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Research Article

Interactive effect of cultivar and plant spacing on sugarcane performance

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ABSTRACT

The traditional methods of sowing sugarcane crop have serious gaps that result in low crop yield and high cost of production. These gaps are high seed rate, high cost of seed material, low plant population and poor seed quality at farmer field level. The adoption of bud chip technology offers a sustainable and efficient path for sugarcane production to remove the mentioned gaps in traditional methods. However, its full benefits can only be achieved by optimizing cultivation techniques. Plant spacing is particularly a critical factor that needs to be investigated. To address this, a field experiment was conducted in spring 2021 at the Sugarcane Research Institute, AARI, Faisalabad. The crop was sown on 15 February 2021 and harvested on 25 December 2021. Randomized complete block design under Split Plot arrangements was used to lay out experiment, with three replications. The treatments included three plant spacing viz. 30 cm, 60 cm, 90 cm and three sugarcane genotypes viz. CPF-251, CPF-253, CP00-1101. The results depict that the 60 cm plant spacing consistently resulted in the highest cane yield (67.31 t/ha), sugar yield (7.84 t/ha), and sugar recovery (11.61%) for CPF-251. The 30 cm plant spacing was more effective for CPF-253 and CP00-1101 genotypes. This spacing created the highest values for cane yield (110.91 t/ha), sugar yield (13.12 t/ha) and sugar recovery (11.86%). It was concluded that the ideal plant spacing is variety-specific, and 60 cm plant spacing is optimum in sugarcane cultivation using bud chip technique. This technique is a cost-effective alternative to conventional sett planting, reduces the quantity and cost of seed cane required with a seed saving of 73–77% over traditional sett planting.

Keywords: Clones; genotype; sugar yield; spacing; agronomy; bud chips.

INTRODUCTION

Traditionally, sugarcane is propagated using sett (small stem cuttings with 2-3 buds), a method that is often inefficient, difficult to handle, require large quantities of planting material and contributing to the spread of diseases (Nayak et al., 2021; Bhatt et al., 2025). Bud chip technology has emerged as a sustainable alternate approach. This method notably reduces the amount of seed cane required (70-80%) and facilitates the rapid seed multiplication of new genotypes (Uchtiawati et al., 2020; Kumar et al., 2025). In addition, seedlings raised in field conditions tend to be healthier and more vigorous, leading to better crop stand and potentially elevated crop yields. Many Studies have reported that bud chip planting technology results in significant increase in cane yield up to 39.7% in comparison to conventional planting methodologies. (Vijayalaxmi et al., 2025).

The arrangement and configuration of plants in the field, dictated by plant and row



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spacing, is a critical to yield. Plant population is directly influenced by plant spacing due to competition for essential resources such as sunlight, water, and nutrients. The crop health, growth, development and maturity are dependent on appropriate spacing and planting geometry (Kumar, 2022; Khaliq et al., 2024). Better growth of individual plants has been promoted under wider row spacing, often ranging from 120 cm to 180 cm. In Pakistan, deep trenches are made to plant sugarcane crop during spring and autumn season. Specially designed sugarcane ridger is used and 120 cm trench spacing is maintained. The end to end cane sett is laid in 22 cm deep and 45 cm wider trenches (Mishra, 2019). Wider plant spacing positively impacts sugarcane's physical characteristics, leading to added tillers, increased plant height, thicker canes, and longer internodes (Munir et al., 2025). For example, planting sugarcane bud chip seedlings at 120 cm spacing produced an 18% higher cane yield as compared to conventional sett planted at narrower 60 cm or 75 cm row spacing (Nayak et al., 2021).

The overall crop yield is significantly influenced by the maintenance of plant population. There was not always a linear relationship between rows spacing and overall yield per unit area (Tayade et al., 2021). The trade-off between plant density and individual plant performance is a critical challenge in agronomy. The reduction in plant population is a potential negative aspect of wider spacing. This in turn can reduce the total count of millable canes and consequently the final crop yield. Conversely, the quantity of millable canes may be boosted up with high-density planting under narrow spacing. The key biometric parameters such as cane height, girth, and weight were adversely affected due to the interspecific competition between plants, eventually resulting in sub-optimal cane and sugar yields (Galal et al., 2022).

The specific genotype, local environment and intended level of mechanization are affected by optimal row spacing (Jain et al., 2010). The weeds dynamics plays a vital role and can affect crop performance in wider and narrower row spacing (Khaliq et al., 2020). A significant interaction has reported by Khalid et al. (2015) between sugarcane cultivars and row configuration with certain genotypes performing better in wider row spacing than others. In certain genotypes, lower plant populations are compensated by producing more tillers and heavier individual stalks (Kumar et al., 2024). Plant spacing has a profound impact on the yield and physical traits of sugarcane. However, research has consistently shown that juice quality attributes remain largely unaffected by different row spacing arrangements. The comparison between 75 cm and 120 cm row spacing with respect to medium maturing sugarcane genotype CPF-253 revealed that it was matured earlier and has 0.5% advantage in sugarcane recovery and field brix percentage in 120 cm wide row spacing (Bhatt et al., 2025).

These quality parameters are generally considered to be more strongly determined by the genetic characteristics of the sugarcane clone and prevailing environmental conditions during the maturation phase (Ahmad et al., 2020). The traditional methods of sowing sugarcane crop have serious gaps that results low crop yield and high cost of production. These gaps are high seed rate, high cost of seed material, low plant population and poor seed quality at farmer field level. The bud chip technology has the potential to address these issues, if the planting geometry of this innovative technology may be optimized. Therefore, this study was planned with the objectives to optimize the planting geometry for the production technology of bud chip adoption by sugarcane growers.

MATERIALS AND METHODS

Experimental Site

This field experiment was carried out in spring 2021 at the Sugarcane Research Institute (SRI), Ayub Agricultural Research Institute, Faisalabad (31.38 °N, 72.99 °E), Pakistan. The climate of research site is semi-arid with plenty of canal irrigation water. The physico-chemical properties of the soil of the experimental site were analyzed before sowing of the sugarcane crop. The soil is sandy clay loam. The soil contains organic matter (0.75%), available phosphorus (19.2 mg kg⁻¹), extractable potassium (150 mg kg⁻¹) and bulk density (1.95 g cm⁻³). The weather data for year 2021 is obtained from crop physiology section, AARI, Faisalabad and are given below in table (1).

Experimental Design and Treatments

The Randomized Complete Block Design (split-plot configuration) was used in layout of trial and has three replications. The treatments include three plant spacing viz. 30 cm, 60 cm, 90 cm and three genotypes viz. CPF-251, CPF-253 and CP00-1101. The plot size was kept 5 m x 6 m. Plant spacing was put in main plot and genotypes was kept in sub plot. All the treatments were randomized completely and provided equal chance of every treatment to fall under any experimental unit to remove biasness and ensure the accuracy in conduct of experiment.

Planting Material

The seed of planting material was obtained from SRI, Faisalabad. The characteristics of planting material are presented in tabulated form in table (2).

Table 1. Meteorological data for crop year 2021.

Month	Air Temp (°C)		Average Temp (°C)	Rel. Humidity %		Pan Evaporation (mm)		Rain fall (mm)
	Max	Min		8am	5:00 PM	8am	5:00 PM	
Jan	17.3	5.5	11.4	89.2	64.8	0.4	0.7	56.5
Feb	25.9	9.8	17.85	85.8	48	0.5	1.1	-
Mar	30.9	15.3	23.1	70.9	45	1	2.1	37.8
Apr	34.5	18.4	26.45	52.4	33.2	1.8	3.4	15.4
May	38.6	24	31.3	54.4	36.1	2.7	4.5	11.2
Jun	39	25.6	32.3	60.2	40.6	3	4.5	14.2
Jul	37.3	26.9	32.1	69	57	2.6	3.8	241.6
Aug	37.7	26.8	32.25	69.4	52.5	2.3	3.4	5
Sep	35.2	25.5	30.35	73.7	58.3	1.4	2.7	29.8
Oct	33.7	19.1	26.4	70	47.4	1.2	2.5	0.3
Nov	28.3	11	19.65	81.3	47.5	0.7	1.3	-
Dec	22.1	5.9	14	87.7	55.5	0.5	0.9	-

Table 2. Traits of planting materials.

Variety Name	Origin	Yield Potential	Variety Features
CPF-251	Fuzz imported from Canal point, USA and other studies from seedling stage to NUYT were conducted at Sugarcane research institute, AARI, Faisalabad and then approved by Punjab seed council in 2019 for general cultivation. The parentage: CP 87-1628 × CP 84-1198	Cane yield: 102.62 t/ha Sugar recovery: 14.1%	It is disease and pest resistant variety. It is famous as early maturing with good germination, tillering capacity, high sugar contents and good ratoonability. It matures in 240 – 270 days
CPF-253	Fuzz imported from Canal point, USA and other studies from seedling stage to NUYT were conducted at Sugarcane research institute, AARI, Faisalabad. It is a valuable option for growers. The parentage: CP 88-1561 × CP 85-1491	Cane yield: 135.50 t/ha Sugar recovery: 12.5%	It is disease and pest resistant variety. It is famous as medium maturing with high cane yield, good ratoonability and sugar contents. It matures in 300 days
CP00-1101	Direct introduction from Canal point, USA and other studies from seedling stage to NUYT were conducted at Sugarcane research institute, AARI, Faisalabad. It is a candidate variety for future recommendation. It will be a valuable option for growers and sugar mills.	Cane yield: 124.00 t/ha Sugar recovery: 13.5%	It is disease and pest resistant variety. It is medium maturing with high germinations percentage and tillering capacity, good ratoonability and high cane and sugar yield. It matures in 300 days

Crop Husbandry

The manual bud chip machine was locally designed and prepared. The unstrapped cane stalk was put in this machine and chipped the bud with two rows of root bands. It is also called as single budded sett. Then prepared sett was dipped in Topsin-M at 2 g per liter of water for 40 minutes. After fungicide treatment the buds were dried and placed in furrows of deep trenches as per plant spacing mentioned above in treatments. Two rows of buds were placed in furrows with row spacing of 23 cm. The fertilizers at 168-112-112 kg per hectare NPK and two bags each of 4 kg Vertako granular pesticide was applied uniformly before placing buds. After completing these operations, buds were covered with light cover of soil with 2 inches' width and light irrigation was made. All other agronomic operations were

carried out uniformly through experimental duration. The crop was sown on 15 February 2021. After attaining physiological maturity, the crop was harvested on 25 December 2021 and all yield and quality parameters were recorded and stripped cane samples were sent to sugarcane technology laboratory for quality analysis.

Data Collection and Analysis

Data on key agronomic and quality parameters were recorded to evaluate the impact of the experimental treatments. The collected data of all traits was analyzed by using the fisher's analysis of variance technique (Steel, et al., 1997) and then compared the difference among treatments means with use of Least Significant Difference (LSD) test at 5% probability level.

Tillering (Tillers plant⁻¹): At 120 days after planting, the tillering potential was quantified by counting the total number of tillers from randomly selected plants within each plot (Kumar, 2020).

Millable Canes (103 ha⁻¹): The final stand of productive stalks was ascertained at harvest by conducting a comprehensive count of all millable canes within each plot (Kumar, 2020).

Cane Yield (t/ha): The cane from each plot was harvested, weighed with digital weigh balance and the stripped cane yield was then calculated and expressed in tons per hectare (t/ha) (Kumar, 2020).

Sugar Recovery (%): Cane samples were assessed for juice quality analysis using standard protocols and procedures of Meade and Chen (1977) in Sugarcane Technology Lab, SRI, AARI, Faisalabad.

Sugar Yield (t/ha): The sugar yield was find out by multiplying the cane yield (t/ha) by the sugar recovery percentage for each respective experimental unit (Meade and Chen ,1977).

RESULTS AND DISCUSSION

The study evaluated the impact of three different plant spacing (30 cm, 60 cm, and 90 cm) on the agro-economic traits of three sugarcane clones (CPF-251, CPF-253, and CP 00-1101). The results revealed significant variations in yield and its contributing components, highlighting a strong interaction between plant spacing and the genetic potential of the sugarcane clones.

1. Tillering

There are many agronomic traits which affect the yield and crop performance in sugarcane. Number of tillers is one of them. In sugarcane germination was completed after 45 days of planting the crop. After that tillering was started and goes on till 120 days after sowing. The number of tillers produced per plant was influenced by spacing across all varieties. For clone CPF-251, tillering increased as spacing widened, from 8.05 tillers per plant at 30 cm to 9.05 at both 60 cm and 90 cm spacing (Fig.1). A similar trend was observed for CPF-253 and CP 00-1101, where tillering increased from 6.16 at 30 cm spacing to approximately 8.0 at the wider spacing. This indicates that wider spacing reduced inter-plant competition, allowing individual plants to produce more tillers.

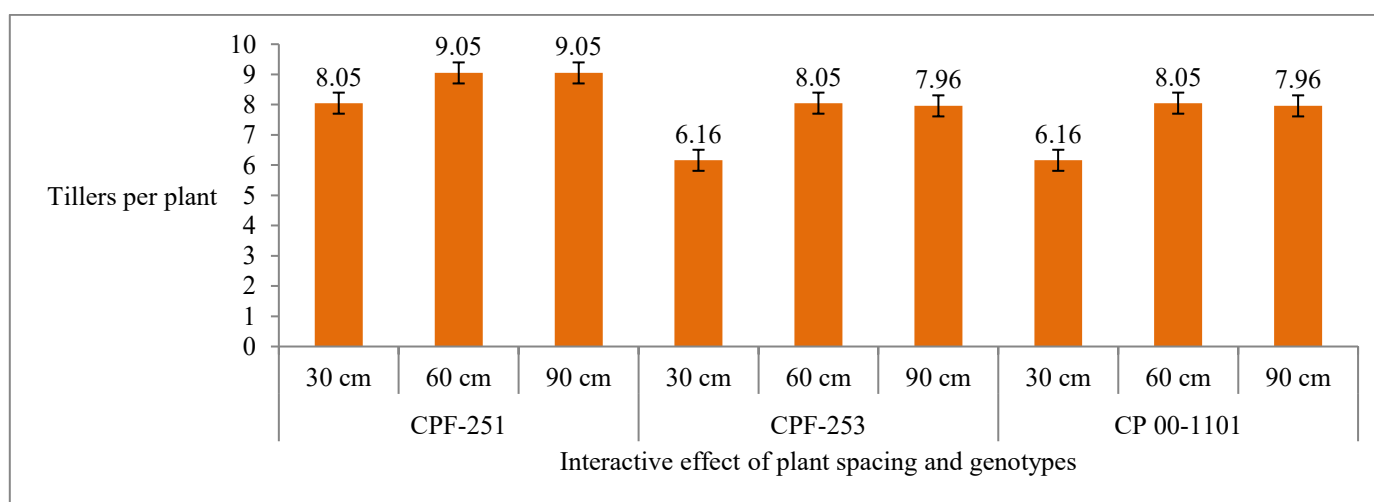


Figure 1. Response of tillers per plant in sugarcane genotypes to different plant spacing.

2. Millable Canes

Another yield related trait is plant density. The density of millable canes per hectare showed a contrasting response to spacing depending on the variety (Fig. 2). For CPF-251, the highest number of millable canes (83,800/ha) was recorded

at the narrowest spacing of 30 cm. As the spacing increased to 60 cm and 90 cm, the cane population decreased to 78,460/ha and 76,460/ha, respectively. Conversely, for both CPF-253 and CP 00-1101, the number of millable canes increased with wider spacing, from 68,460/ha at 30 cm to 77,800/ha at 90 cm.

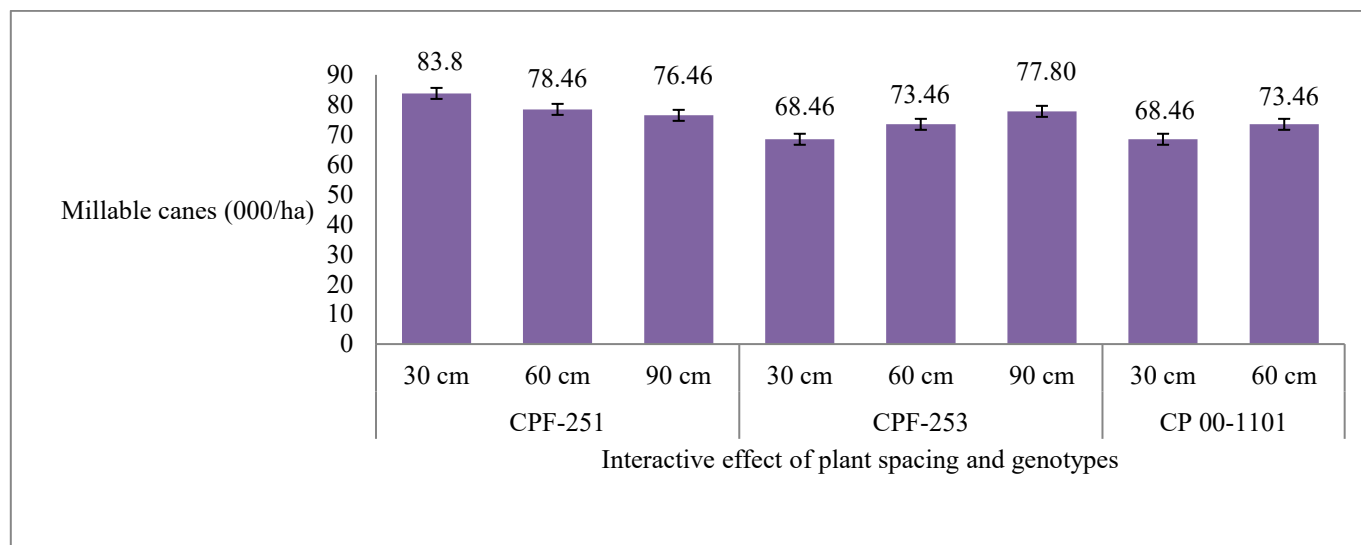


Figure 2. Response of millable canes (000/ha) in sugarcane genotypes to different plant spacing.

3. Cane Yield (Tons/ha)

Cane yield was significantly affected by the interaction between variety and spacing (Fig. 3). CPF-251 achieved its highest cane yield (67.31 t/ha) at the 60 cm spacing. The 30 cm spacing, despite having the highest cane population, resulted in the lowest yield (59.9 t/ha) for this variety. In a striking contrast, both CPF-253 and CP 00-1101 produced an exceptionally high cane yield of 110.91 t/ha at the narrowest 30 cm spacing. Their yields dropped dramatically at wider spacing, falling to around 66.75 t/ha at 60 cm and 59.46 t/ha at 90 cm.

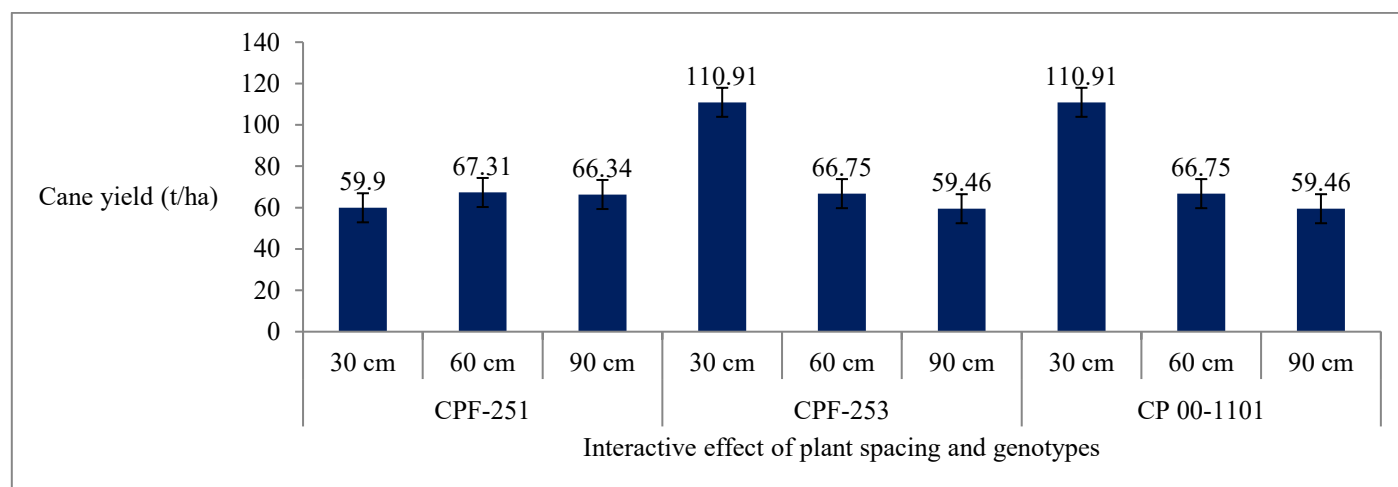


Figure 3. Response of cane yield (t/ha) in sugarcane genotypes to different plant spacing.

Sugarcane Quality Traits

Sugar recovery is important quality traits in sugarcane crop. It depends upon many factors including genotypes variation, sowing time, maturity time, fertilizer application, temperature, humidity, irrigation management etc. It presents total soluble sucrose contents in juice of cane.

Sugarcane recovery is used as basis by sugar mills for payment to growers on quality basis. Sugar recovery showed minor variations (Fig. 4). For CPF-251, the highest recovery (11.61%) was at 60 cm spacing. For CPF-253 and CP 00-1101, the highest sugar recovery (11.86%) was recorded at the 30 cm spacing, which corresponded with their highest cane yield.

Sugar yield, being a function of cane yield and sugar recovery, followed a similar pattern to cane yield (Fig. 5). CPF-251 recorded its maximum sugar yield (7.84 t/ha) at 60 cm spacing. CPF-253 and CP 00-1101 demonstrated a remarkably superior sugar yield of 13.12 t/ha at the 30 cm spacing, which was nearly double the yield achieved by CPF-251 at any spacing.

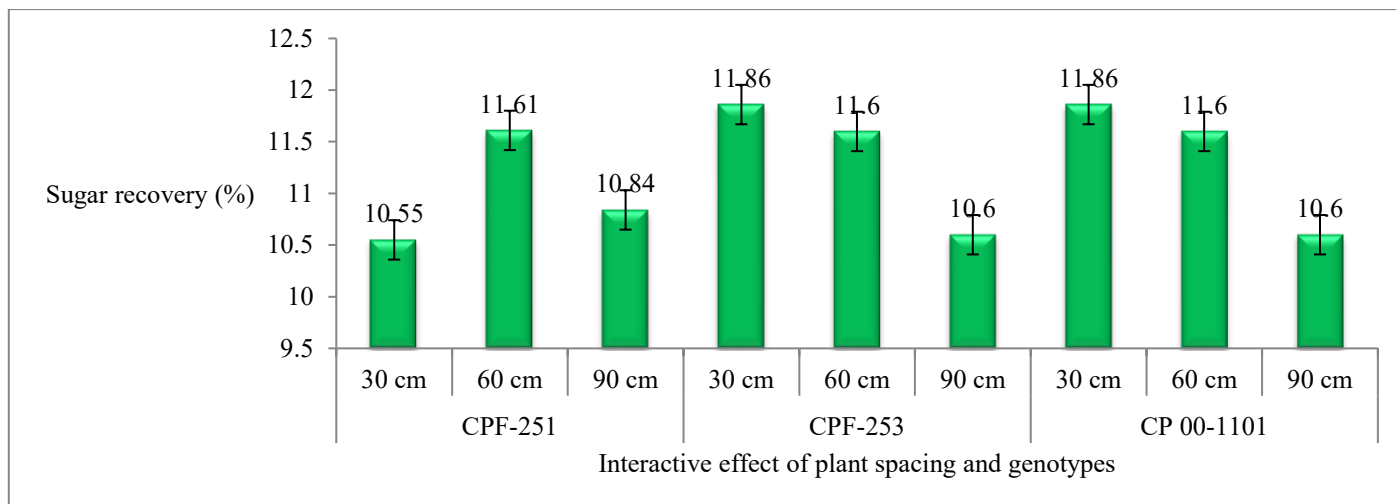


Figure 4. Response of sugar recovery (%) in sugarcane genotypes to different plant spacing.

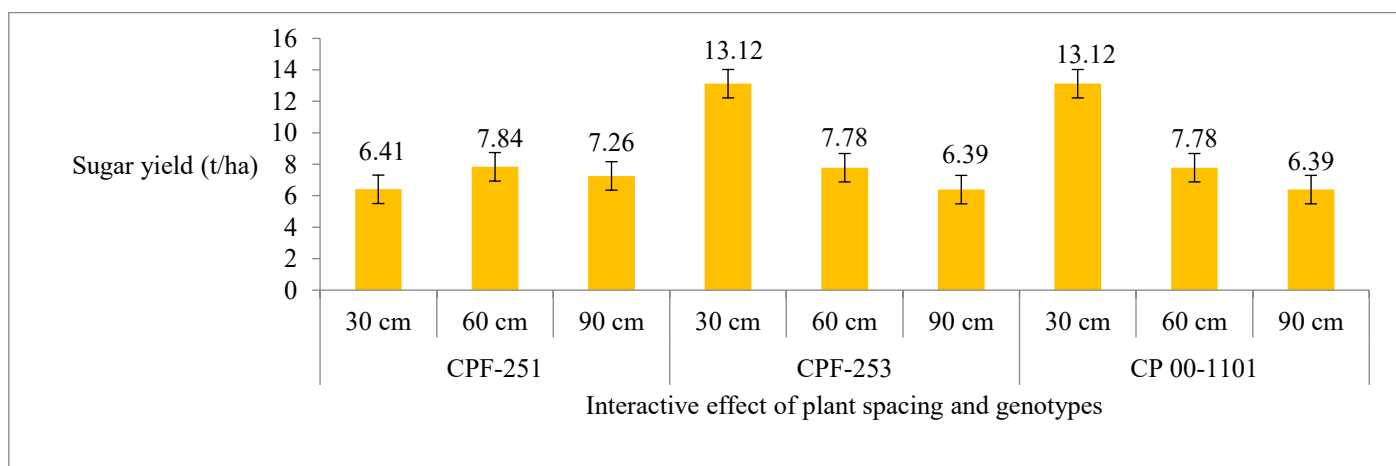


Figure 5. Response of sugar yield (t/ha) in sugarcane genotypes to different plant spacing.

The results clearly demonstrate that the optimal plant spacing for sugarcane is highly dependent on the growth habit of the specific clone. A "one-size-fits-all" approach to spacing is not effective for maximizing yield across different varieties (Kumar, 2020). For all clones, wider spacing (60 cm and 90 cm) led to increased tillering per plant. This is a well-established phenomenon where reduced plant-to-plant competition for resources like sunlight, water, and nutrients allows for better individual plant development and vigor. This aligns with the findings of Nayak et al. (2021). The response of yield components, however, varied significantly. For clone CPF-251, the data suggests a classic trade-off between plant population and individual plant performance. At 30 cm spacing, the high density of millable canes (83,800/ha) likely induced severe competition, leading to thinner, lighter canes and ultimately a lower overall yield. The 60 cm spacing provided the best balance, optimizing individual cane growth without sacrificing too much of the plant population, resulting in the highest cane and sugar yield for this variety. The 90 cm spacing appears to be too wide, leading to an insufficient number of canes to achieve maximum land utilization and yield. This aligns with the findings of Khaliq et al. (2020).

The performance of CPF-253 and CP 00-1101 was remarkably different and indicates that these clones are exceptionally well-suited to high-density planting. The extraordinary cane yield (110.91 t/ha) at the 30 cm spacing, despite having the lowest number of tillers per plant and a relatively low millable cane count, implies that the individual canes produced under these high-density conditions were significantly heavier and thicker than those of CPF-251.

These clones appear to be highly efficient in converting resources into stalk weight under competitive pressure. For these two varieties, increasing the spacing led to a drastic reduction in both cane and sugar yield, demonstrating that wider spacing is detrimental to their productivity. A similar trend was observed by Galal et al (2022).

This study highlights a strong genotype-by-spacing interaction. The optimal spacing for clone CPF-251 was found to be 2 feet. In contrast, clones CPF-253 and CP00-1101 exhibited a clear preference for high-density planting, with 1-foot spacing delivering outstanding cane and sugar yields. This aligns with the findings of Tayade et al. (2021). These findings underscore the critical importance of tailoring agronomic practices, particularly plant spacing, to the specific genetic characteristics of sugarcane clones to unlock their full yield potential.

Table3.Comparison of cost of seed: bud chips vs. sett planting.

Parameters	CPF-251	CPF-253	CP00-1101
No of Buds/ha	150000	150000	150000
No of Buds/acre	60000	60000	60000
Per Bud Chip Weight	42.21 gm	50 gm	42.86 gm
Weight of buds chips /acre	919 kg	1089 kg	933 kg
Rate of cane seeds per 40 kg (Rs.)	400	400	400
Cost of seed in Bud chips per acre (Rs.)	9190/-	10890/-	9330/-
Cost of seed (@4000 kg/acre) in setts planting per acre (Rs.)	40000/-	40000/-	40000/-
Saving per acre (Rs.)	30810/-	29110/-	30670/-

Economics Feasibility of Bud Chips Technology

The data in table-3 shows a comparison of seed cost in bud chips vs. sett planting. A uniform planting density of 150,000 buds per hectare was maintained for three sugarcane varieties CPF-251, CPF-253 and CP00-1101. Their average weight of individual bud chips varied slightly across varieties, with CPF-251 at 42.21 g, CPF-253 at 50 g, and CP00-1101 at 42.86 g. This resulted in a total bud chip requirement per acre of 919 kg, 1089 kg for CPF-253 and 933 kg for CP00-1101. Keeping in view, the market rate of cane seed at Rs. 400 per 40 kg, the calculated seed cost in bud chip planting was Rs. 9190/- for CPF-251, Rs. 10,890/- for CPF-253 and Rs. 9330/- for CP00-1101 genotype. Based on values in comparison, the conventional sett planting method, which requires approximately 4000 kg of seed per acre, incurred a uniform cost of Rs. 40,000/- per acre for all varieties. The savings achieved through bud chip planting were Rs. 30,810/- per acre for CPF-251, Rs. 29,110/- per acre for CPF-253, and Rs. 30,670/- per acre for CP00-1101. These results showed that bud chips are less bulky, easily transportable and more economical seed material. The bud chip technology holds great promise in rapid multiplication of new cane varieties which are free from pest attack and disease infections. Healthy, pure, true to type seed can be multiplied through bud chip is a. The left-over cane can be well utilized for preparing juice or sugar or jiggery. These results also in line with Khaliq et al., (2020) and Galal et al., (2022) that presented bud chip planting as a cost-effective alternative to conventional sett planting. It reduced the quantity and cost of seed cane with a saving of nearly 73–77%. The innovative method of bud chip can be used effectively for rapid healthy seed multiplication of new cane varieties.

CONCLUSION

The experiment highlights significant interaction between sugarcane variety and plant spacing and clearly demonstrates that ideal plant spacing is variety-specific. The wider 60 cm spacing was optimal in producing the best results for the CPF-251 across all key agronomics metrics: cane yield (67.31 t/ha), sugar yield (7.84 t/ha), and sugar recovery (11.61%). However, narrower 30 cm spacing yielded the best performance for the other two sugarcane clones, CPF-253 and CP 00-1101, including a stripped cane yield of 110.91 t/ha, sugar yield of 13.12 t/ha, and sugar recovery of 11.86%. Therefore, spacing recommendations must be adapted to the specific genotype being cultivated. This technique is a cost-effective alternative to conventional sett planting, reduces the quantity and cost of seed cane required with a seed saving of 73–77% over traditional sett planting.

FUTURE RECOMMENDATIONS

Small-scale trials may be conducted on farmer's farm with different spacing for new varieties to determine the most effective approach under specific soil and climatic conditions. Multi-year trials may be conducted to assess the long-term sustainability and productivity of bud chip cultivation with optimized spacing. Further research is needed to

develop economically viable and adaptable specialized machinery for efficient bud chip planting to quantify the benefits of bud chip technology and optimal spacing across various farm sizes and regions. Workshops and farmer days may be conducted by research institute and agriculture extension departments to effectively transfer these research findings and recommendations to farmers.

DECLARATIONS

The authors declare no conflict of interest.

AUTHOR'S CONTRIBUTION

Abdul Khaliq planned and conducted the experiment and write the manuscript, Amina Rashid helps in writing manuscript, Muhammad Sajjad helps in statistical analysis, Muhammad Luqman improve the language, Muhammad Shafqat analyzed the data, Hafiz Saad bin Mustafa helps in graphics, Zaheer Sikandar supervise the trial, Muhammad Muzzafar Raza helps to wrote the manuscript, Imran Rasheed helps in improving the grammer, Mubashra Yasin and Usama Bilal help to write manuscript. All authors read and approved to submit the research paper to the journal.

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There was no external funding for this research project.

AVAILABILITY OF DATA AND MATERIAL

All data generated or analyzed in this study are presented within this article in the form of tables and figures.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

Not applicable.

CONSENT FOR PUBLICATION

Not applicable.

CONFLICT OF INTERESTS

Authors declare no conflict of interest.

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