and year x location interactions also showed highly significant (p≤0.01) differences for plant height. Similarly, years, locations and year x location interactions also showed highly significant (p≤0.01) differences for plant height. However, interactions of genotype x year, genotype x location and genotype x year x location were non-significant.

Mean results showed that plant height ranged from 149.19 to 186.82 cm at SCRI, Mardan while 125.00 to 204.32 cm at Harichand (Table 2). About 68.75% of the genotypes at SCRI, Mardan exhibited greater plant height than at Harichand. At SCRI, Mardan the tallest (186.82 cm) genotype was MS99HO391 while the shortest (149.19 cm) was MS99HO93. Similarly, at Harichand the tallest (204.32 cm) genotype was Hoth127 whereas the shortest (125.00 cm) was MS91CP238. Averaged over 16 sugarcane genotypes, plant height at SCRI, Mardan and Harichand were 165.23 and 157.46 cm, respectively.

1.1.4 Number of nodes/plant
Mean squares across years and locations for number of nodes/plant exhibited highly significant (p≤0.01) genetic variations among genotypes (Table 1). These results are corroborated with the findings of Arain et al. (2011) who evaluated new candidate sugarcane varieties for some qualitative and quantitative traits under agro-climatic conditions of Thatta during 2001-04 crop seasons and got similar results. Similarly, both tested years and locations and interactions of year x location, genotype x year and genotype x location showed highly significant differences for this attribute. However, three way interactions were non-significant.
Table 1 Mean squares for germination, tillers, plant height, nodes/plant, internode length, cane diameter and cane yield of 16 sugarcane genotypes at two locations of Khyber Pakhtunkhwa, during 2011-12 and 2012-13.

| SOV                              | D.F | Germination | Number of tillers | Plant height | Nodes/plant | Internode length | Cane diameter | Cane yield   |
|---------------------------------|-----|-------------|-------------------|--------------|-------------|------------------|---------------|-------------|
| Years                           | 1   | 17591.766** | 5177.130**        | 9646.088**   | 140.135**   | 65.649**         | 198.453**     | 7335.537**  |
| Locations                       | 1   | 1434.72668**| 12224.083**       | 13475.376**  | 50.666**    | 67.889**         | 46.237**      | 28432.284** |
| Years x Locations               | 1   | 343.550**   | 12304.005**       | 9281.031**   | 192.060**   | 181.994**        | 182.559**     | 18417.930** |
| Reps (Years x Locations)        | 8   | 656.024     | 7089.148          | 820.338      | 6.417       | 5.763            | 17.431        | 1767.508    |
| Genotypes                       | 15  | 383.072**   | 16764.226**       | 2543.807**   | 15.094**    | 12.053**         | 8.706**       | 380.859*    |
| Genotypes x Years               | 15  | 351.705**   | 3089.119*         | 396.493**    | 20.530**    | 2.787**          | 9.319**       | 196.457 NS  |
| Genotypes x Locations           | 15  | 175.234 NS  | 3047.122 NS       | 1160.113 NS  | 14.773**    | 7.033**          | 11.595 NS     | 276.726 NS  |
| Genotypes x Years x Locations   | 15  | 110.27 NS   | 3212.205**        | 881.078 NS   | 7.501 NS    | 5.569*           | 9.454 NS      | 365.596*    |
| Error                           | 120 | 116.103     | 1755.611          | 774.197      | 4.546       | 2.67             | 8.017         | 177.513     |
| C. V%                           | 30.33 | 24.137     | 17.739           | 10.598       | 10.685      | 13.040           | 23.565        |             |

Note: * , ** = Significant at 5% and 1% levels of probability; ns = non-significant
Table 2: Mean performance for germination, tillers and plant height of 16 sugarcane genotypes evaluated at two locations of Khyber Pakhtunkhwa during 2011-12 and 2012-13

| Genotypes       | Germination (%) | Tillers          | Plant height (cm) |
|-----------------|-----------------|------------------|-------------------|
|                 | Mardan | Harichand | Genotype mean | Mardan | Harichand | Genotype mean | Mardan | Harichand | Genotype mean |
| MS91CP272       | 40.33   | 34.17     | 37.25         | 216.59  | 221.83    | 219.21        | 154.33  | 155.94    | 155.13        |
| MS94CP15        | 39.11   | 27.83     | 33.47         | 173.00  | 166.00    | 169.50        | 174.88  | 174.40    | 174.64        |
| MS91CP238       | 45.00   | 35.42     | 40.21         | 279.83  | 238.50    | 259.17        | 161.49  | 125.00    | 143.24        |
| MS92CP979       | 45.84   | 34.83     | 40.33         | 229.58  | 192.67    | 211.12        | 168.67  | 133.19    | 150.93        |
| MS99HO391       | 42.67   | 30.59     | 36.63         | 168.75  | 137.34    | 153.04        | 186.82  | 192.00    | 189.41        |
| S97CP288        | 28.28   | 27.34     | 27.81         | 139.84  | 155.67    | 147.75        | 163.27  | 155.13    | 159.20        |
| MS99HO317       | 38.89   | 38.83     | 38.86         | 195.92  | 147.50    | 171.71        | 165.42  | 159.34    | 162.38        |
| RS97N45         | 46.22   | 37.83     | 42.03         | 190.67  | 178.17    | 184.42        | 159.12  | 125.04    | 142.08        |
| MS99HO388       | 44.56   | 30.50     | 37.53         | 213.50  | 155.17    | 184.33        | 165.74  | 155.12    | 160.43        |
| MS99HO675       | 38.28   | 29.00     | 33.64         | 170.50  | 175.67    | 173.08        | 157.19  | 176.07    | 166.63        |
| MS99HO93        | 30.56   | 19.09     | 24.82         | 154.42  | 66.67     | 110.54        | 149.19  | 134.40    | 141.79        |
| S96SP1215       | 27.11   | 32.59     | 29.85         | 121.25  | 141.50    | 131.38        | 164.57  | 145.14    | 154.85        |
| Hoth127         | 32.28   | 36.25     | 34.26         | 122.83  | 121.17    | 122.00        | 165.32  | 204.32    | 184.82        |
| CP89831         | 35.61   | 48.75     | 42.18         | 174.67  | 204.00    | 189.34        | 177.62  | 175.89    | 176.75        |
| CP77400         | 30.89   | 23.84     | 27.36         | 169.75  | 165.34    | 167.54        | 162.32  | 162.57    | 162.44        |
| Mardan93        | 46.61   | 37.92     | 42.26         | 184.08  | 182.67    | 183.38        | 167.84  | 145.85    | 156.84        |
| Location mean   | 38.26   | 32.80     | 32.80         | 181.57  | 165.62    | 165.23        | 157.46  |           |               |
| Genotype LSD (0.05) | 8.71  |         |               | 33.87      | 22.49      |               |
| Location LSD (0.05) | 3.08  |         |               | 11.97      | 7.95        |               |
| G X L LSD (0.05)  | 12.32  |         |               | 47.90      | 31.81      |               |

Note: ns = Non-significant; G X L = Genotype x location
Mean results indicated that number of nodes plant-1 ranged from 17.16 to 23.72 at SCRI, Mardan vs. 19.00 to 23.62 at Harichand (Table 3). Approximately 68.75% of the sugarcane genotypes produced more nodes at Harichand than at SCRI, Mardan. At SCRI, Mardan, the maximum (23.72) nodes plant-1 were produced by genotype Hoth127 whereas the minimum (17.16) by genotype MS99HO675. Similarly, at Harichand, the highest nodes plant-1 (23.62) were produced by genotype MS99HO388 while the lowest (19.00) were produced by check genotype Mardan93. Averaged over 16 sugarcane genotype, nodes/plant at SCRI, Mardan and Harichand were 19.61 and 20.63, respectively.

Table 3 Mean performance for nodes plant-1, internode length and cane diameter of 16 sugarcane genotypes evaluated at two locations of Khyber Pakhtunkhwa during 2011-12 and 2012-13

| Genotypes | Nodes/plant | Internode length (cm) | Cane diameter (mm) |
|-----------|-------------|-----------------------|--------------------|
|           | Mardan | Harichand | Mardan | Harichand | Mardan | Harichand | Mardan | Harichand |
| MS91CP272 | 19.28 | 20.50 | 19.89 | 15.49 | 14.86 | 15.18 | 22.60 | 21.43 | 22.01 |
| MS94CP15 | 19.72 | 19.84 | 19.78 | 18.83 | 15.10 | 16.97 | 23.05 | 19.94 | 21.49 |
| MS91CP238 | 17.93 | 22.39 | 20.16 | 17.28 | 15.15 | 16.22 | 23.43 | 22.47 | 22.95 |
| MS92CP979 | 21.11 | 19.34 | 20.22 | 14.91 | 13.61 | 14.26 | 23.41 | 20.52 | 21.97 |
| MS99HO391 | 20.52 | 21.61 | 21.06 | 13.77 | 13.91 | 13.84 | 22.59 | 20.90 | 21.74 |
| S97CP288 | 20.50 | 19.61 | 20.06 | 15.92 | 14.02 | 14.97 | 24.52 | 22.06 | 23.29 |
| MS99HO317 | 22.58 | 20.95 | 21.76 | 15.86 | 15.07 | 15.46 | 21.03 | 21.78 | 21.41 |
| RS97N45 | 18.39 | 20.45 | 19.42 | 17.15 | 15.31 | 16.23 | 20.01 | 21.06 | 20.53 |
| MS99HO388 | 20.06 | 23.62 | 21.84 | 14.47 | 13.08 | 13.77 | 21.34 | 23.84 | 22.59 |
| MS99HO675 | 17.16 | 19.28 | 18.22 | 14.61 | 15.96 | 15.28 | 22.55 | 18.27 | 20.41 |
| MS99HO93 | 17.95 | 22.34 | 20.14 | 15.98 | 13.72 | 14.85 | 21.26 | 23.28 | 22.27 |
| S96SP1215 | 17.69 | 20.39 | 19.04 | 16.09 | 13.50 | 14.79 | 22.37 | 19.73 | 21.05 |
| Hoth127 | 23.72 | 20.95 | 22.33 | 12.54 | 13.97 | 13.25 | 21.87 | 22.39 | 22.13 |
| CP89831 | 18.86 | 19.78 | 19.32 | 15.92 | 14.35 | 15.14 | 22.46 | 20.33 | 21.39 |
| CP77400 | 18.14 | 20.12 | 19.13 | 17.12 | 14.23 | 15.67 | 22.51 | 21.07 | 21.79 |
| Mardan93 | 20.09 | 19.00 | 19.54 | 13.52 | 14.59 | 14.05 | 20.31 | 20.54 | 20.42 |
| Location mean | 19.60 | 20.63 | 15.59 | 14.40 | 22.20 | 21.22 | 1.72 | 1.30 | Ns |
| Location LSD (0.05) | 0.609 | 0.458 | 1.87 | Ns |
| Genotype LSD (0.05) | 2.44 | 1.72 | 1.30 | Ns |

Note: Ns = Non-significant, G X L = Genotype x location

1.1.5 Internode length

Analysis of variance results across locations and years exhibited highly significant (p≤0.01) genetic differences among the sugarcane genotypes for internode length (Table 1). Similarly, highly significant (p≤0.01) differences were also observed for both tested years and locations and interactions of year x location, genotype x year and genotype x location for this attribute. Jackson and Hogarth (1992) found that genotype x location interactions were more important than genotype x crop-year interactions in Australia. However, genotype x year x location interactions were non-significant.

The mean results indicated that internode length ranged from 12.54 to 18.83 cm at SCRI, Mardan vs. 13.08 to 15.96 cm at Harichand (Table 3). About 75% of the sugarcane genotypes had longer internode at SCRI, Mardan than at Harichand. At SCRI, Mardan, genotype MS94CP15 had longest (18.83 cm) internode while the genotype Hoth127 the shortest (12.54 cm). Similarly, at Harichand genotype MS99HO675 had the longest (15.96 cm) internode while genotype MS99HO388 the shortest (13.08 cm). Averaged over 16 sugarcane genotypes, internode length at SCRI, Mardan and Harichand were 15.59 and 14.40 cm, respectively.

1.1.6 Cane diameter

The combined over years and locations mean square results exhibited non-significant (p≥0.05) variations among
the genotypes for cane diameter (Table 1). These results are in good agreement with those of Arain et al. (2011) who got similar results for the same parameter in a qualitative and quantitative traits study of sugarcane candidate varieties at Thatta. Two tested years and year x location interactions showed highly significant differences while locations showed significant differences for this trait. However, the interactions of genotype x year, genotype x location and genotype x year x location were non-significant.

Mean results indicated that cane diameter ranged from 20.01 to 24.52 mm at SCRI, Mardan vs. 18.27 to 23.84 mm at Harichand (Table 3). About 62.50% of the sugarcane genotypes had thicker diameter at SCRI, Mardan than at Harichand. At SCRI, Mardan, genotype S97CP288 was the thickest (24.52 mm) while genotype RS97N45 was the thinnest (20.01 mm). Similarly, at Harichand genotype MS99HO388 was the thickest (23.84 mm) while genotype MS99HO675 was the thinnest (18.27 mm). Averaged over 16 sugarcane genotypes, cane diameter at SCRI, Mardan and Harichand were 22.20 and 21.22 mm, respectively.

1.1.7 Cane yield

Combined over years and location mean square results showed significant (p≤0.05) differences among the genotypes for cane yield (Table 1). Similarly, three way interactions were also significant. Years, locations and year x location interactions showed highly significant (p≤0.01) variations for this trait. However, the interactions of genotype x location and genotype x year were non-significant. Similar results were reported by Rea and Vieira (2002) wherein they conducted experiment on genotype x environment interactions in sugarcane in the central-western region of Venezuela and got similar results for the same parameter. The results suggested that a single trial at single location could be sufficient for selection of superior genotypes.

Mean results indicated that cane yield ranged from 59.20 to 88.98 t/ha at SCRI, Mardan while 30.72 to 52.91 t/ha at Harichand (Table 4). All the genotype at SCRI, Mardan showed greater cane yield than at Harichand. At SCRI, Mardan, the maximum cane yield (88.98 t/ha) was recorded for the genotype MS99HO317 while the minimum (59.20 t/ha) for the genotype Hoth127. In this way, at Harichand the highest cane yield (52.91 t/ha) was recorded for genotype MS99HO391 while the lowest (30.72 t/ha) for genotype S96SP1215. Averaged over 16 sugarcane genotypes, cane yield at SCRI, Mardan and Harichand were 68.71 and 44.37 t/ha, respectively.

Table 4 Mean performance for cane yield and milliblecane of 16 sugarcane genotypes evaluated at two locations of Khyber Pakhtunkhwa during 2011-12 and 2012-13

| Genotypes      | Cane yield (t/ha) | Millible cane |
|----------------|------------------|---------------|
|                | Mardan | Harichand | Genotype Mean | Mardan | Harichand | Genotype Mean |
| MS91CP272      | 65.10   | 51.62     | 58.36         | 78.17   | 69.67     | 73.92         |
| MS94CP15       | 70.92   | 52.34     | 61.63         | 70.00   | 63.17     | 66.58         |
| MS91CP238      | 67.52   | 52.29     | 59.90         | 91.67   | 80.67     | 86.17         |
| MS92CP979      | 73.16   | 51.48     | 62.32         | 81.33   | 94.33     | 87.83         |
| MS99HO391      | 66.99   | 52.91     | 59.95         | 87.67   | 66.50     | 77.08         |
| S97CP288       | 71.62   | 33.91     | 52.76         | 85.17   | 60.17     | 72.67         |
| MS99HO317      | 88.98   | 47.86     | 68.42         | 91.67   | 69.33     | 80.50         |
| RS97N45        | 75.13   | 38.96     | 57.04         | 74.00   | 72.67     | 73.33         |
| MS99HO388      | 70.45   | 35.29     | 52.87         | 87.17   | 54.50     | 70.83         |
| MS99HO675      | 66.59   | 45.86     | 56.22         | 80.50   | 71.17     | 75.83         |
| MS99HO93       | 60.47   | 32.00     | 46.24         | 89.83   | 47.83     | 68.83         |
| S96SP1215      | 65.48   | 30.72     | 48.10         | 74.00   | 43.50     | 58.75         |
| Hoth127        | 59.20   | 42.05     | 50.63         | 80.33   | 70.50     | 75.42         |
| CP89831        | 65.72   | 50.91     | 58.31         | 83.34   | 81.50     | 82.42         |
| CP77400        | 66.97   | 48.10     | 57.53         | 86.17   | 80.67     | 83.42         |
| Mardan93       | 65.03   | 43.67     | 54.35         | 76.50   | 80.67     | 78.58         |
| Location Mean  | 68.71   | 44.37     | 78.17         | 69.67   |           |               |
| Genotype LSD (0.05) | 10.77 |          |               |         |     |               |
| Location LSD (0.05)   | 3.81   |           |               |         |     |               |
| G X L LSD (0.05)      | 15.23  |           |               |         |     |               |

Note: Ns = Non-significant, G X L = Genotype x location
1.1.8 Number of millable canes
The mean squares across years and locations of the sugarcane genotypes showed similar performance (p≥0.05) for number of millable canes (Table 5). Similarly, interactions of genotype x year, genotype x location and genotype x year x location were also non-significant for this trait. However, two tested years and locations and year x location interactions were highly significant (p≤0.01) for this trait. Our result are in contrary with those of Okaz et al. (2011) who performed research on stability parameters of cane yield and its components under various planting dates and inter-row spacing for 16 sugarcane genotypes.

Table 5 Mean squares for millable cane, c. brix, pol, purity, sugar recovery and sugar yield of 16 sugarcane genotypes at two locations of Khyber Pakhtunkhwa, during 2011-12 and 2012-13

| SOV                      | D. F | Millable canes | Sugar recovery | Sugar yield |
|--------------------------|------|----------------|----------------|-------------|
| Years                    | 1    | 102397.686**   | 1.744 NS       | 73.966**    |
| Locations                | 1    | 8321.333**     | 94.613**       | 506.513**   |
| Years x Locations        | 1    | 4840.083**     | 16.089**       | 147.263**   |
| Reps (Years x Locations) | 8    | 4117.750       | 2.972          | 17.321      |

Note: * , ** =Significant at 5% and 1% levels of probability; ns = non-significant

Mean results for millable canes ranged from 70.00 to 91.67 at SCRI, Mardan vs. 43.50 to 94.33 at Harichand (Table 4). About 87.50% of sugarcane genotype showed maximum number of millable canes than at Harichand. At SCRI, Mardan, the maximum number of millable canes (91.67) were produced by genotype MS91CP238 while the minimum (70.00) by genotype MS94CP15. Similarly, at Harichand, the maximum number of millable canes (94.33) were produced by genotype MS92CP979 while the minimum (43.50) by genotype S96SP1215 against the check cultivars. Averaged over 16 sugarcane genotypes, number of millable canes at SCRI, Mardan and Harichand were 78.17 and 69.67, respectively.

1.1.9 Sugar recovery (%)
Combined over year and location mean squares of sugarcane genotypes were non-significant (p≥0.05) for sugar recovery (Table 5). These results are in contrary with those of Khan et al. (2004) who evaluated the performance of promising sugarcane genotype for yield and quality traits in different ecological zones of Sindh. The possible reason for this discrepancy was the use of more tested locations by author. Similarly, two tested years and the interactions of genotype x year, genotype x location and genotype x year x location were non-significant as well. However, two tested locations and year x location interactions were highly significant (p≤0.01) for this trait. Mean results showed that sugar recovery among sugarcane genotypes ranged from 10.44 to 11.75% at SCRI, Mardan whereas 8.36 to 10.57% at Harichand (Table 6). All sugarcane genotypes exhibited superior performance at SCRI, Mardan than at Harichand. At SCRI, Mardan, the maximum sugar (11.75%) was recovered from genotype MS99H093 while the minimum (10.44%) from genotype MS99HO388 against check cultivars. Similarly, at Harichand the maximum sugar (10.57%) was recovered from check genotype Mardan93 whereas the minimum (8.36%) from genotype MS99HO388. Averaged over 16 sugarcane genotypes, sugar recovery at SCRI, Mardan and Harichand were 11% and 9.60%, respectively.

1.2 Sugar yield
The mean squares across years and locations of the sugarcane genotypes were non-significant (p≥0.05) for sugar yield (Table 5). These results are in contrary with the findings of Panhwar et al. (2004) who evaluated new
sugarcane genotypes for quality attributes and cane yield in different ecological zones of Sindh. Similarly, interactions of genotype x year, genotype x location and genotype x year x location were non-significant for this trait as well, while years, locations and year x location interactions were highly significant (p≤0.01) for this trait.

Table 6 Mean performance for sugar percentage recovery and sugar yield of 16 sugarcane genotypes evaluated at two locations of Khyber Pakhtunkhwa during 2011-12 and 2012-13

| Genotypes   | Sugar recovery (%) | Sugar yield (t/ha) |
|-------------|--------------------|--------------------|
|             | Mardan  | Harichand | Genotype Mean | Mardan  | Harichand | Genotype Mean |
| MS91CP272   | 10.77   | 10.48     | 10.62         | 6.97    | 5.30      | 6.13         |
| MS94CP15    | 10.58   | 10.32     | 10.45         | 7.43    | 5.33      | 6.38         |
| MS91CP238   | 10.72   | 8.87      | 9.79          | 7.11    | 4.70      | 5.90         |
| MS92CP979   | 10.69   | 9.73      | 10.21         | 7.74    | 4.82      | 6.28         |
| MS99HO391   | 11.19   | 8.56      | 9.87          | 7.38    | 4.71      | 6.04         |
| S97CP288    | 10.74   | 9.95      | 10.35         | 7.65    | 3.35      | 5.50         |
| MS99HO317   | 11.43   | 8.83      | 10.13         | 10.01   | 4.14      | 7.07         |
| RS97N45     | 10.88   | 10.18     | 10.53         | 8.19    | 4.03      | 6.11         |
| MS99HO388   | 10.44   | 8.36      | 9.40          | 7.26    | 2.94      | 5.10         |
| MS99HO675   | 11.32   | 8.70      | 10.01         | 7.46    | 4.12      | 5.79         |
| MS99HO93    | 11.75   | 10.20     | 10.97         | 6.97    | 3.19      | 5.08         |
| S96SP1215   | 10.75   | 9.49      | 10.12         | 6.96    | 3.00      | 4.98         |
| Hoth127     | 10.76   | 9.98      | 10.37         | 6.44    | 4.22      | 5.33         |
| CP98931     | 11.57   | 10.07     | 10.82         | 7.54    | 5.15      | 6.34         |
| CP77400     | 11.22   | 9.36      | 10.29         | 7.49    | 4.42      | 5.95         |
| Mardan93    | 11.28   | 10.57     | 10.92         | 7.30    | 4.50      | 5.90         |
| Location Mean | 11.00   | 9.60      |               | 7.49    | 4.24      |               |
| Genotype LSD (0.05) | Ns      | Ns        |               |        |           |               |
| Location LSD (0.05) | Ns      | Ns        |               |        |           |               |
| G X L LSD (0.05) | Ns      | Ns        |               |        |           |               |

Note: Ns = Non-significant, G X L = Genotype x location

Mean results for sugar yield ranged from 6.44 to 10.01 t/ha at SCRI, Mardan vs. 2.94 to 5.33 t/ha at Harichand (Table 6). All sugarcane genotypes showed superior performance at SCRI, Mardan than at Harichand. At SCRI, Mardan, the highest sugar yield (10.01 t/ha) was produced by genotype MS99HO317 against check cultivars while the minimum (6.44 t/ha) by genotype Hoth127. Similarly, at Harichand, the highest sugar yield (5.33 t/ha) was produced by genotype MS94CP15 against the check cultivars while the lowest (2.94 t/ha) by genotype MS99HO388. Averaged over 16 sugarcane genotypes, sugar yield at SCRI, Mardan and Harichand were 7.49 and 4.24 t/ha, respectively.

2 Conclusions

Based on tillering ability, millable canes, cane yield, sugar recovery and sugar yield, the genotypes MS99HO317, MS99HO93, MS92CP979 and MS91CP238 were superior at SCRI, Mardan. The performance of other genotypes was also appreciable. At test location-II, the cultivars MS91CP272, MS99HO391, MS94CP15 and MS99HO391 were superior on the basis of tillers, millable canes, sugar recovery and sugar yield compared to other genotypes. A reason for the low performance of genotypes at location-II was the higher infestation of the sugarcane crop by termites in the soil, excessive rainfall, flood and fluctuations in sowing time. It could be concluded that none of the genotypes including check cultivars were superior with respect to all attributes across all environments. Based on combined over years and locations performance, it could be concluded that genotypes MS99HO317, MS91CP238, MS92CP979 and CP98931 exhibited comparatively superior performance in terms of percentage germination, cane yield, number of tillers, millable canes, sugar recovery and sugar yield. It is suggested that Mardan is the best location for sugarcane cultivation because all the genotypes showed relatively better performance there as the performance of some genotypes was almost double for some parameters. These
genotypes may be put in further evaluation and uniform yield trials. Furthermore, it is suggested that the poor performed sugarcane genotypes may also be further tested under potential areas as two years screening is not sufficient to judge the performance of these genotypes.

3 Materials and Methods
3.1 Experimental location, material and design
To assess the genotype x environment interactions, a set of 16 promising sugarcane genotypes introduced from various international sugarcane research institutes (Table 7) was studied during the spring cropping seasons of 2011-12 and 2012-13. This experiment was conducted at two different locations of Khyber Pakhtunkhwa-Pakistan i.e., Sugar Crops Research Institute (SCRI), Mardan, and Sugarcane Seed Multiplication Farm (SSMF), Harichand-Charsadda. The two sites are regularly irrigated zones and have usually no water deficiency. Status of each site is given in the Table 8

Table 7 List of 16 sugarcane genotypes and their source used for genotype x location studies at scri, mardan and ssmf, harich and during 2011-12 and 2012-13

| S. No | Genotypes       | Source                                                      |
|-------|-----------------|-------------------------------------------------------------|
| 1     | MS91CP272       | USDA-ARS stations at Canal Point, USA                        |
| 2     | MS94CP15        | USDA-ARS stations at Canal Point, USA                        |
| 3     | MS91CP238       | USDA-ARS stations at Canal Point, USA                        |
| 4     | MS92CP979       | USDA-ARS stations at Canal Point, USA                        |
| 5     | MS99HO391       | USDA-ARS stations, Houma, Louisiana, USA                    |
| 6     | S97CP288        | USDA-ARS stations at Canal Point, USA                        |
| 7     | MS99HO317       | USDA-ARS stations, Houma, Louisiana, USA                    |
| 8     | RS97N45         | South African Research Institute, Natal (South Africa)      |
| 9     | MS99HO388       | USDA-ARS stations, Houma, Louisiana, USA                    |
| 10    | MS99HO675       | USDA-ARS stations, Houma, Louisiana, USA                    |
| 11    | MS99HO93        | USDA-ARS stations, Houma, Louisiana, USA                    |
| 12    | S96SP1215       | São Paulo (Brazil)                                          |
| 13    | Hoth127         | USDA-ARS stations, Houma, Louisiana, USA and Sugarcane Research Institute, Thatta |
| 14    | CP89831         | USDA-ARS stations at Canal Point, USA                        |
| 15    | CP77400 (Check-I) | USDA-ARS stations at Canal Point, USA               |
| 16    | Mardan93 (Check-II) | USDA-ARS stations at Canal Point, USA             |

Note: MS: Mardan Selection, Hoth: Houma-Thatta, SP: São Paulo, HO: Houma, N: Natal USDA-ARS: United States Department of Agriculture-Agriculture Research Service

Table 8 Geographical characteristics of the two test locations of KPK

| S. No | Test locations         | Soil and environmental condition | Altitude (m) | Latitude            |
|-------|------------------------|----------------------------------|--------------|---------------------|
| 1     | SCR, Mardan (Test location-I) | Silty clay loam, heavy frost     | 285          | 34.2°N, 72.05°E     |
| 2     | SSMF, Harichand (Test location-II) | Heavy clay, mild frost          | 381.91       | 34°23'22"N, 71°48'18"E |

At each site triplicate RCB, design was used with plot area of 67 m² (10 m x 6.7 m). Each genotype was sown in seven rows with row to row distance of 90 cm. Double three budded sets were used as sowing material. The central row consisted of 150 buds. Data were recorded on five randomly selected genotypes from central row of each plot. Two plant crops were harvested from each location, successively. Ten parameters were examined in each plant crop. Recommended dose of fertilizer was applied as N (150 kg/ha), P (100 kg/ha), and K (100 kg/ha) from SOP, DAP and Urea as 225.00 kg DAP/ha at planting time and 250.00 kg SOP with 125 kg urea/ha in May/June. Urea was also additionally applied at 125.00 kg/ha at the time of earthing up. The detail description of each parameters as following.
3.2 Description of morphological traits

3.2.1 Germination
Germination is the foundation of any crop and the success of a crop heavily depends on emergence. Sugarcane propagation occurs through cuttings of the stalk or seed cane containing usually three or more nodes with buds. Germination under field condition starts usually from 7 to 10 days. Two times germination data were recorded as:

1) Germination count in stage-i: Number of buds germinated per 150 buds in a 10m long central row was recorded after 30 days of sowing.

2) Germination count in stage-ii: This attribute was recorded as number of buds germinated per 150 buds in a 10 m long central row after 30 days of the 1st germination. Both germinations data were first averaged and the germination percentage was then calculated.

Germination percentage = \((\text{Total germinated buds} / \text{Total sown buds}) \times 100\)

3.2.2 Number of tillers
Tillering behavior is a beneficial attribute of a variety because it provides the plants with appropriate number of stalks for a good yield. Tillering starts from around 35- 40 days after planting and may last up to 130-135 days. Tillering in sugarcane is not a synchronized process, therefore, it was also recorded twice as:

1) number of tillers count in stage-i: This parameter was counted as number of tillers in a 10 m long central row after 90 days of the plantation in the month of May.

2) number of tillers count in stage-ii: This was counted like stage-i, after one month of the stage-i.

Data recorded in both stages were averaged and used in final analysis.

3.2.3 Plant height
Plant height was measured from the soil surface to the top dewlap of the plant with the help of meter rod. This parameter was also recorded two times.

1) plant height in growth stage-i: Height of the standing five canes in the field was recorded using meter rod from soil surface to the top in the month of July.

2) plant height in growth stage-ii: This was also recorded on five plants after 30 days of the stage-i.

3.2.4 Cane diameter
At maturity stage, cane diameter was measured on five randomly selected canes with the help of digital Vernier Caliper by holding the individual cane (top, middle and base) between two jaws of the instrument. The averaged value was used as cane diameter.

3.2.5 Number of nodes plant-1
This was recorded at cane maturity stage by counting the number of buds per plant.

3.2.6 Inter node length
This was measured as the average value of the distance between two nodes recorded in the top, middle and base of the cane.

3.2.7 Cane yield
Cane yield was determined with the help of the following formula:
\[ \text{Cane yield (t/ha)} = (X \times 10,000) / \text{Plot size} \times 1000 \]
Where “X” is sugarcane yield
3.2.8 Number of millable canes
This parameter was recorded on plot basis by counting the number of canes that were millable (excluding the tillers which had not developed in to mature canes).

3.2.9 Sugar recovery (%)
Sugar recovery was calculated with the help of the relationship following (Islam et al., 2011).
Sugar recovery (%) = [Pol % – 0.5(Brix – Pol %)] x 0.70

For quality analysis of sugar quality attributes, five canes of each clone were collected from the field and samples were subjected to sugarcane quality analysis in the laboratory at SCRI, Mardan and the obtained data were analyzed statistically.

3.2.10 Sugar yield
It is the total recoverable percentage sugar in the cane. This was calculated by the following relationship following (Khaled, 2010).
Sugar yield (t/ha) = [Yield (t/ha) x Sugar recovery (%)] /100

3.3 Statistical analysis
Analysis of variance was calculated using the following model:
Yijk = μ + Gi + Ej + Lk + Bjkl+ GEij + GLik + ELjk + GELijk + eijk

Where Yijk is the corresponding variable of the i-th genotype in j-th year and k-th location or the expected yield of the ith genotype in the jth environment and kth location, μ is the overall mean or grand mean, Gi is the main effect of i-th Genotype, Ej is the main effect of j-th year, Bjkl is the effect of l-th replication in the j-th year and k-th location, GEij is the interaction of i-th genotype with j-th year, GLik is the interaction of i-th genotype with k-th location, ELjk is the interaction of j-th year with k-th location, GELijk is the interaction of i-th genotype with j-th environment and k-th location and eijk is the random error term. This model was used by (Bissessur et al., 2010) with little modification in notations regarding this study. Data recorded in each location and years were analyzed as combined experiment series in RCBD with the General Linear Model (GLM) procedure of the SAS statistical software (SAS Institute, 2007).

Authors’ contributions
Dr. Muhammad Khalid designed this research idea, carried out the analysis of data using different computer softwares and drafted this scientific article. Other all co-authors (Dr. Hidayt ur Rahman, Dr. Farhatullah, Dr. Ashiq Rabbani and Dr. Muhammad Iqbal) helped in various sections of the manuscript. Finally, Dr. David A. Lightfoot incorporated his valuable suggestion during writ-up of this manuscript to be published in Plant Gene & Trait.

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