Research Article

Trenched and Open-Field Segments Affecting Qualitative Traits of CP77/400 Sugarcane Variety

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Abstract | Sugarcane holds a unique status worldwide based on its economic and nutritional value, as well as its ability to grow under different environmental conditions. The roles of sugarcane stalk portions and the number of setts on the qualitative characteristics of sugarcane were investigated over two years. Sugarcane variety CP 77/400 was used in open field sugarcane exposed to frost and protected from frost integrated with sugarcane stalk portions (SSP), mixed setts, upper, middle, and lower portions, and number of setts, single three-budded cane, one and a half, double, and triple cane pieces were used. Sugarcane stalk portions (SSP) significantly decreased the purity percentage and sugar yield t $ha^{-1,}$ whereas the number of setts significantly increased sugar yield t ha^{-1}. SSP has significantly affected Pol% (17.43), Purity% (85.43), and sugar yield t ha^{-1} (8.03). Different numbers of sugarcane setts (NOS) significantly enhanced the Pol% and sugar yield (t ha-1). Field open sugarcane (frost-exposed) canes proved best for raising plant crops compared to trenched (stored, frost-protected) sources. The top portions showed the maximum number of buds, short internodes, and the least weight, followed by the middle stalks. The mixed setts were more productive than the bottom portions. Double setts of the top cane portions gave the best results for sugar yield as compared to others. Triple-sett placement, either from field-open sugarcane or trenched canes, also increased sugar yield. An improved purity percentage was observed in double to triple freshly planted setts. Taken together, open field sugarcane planting sources are more productive, regardless of the sugarcane setts number, , as compared to trenched method for the qualitative, vegetative and quantitative traits. The sugarcane trenched appears more suitable to control unpredictable detrimental effects of frost in selected areas.

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Introduction

Sugarcane (*Saccharum* spp.) is a vital cash crop in tropical and subtropical regions, cultivated across more than 121 countries, covering 27 million hectares globally (Kumar *et al*., 2014, 2024). It accounts for approximately 80% of global production of sugar and serves as the best source of feedstock for bioethanol, diesel thereby contributing almost 40% production of biofuel in the world (Wu and Altpeter, 2015). Additionally, sugarcane is source of several valuable products, including animal feed, board, paper, plywood, fibers, bio-fertilizer, and industrial enzymes. As a C4, and highly photosynthetic plant, enabling exceptional biomass accumulation and energy efficiency, making it vital for both agriculture and industry (Budeguer *et al*., 2021).

Sugarcane production extends beyond merely achieving higher yields, with significant emphasis on quality parameters such as Brix, Pol, and recovery percentage. High-yielding sugarcane with low recovery is not advantageous for the farmer (Manzoor *et al*., 2023). The quality of crops is influenced by inputs, proper management, adequate input application, and proper irrigation, being critical factors that enhance both yield and quality. However, the yield and recovery rates of sugarcane remain below their potential (Rezaei *et al*., 2023; Rauf *et al*., 2023). Several factors contribute to low sugarcane yield and sugar production, including suboptimal and traditional management practices, such as imbalanced fertilizer application, which adversely affects the crop from the outset, reducing germination and resulting in thin and stunted canes that fail to meet production and recovery (Mehdi *et al*., 2024; Sultan *et al*., 2024). Thus, the crop must also exhibit a good recovery percentage.

Improved production techniques are necessary to address the challenges faced by cane growers and to optimize yields from limited resources. These planting techniques would enhance plant population and maximize the benefits derived from water, air, and sunlight (Ngcobo *et al*., 2023). Conventional sugarcane sowing involves rows spaced 60 to 75 cm apart, which complicates management practices. These practices are crucial for optimal crop production, and thus, yield is significantly reduced (Singh *et al*., 2019; Ngcobo *et al*., 2023). In contrast, trench planting of sugarcane is considered a more effective system, optimizing water use, reducing lodging, and facilitating management operations such as earthing up and intercultural activities.

Planting sugarcane in trenches with one meter spacing between trenches has been shown to result in higher yield (Ghaffar *et al*., 2012; Kumar *et al*., 2024). Previous studies also indicated the improved quality of sugarcane juice compared to crops grown in narrow-spaced trenches. Lower sucrose content in sugarcane planted in triple rows with 100 cm spacing compared to double-row strips with 90 cm spacing (Ghaffar *et al*., 2012; Nadeem *et al*., 2020). However, purity showed no significant differences concerning inter-row spacing and varying seed application rates. The percentage of commercial cane sugar (CCS) did not significantly differ across different spatial designs and planting methods (Ali *et al*., 2001, 2020).

Sugarcane setts derived from the top, middle, bottom, and mixed sections of the sugarcane stalk demonstrated superior sprouting ability and emergence compared to the bottom sections (Sime, 2013). The most effective standing establishment was achieved by planting the top portions of the sugarcane, resulting in increased total cane yield and Brix percentage (Ahmad *et al*., 2013). The combination of the stalk portions (top and middle) yielded comparatively better outcomes as compared to bottom portions used in planting (Kolo *et al*., 2005). A row spacing of 90 cm significantly enhanced sugarcane yield (91 t ha^{-1}), millable canes (1,18,200 ha^{-1}), benefit-cost ratio (2:64), net returns (169 x103 ha^{-1}), number of nodes per cane, cane diameter, weight per cane along with percent sucrose (17.81%) in juice of cane as compared to 150 cm wide rows (Chakrawal and Kumar, 2014).

The present study was designed to investigate the optimal interaction of different seed cane sources, field open sugarcane (exposed to frost), and trenched cane (protected from frost), with altered pieces of sugarcane as well as cane parts of upper portion, middle portion and lower portions, and mixed part along with varying numbers of setts obtained from source of single cane, one and a half canes, double canes, triple cane. The study aimed to determine the best interaction of (planting source of sugarcane × sugarcane stalk portions), (source of planting × number of setts), (sugarcane stalk portions × number of setts), and (source of planting × sugarcane stalk portions × number of setts) for qualitative traits such as Brix percent, Pol percent, purity percent, and recovery percentage.

Materials and Methods

The sugarcane variety CP 77/400 was utilized in this experiment. The main plots were assigned different seed cane sources. The treatments consisted of field-open sugarcane, trenched cane, and stalk portions, including upper, middle, and lower segments, as well as a mixed treatment composed of an equal proportion (33%) of each segment.

The number of setts, one, one and a half, two, and three setts, each measuring about 40 cm in length, were assigned to the subplots. Each experimental plot is 3.6 m x 4.5 m, consisting of five rows with n row to row distance of 90 cm. This study was performed at the experimental field in Sugar Crop Research Institute (SCRI) Mardan, Pakistan, situated at 34°12'30.9"N latitude and 71°58'24.2"E longitude, during the period from 2012 to 2013. This experimental site is located within the subtropical zone. The minimum and maximum temperatures and rainfall recorded in 2012 to 2013 were shown (Figure 1), respectively, during the growing seasons (two years) using a statistical method RCBD with three replicates under a split-plot arrangement.

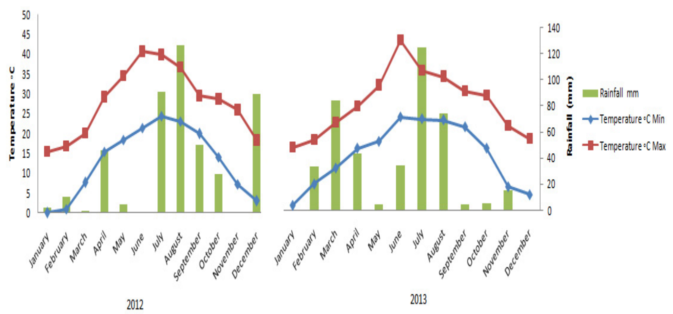

Figure 1: *Average maximum and minimum temperature °C and rainfall (mm) during the growing period 2012-13 and 2013-14 at SCRI Mardan.*

The experimental site's soil was characterized as silty clay loam with a pH of 7.3 (alkaline). Fertilizers, including nitrogenous, phosphate, and potash, were applied at a rate of 150: 100:100 Kg ha^{-1}, sourced from urea, di-ammonium phosphate (DAP) combined with sulfate of potash (SOP), respectively. Methods for the placement of sugarcane setts were assigned to the subplots. Nitrogenous fertilizer was applied in split doses to minimize damage due to the volatile nature of nitrogen. The entire sugarcane stalks, including tops, trash, and roots, were trenched before frost damage. However, roots and trash were removed before re-sowing. Standard practices were uniformly applied across all treatments. Data collected, including Brix (%), Pol (%), Purity (%), Sugar Recovery (%), and cane sugar yield (t ha^{-1}) for selected traits and subjected to statistical analysis.

Qualitative parameters of CP 77/400 sugarcane

Random selection of ten stalks was made from each cane sample and processed using a sugarcane crusher to estimate the degree Brix. Sugarcane juice temperature was recorded using a Brix hydrometer. To calculate the Corrected Brix (%) for a given temperature using, using our previous investigations (Ali *et al*., 2020). The Pol (%) was determined using a polarimeter. The observed reading was the Pol reading, which was utilized to determine Pol (%). Purity (%) is a significant qualitative characteristic, with higher purity values indicating increased sucrose content in the total soluble solids (referred to as Brix % in sugarcane). The following formula was used to calculate the percentage of Purity:

$$Purity\ (\%) = \frac{Pol\ \%}{Corrected\ Brix} \times 100$$

Observed Brix and temperature of juice worked out for getting corrected Brix values.

Sugar Recovery (%) CP 77/400

Sugar recovery was calculated using the formula:

$$Sugar\ Recovery\ (\%) = [POL\% - 0.4(Corrected\ Brix - Pol\ \%)] \times 0.73$$

Sugar yield (t ha^{-1}) CP 77/400 sugarcane

Calculation of sugar yield was performed using the formula:

$$\text{Sugar yield (t ha}^{-1}) = \frac{\text{Cane yield (t ha}^{-1}) \times \text{sugar recovery (\%)}}{100}$$

Field data were analyzed by using ANOVA for randomized complete block design with split plot arrangements given by (Steel *et al*. 1997), treatment means comparison was carried out at a ($P \leq 0.05$) probability level via LSD test.

Results

Brix (%)

Data presented in Table 1 regarding percentages of Brix showed significant influenced by SCS in every year under study. SSP, the number of setts, and all interactions SCS x SSP, SCS x NOS, SSP x NOS, and SCS x SSP x NOS were found to be non-significant each year, with similar results observed in the averages over the two years. SCS significantly affected the Brix percentage, with a recorded Brix of 20.44% in the year 2012-13, increasing to 20.55% in 2012-14, resulting in an average Brix of 20.50%.

Pol (%)

Data recorded for Pol% of sugarcane (Table 1) indicated that seed cane sources and sugarcane stalk portions in the first year, as well as the number of setts during the 2nd year under experiment, had significant effects on Pol%. It was observed that all interactions ST x SSP, ST x NOS, SSP x NOS, and ST x SSP x NOS and the averages over two years were found to be non-significant. The field open fresh planting sugarcane source showed significant effects on Pol percent of 17.42 and 17.49% for both years successively, with an average of 17.45% over two years, when compared to other sources as 17.36% and 17.42% i.e. trenched planting source. Sugarcane stalk portions significantly influence Pol% only for the 2nd year , with percentage of 17.49 that was recorded in the upper and mixed portions that was by middle sugarcane stalk segments, while non-significat over two years. It was observed that Pol percent under the Sett placement methods in initial year, with a Pol percent to maximum value of 17.44% as was observed in triple setts.

Purity (%)

Sugarcane stalk portions (SSP) and the interaction SCS x NOS during 2012-13 indicated a significantly increased purity % over the years. Seed cane sources (SCS), sugarcane stalk portions (SSP), and the number of setts did not exhibit fluctuations in purity percentages (Table 1). However, sugarcane stalk portions (SSP) demonstrated a significant increase in purity percentage during the 2012-13 period, with the cane top portion achieving 85.43% purity compared to 84.79% in the cane bottom portion. The interaction

Table 1: *Brix (%), Pol (%), Purity (%), Recovery (%) and sugar yield (t ha^{-1}) of sugarcane as affected by seed cane sources, sugarcane stalks and number of setts in two years i.e. 2012-13 and 2013-14.*

Seed cane sources (SCS)	Brix (%)			Pol (%)			Purity (%)			Recovery*%)			Sugar yield (t ha^{-1})		
	2012-13	2013-14	Mean	2012-13	2013-14	Mean	2012-13	2013-14	Mean	2012-13	2013-14	Mean	2012-13	2013-14	Mean
Field open sugarcane (S)	20.44a	20.55a	20.50	17.42	17.49	17.45	85.19	85.09	85.14	7.77a	7.90a	7.83	11.13	11.17	11.15
Trenched (T)	20.39b	20.48b	20.43	17.36	17.42	17.39	85.18	85.06	85.12	7.71b	7.79b	7.75	11.10	11.11	11.10
Significance	*	*	NS	*	*	NS	NS	NS	NS	*	**	NS	NS	NS	NS
Sugarcane stalk portions (SSP)															
Top	20.41	20.55	20.48	17.43	17.49a	17.46	85.43a	85.13	85.28	8.03a	8.15a	8.09a	11.16	11.17	11.17
Middle	20.42	20.52	20.47	17.41	17.45b	17.43	85.25a	85.03	85.14	7.80b	7.89b	7.85b	11.13	11.14	11.13
Bottom	20.44	20.49	20.46	17.33	17.37c	17.35	84.79b	84.80	84.80	7.33c	7.47c	7.40c	11.05	11.07	11.06
Mixed 33.3% each	20.39	20.50	20.45	17.39	17.49a	17.44	85.29a	85.34	85.31	7.79b	7.87b	7.83b	11.12	11.18	11.16
LSD (0.05)	NS	NS	NS	NS	0.064	NS	0.066	NS	NS	0.073	0.078	0.16	NS	NS	NS
Number of setts (NOS)															
Single sett	20.39	20.51	20.45	17.40a	17.47	17.43	85.33	85.20	85.27	7.23d	7.31d	7.27d	11.13	11.16	11.15
One and half sett	20.46	20.51	20.48	17.38b	17.43	17.40	84.92	85.02	84.97	7.69c	7.80c	7.74c	11.08	11.13	11.11
Double setts	20.38	20.51	20.45	17.34c	17.47	17.40	85.09	85.14	85.12	7.91b	8.05b	7.98b	11.08	11.16	11.12
Triple setts	20.43	20.53	20.48	17.44a	17.44	17.44	85.41	84.95	85.18	8.12a	8.21a	8.17a	11.17	11.13	11.15
LSD (0.05)	NS	NS	NS	0.067	NS	NS	NS	NS	NS	0.057	0.076	0.05	NS	NS	NS
Interaction	P value	P value	P value	P value	P value	P value	P value	P value	P value	P value	P value	P value	P value	P value	P value
SCS x SSP	0.35	0.96	0.99	0.75	0.74	0.99	0.35	0.95	0.98	0.56	0.38	0.95	0.63	0.92	0.98
SCS x NOS	0.17	0.18	0.12	0.09	0.53	0.12	0.04	0.13	0.03	0.23	0.61	0.38	0.03	0.68	0.09
SSP x NOS	0.75	0.50	0.43	0.51	0.15	0.39	0.97	0.01	0.52	0.00	0.01	0.00[a]	0.84	0.04	0.35
SCS x SSP x NOS	0.47	0.83	0.26	0.64	0.76	0.37	0.84	0.78	0.78	0.93	0.94	0.90	0.87	0.95	0.78

Means for each category followed by dissimilar letters differ significantly from one another at ($P \leq 0.05$) level of probability NS= non-significant.

between SCS and the number of setts (NOS) was found to be significant for purity percentage (Figure 2). Results indicate that a single sett from a field open source achieved purity of 85.32% , whereas a triple sett from trenched canes achieved 84.74% purity. At one and a half setts from a field of open sugarcane fresh crop and purity % initially decreased and then the number of setts raised to three from initial number i.e. two setts.

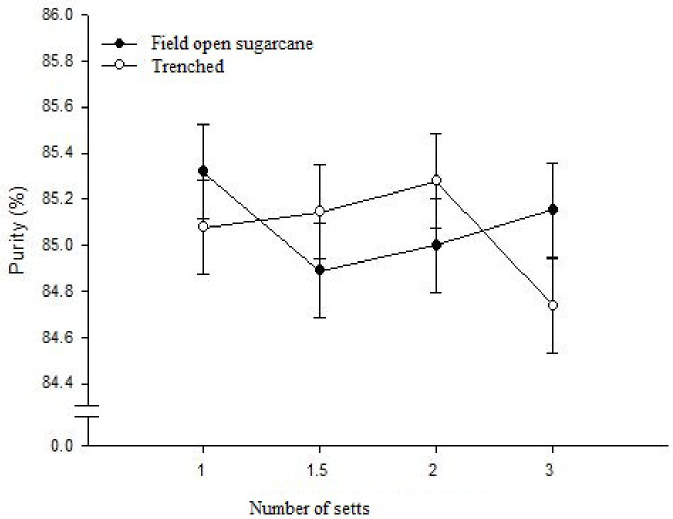

Figure 2: *Purity (%) of sugar cane as affected by sugarcane stalk portions and number of setts.*

In contrast, single, one and a half, and two setts from the source of trench showed an increase in purity, followed by a drastic reduction in purity percentage with triple setts. One and a half setts from the trench source were superior to three setts. Trenched 2-3 setts resulted in decreased purity percentages. Therefore, 2-setts from the trench source were more effective than field open sugarcane with 2 setts. Setts from the field open sugarcane source yielded higher purity in the case of one sett, followed by one and a half setts, while three setts increased the purity percentage. Sugarcane stalk portions (SSP) significantly raised purity (%) in the first year. Purity percentages were observed maximum in canes from the uppper portion, resulting in lower purity percentage than the bottom portions. The interaction for the purity percentage between SCS and NOS was found significant. The data as revealed in Figure 2 showed purity percentages as maximum in canes obtained from sugarcane single setts of field open source, compared to three setts from the source of trench.

Recovery (%)

Seed cane sources (SCS), number of setts (NOS), and sugarcane stalk portions (SSP) (Table 1) showed effects as non-significant for the percent recovery in both years as well as combined for both years. It was observed that overall interactions SCS x SSP, SCS x NOS, SSP x NOS, and SCS x SSP x NOS were found to be non-significant. Seed cane sources (SCS), sett placement methods, and sugarcane stalk portions (SSP) non-significantly affected recovery % in both years and the average of both years. Moreover all interactions SCS x SSP, SCS x NOS, SSP x NOS, and SCS x SSP x NOS were found non-significant.

Sugar yield (t ha^{-1})

Significant variations in sugar yield (t/ ha^{-1}) were not attributable to Seed Cane Sources (Table 1), such as field open sugarcane and trenched, nor the interaction of SSP x NOS. Similarly, the mean sugar yields for SCS x SSP, SCS x NOS, and SCS x SSP x NOS were found to be non-significant. Setts derived from the upper segments of the cane significantly outperformed in sugar yield (8.09 t ha^{-1}) compared to those from the middle, bottom, and mixed setts. The use of triple setts (higher sett rate) resulted in increased sugar yield compared to fewer setts. The interaction between sugarcane stalk portions and the number of setts significantly enhanced sugar yield (t ha^{-1}) compared to other interactions. The sources of Seed Cane increased sugar yields each year significantly. However, non-significant effects were observed in the average over two years. The maximum sugar yield was consistently obtained from the field open source each year, with lower yields recorded from the trenched source in the two-year average. Sugarcane stalk portions significantly enriched the sugar yield of the cane. The top portion of the sugarcane produced the highest sugar yield (8.03 t ha^{-1}) in 2012-13, increased to (8.15 t ha^{-1}) in the subsequent year. The highest sugar yield (8.09 t ha-1) was obtained in the upper segments of cane during both years of trial.

The use of three setts resulted in higher sugar yields (8.12 and 8.21 tha^{-1}), while lower yields (7.23 and 7.31 tha^{-1}) were observed with the single sett placement method for both years. The mean sugar yield (8.17 tha^{-1}) was observed with three setts compared to the single sett method of cane placement, yielded 7.27 t ha^{-1} over two years (Figure 2). SSP x NOS demonstrates that sugar yield depreciated with decrease in setts number from three to only one (Figure 2). The highest sugar yield (8.63 tha^{-1}) was obtained from three setts in the cane top portions, compared to (6.99 tha^{-1}) a single sett of the sugarcane bottom portion. Sugar yield showed significant effects by Seed Cane Sources (SCS), sugarcane stalk portions (SSP), the number of setts (NOS), and the interaction between SSP x NOS. However, interactions SCS x SSP, SCS x NOS, and SCS x SSP x NOS were not significant. Seed Cane Sources (SCS) significantly increased sugar yields each year, with a non-significant effect on the two-year average. Nevertheless, the highest sugar yield was obtained from the field open source each year compared to the trenched source over two years.

Sugarcane stalk portions (SSP) enhanced sugar yield significantly. The top cane portions gave the maximum sugar yield in the first year, which increased in the subsequent year. Highest sugar yield was found in the cane top portions during two years. The use of triple setts (NOS) resulted in higher sugar yields when compared with single setts each year. Highest sugar yield was observed in canes raised with triple setts compared to single setts over both years.

Discussions

The impact of various sett placement methods, both stored and fresh, as well as different numbers of setts on the quality characteristics of sugarcane that the placement of setts, specifically at 60, 75, and 90 cm apart in two row directions (North-South and East-West), did not affect the Brix percentage (Shakoor *et al*., 2014). However, seed sources (SCS) significantly influenced the Brix percentage, with the maximum Brix (%) recorded in the first year and an increase in the second year. The highest average Brix (%) was observed in the field open sugarcane planting source. Staling increased the total soluble solids (TSS) in sugarcane juice, and our findings corroborated these results for seed cane sources in both years. The Brix percentage was recorded at 20.44% during 2012-13, which enhanced to 20.55 percent in 2013-14, with an average Brix of 20.50%. Our findings indicated that seed cane sources and stalk portions in the first year of the experiment significantly affected the pol percentage of sugarcane. Conversely, the number of setts significantly affected the Pol% in the second year (Shrivastava *et al*., 2008), noting that staling decreased the sucrose percentage.

Sugarcane stalk portions significantly affected the pol percentage in the second year, with the highest Pol% found in the upper and mixed portions. This was followed by middle portion as observed in first year and the mean of the two years, the results were observed to be statistically non-significant. Sett placement methods affected the Pol% only in the 1st year, with maximum higher Pol percent as found in the three setts method. Higher-density sugarcane improves sugar yield by enhancing the interception of radiation in the earlier stages of crop growth. The interaction (SSP x NOS) effects clearly show that sugar yield declined as the number of setts per unit area decreased from triple to single setts (Garside and Bell, 2009).

The use of normal-budded seed supported a rate per hectare over a lower seed rate (Patel and Patel, 2014). Five intra-row sett spacing found that 5 cm and 10 cm between setts, as well as 5 cm and 10 cm end-to-end and ear-to-ear overlaps, had no significant effect on sucrose content (Getaneh *et al*., 2016). Purity percentage was affected by the stalk portions and the interaction between SCS and NOS. Sugarcane stalk portions (SSP) significantly increased purity percentage during 2012-13, with percentage of 85.43 from the top portions of cane compared to 84.79% in the lower cane portions.

The interaction between SCS and NOS was found to be significant for purity percentage (Figure 2). El-Sogheir *et al*. (2003) found the interaction of stalk height and purity percentage in the initial season to be significant. The effects of single, double, and triple budded setts were non-significant concerning purity percentages (Shukla and Menhilal, 2003; Sultan *et al*., 2024). The present study also revealed that sugarcane stalk portions (SSP) affected the purity percentage significantly during the first year. Maximum purity percentages were revealed in the top portion, resulting in canes with a lower purity percentage as compared to the lower segments. Sugarcane recovery was not affected by seed cane sources (SCS), the number of setts (NOS), or sugarcane stalk portions (SSP) in both years, along with their interactions. Similarly, the effects of 60,000, 75,000, and 90,000 double-budded setts per hectare were statistically non-significant in terms of commercial cane sugar (Ehsanullah *et al*., 2011).

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Novelty Statement

This study evaluates the effects of trenched and open-field segments on the qualitative traits of the CP77/400 sugarcane variety, providing valuable insights for enhancing crop management and sugar recovery under local conditions.

Author's Contribution

Shahid Ali, Tanweer Kumar and Nur Ul Haq conceived and supervised the research. Muhammad Usman and Muhammad Ismail assisted in data collection and analysis. Adnan Nasim, Muhammad Arif, Wajid Khan, Subhan Ullah and Abdur Rauf contributed to field experimentation, data interpretation, and manuscript improvement/revision. All authors read and approved the final manuscript.

Generative AI and AI-assisted technology statement
The authors declare that no generative AI or AI-assisted tools were used in the writing, analysis, or data interpretation.

Conflict of interest
The authors have declared no conflict of interest.

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