Journal of Ecological Engineering

Journal of Ecological Engineering, 2025, 26(12), 229–242
https://doi.org/10.12911/22998993/208498
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Received: 2025.07.20
Accepted: 2025.09.01
Published: 2025.10.01

Effects of sowing dates and planting density on yield and quality characteristics of super sweet corn in Huang-Huai-Hai area

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ABSTRACT

Sweet corn is significantly influenced by climatic variability and planting geometry in account of its high sugar content and consumer appeal. Therefore, this study was conducted to evaluate the effects of four sowing dates i.e. 25th April, 10th May, 25th May and 10th June and three plant densities i.e. 3000, 3500, and 4000 plants per 667 m^2 on the yield attributes and qualitative traits of the Fengtian 188 (sweet corn hybrid) under the agro-ecological conditions of the Huang-Huai-Hai (HHH) region. Results demonstrated that early sowing (25th April) significantly enhanced yield component including cob weight and kernel weight, whereas high planting density (4000 plants/667 m^2, PD3) was optimal for improving qualitative traits like sugar and vitamin C content. Early sowing (25th April) combined with moderate to high planting density improved yield attributes like cob weight and kernel weight, while late sowing (25th May) with high density enhanced sugar and starch accumulation. Therefore, the optimal combination depends on whether the production goal prioritizes yield or nutritional quality. These findings provide valuable insights into optimizing sweet corn cultivation practices in the HHH region and similar agro-climatic areas.

Keywords: sweet corn, sowing date, plant density, qualitative traits, yield.

INTRODUCTION

Sweet corn, harvested when grains are still soft and immature, is prized for its high sugar content, sweet taste and nutritional benefits, making it a staple in many global diets. The high content of protein, soluble sugar, vitamin C and folic acid, support the dietary need of health-conscious consumers (Xu et al., 2021). Globally, sweet corn production has expanded significantly, particularly in countries like the United States (Paranhos, 2024; Guo et al., 2025), Brazil(Chagas Kerchner et al., 2024; Bigolin and Talamini, 2024; Maranhão et al., 2024), Mexico (Govaerts et al., 2019), Argentina (Carvajal-Larenas and Cepeda, 2019; Bert et al., 2006; Amás et al., 2024), India (Das et al., 2024; Behera et al., 2025; Behera et al., 2024), Ukraine (Sydiakina, 2024; Baklanova, 2024; Drobitko et al., 2024), Hungary (Ssemugenze et al., 2024; Zargar et al., 2025) and Thailand (Trakoonyingcharoen et al., 2025; Thithuan, 2024; Kanchanakesorn et al., 2024) where it is cultivated for both fresh consumption and processing industries. To meet growing demand, sweet corn cultivation has expanded worldwide, with China emerging as one of the largest producers, cultivating over 530,000 hectares of the land annually (Swapna et al., 2020; Sher et al., 2017; Dhaliwal and Williams, 2019; Ming Bo et al., 2017). The Huang-Huai-Hai (HHH) region a major agricultural zone contributing over 33% of China's total corn production (Li et al., 2018; Ye et al., 2023; Zhai et al., 2021; Liang et al., 2011), plays a pivotal role in this effort, with summer corn accounting for 30.68% of the country's output (Wang et al., 2020; Mkhabela et al., 2011; Lobell et al., 2011; Amouzou et al., 2019; Zhang et al., 2015; Godfray et al., 2010; Foley et al., 2011). However, challenges such as limited cultivated land, suboptimal PD, and climate-induced heat stress threaten productivity (Swapna et al., 2024). The current average number of PDs in southern China, at approximately 51,000 plants per hectare, is short of the optimal 73,000 plants per hectare needed for maximum yield (Brink et al., 2006; Basaglia et al., 2021). Similarly, adjusting SDs is critical for mitigating the effects of climate change and synchronizing crop development with favorable weather conditions (Bonelli et al., 2016; Khan et al., 2017; Nielsen et al., 2002; Kaur and Prabhjyot-Kaur, 2018; Yue et al., 2022; Tabaković et al., 2022; Dekhane and Dumbre, 2017). Both PD and SD significantly influence sweet corn quality and yield, particularly in regions like HHH, where sustainable management practices are essential for ensuring reliable production outcomes and informing agricultural policy (Aboul-El-Hassan et al., 2020; Khosravani et al., 2017; Tsimba et al., 2013; Abendroth et al., 2017; Lauer et al., 1999).

In this study, Fengtian 188 (FT188) being used is a hybrid sweet corn developed specifically for Huang-Huai-Hai region and is adapted to varied sowing dates and plant densities. Sweet corn ideally requires balancing PD and SD so that quality and yield may be achieved, as these two agronomic factors directly affect resource utilization and crop performance (Andrade et al., 2005). A big challenge around the world is the optimization of these factors, since different climatic zones call for tailored methods to maximize productivity. PD will limit the ability of the crop to maximize its absorption of sunlight, water, and nutrients, whereas SD will assure that the growth stages are synchronized with favorable environmental conditions (Paradiso and Proietti, 2022). In temperate zones such as in the United States and Canada, early sowing enhances yield potential, while an altered PD has the advantage of avoiding language competition for nutrients in the tropics of Brazil and Thailand. Being that important, the presently accepted practices in the HHH plain regions largely remain below the input optimal value, thereby causing large variations in PDs and SDs that, in turn, affect yield as well as nutritional quality (Xiao et al., 2022). These questions merit critical consideration: How can the plant density be altered in order to benefit fresh ear yield without compromising grain quality? How does sowing density reduce the environmental stresses imposed by heat waves, which are increasingly frequent with climate change? Not only for sustainable agriculture in the HHH plain but also for global food security under climate change, these issues need to be addressed.

Previous research reports emphasize the paramount importance of sowing density and plant density in relation to the quality and yield of sweet corn. The works done on sweet corn in different areas strongly highlight that the optimal sowing density and plant density vary widely with shifts in climate and soil conditions (Silva, 2024; Coronel, 2016; Morata, 2024). Early sowing, such as on 25th April, increases growth outcomes, however late sowing decreases the leaf area index (Yu et al., 2014). Studies in the USA have established that early sowing, from late April to early May, allows the maximum accumulation of sugar in kernels and ear size, and the delayed sowing reduces saleable yield (Williams, 2008). Mehta et al. (2017) in a study concludes that in 68% of the hybrids, kernel sweetness reaches its peak during the third sowing period, late sowing hence favoring cob yield and sometimes sweetness as well. Conversely, in Brazil, different sowing dates have been linked to variations in cobs because growing early aids in retaining sugar due to lower night temperatures (Revilla et al., 2021).

PD also significantly influences yield traits, with optimal densities of 75,000–90,000 plants per hectare improving productivity (Yue et al., 2018). In Thailand, research indicates that while high PD increases fresh ear yield, it may also reduce individual cob size, requiring careful density adjustments for commercial production (Dermail et al., 2021). However, higher densities can reduce grain weight and slow filling, highlighting the trade-off between quantity and quality. Environmental factors may further modify these effects (Williams et al., 2023). By comparing these global trends, it becomes evident that PD and SD must be fine-tuned to specific agro ecological conditions to maximize both yield and grain quality.

While several studies have examined the impact of SD and PD on physiological characteristics such as cob weight, 100-grain weight, and ear characteristics, research on their effects on nutritional quality remains limited. Most existing studies primarily focus on yield-related traits, with little emphasis on how these agronomic factors influence key biochemical components of sweet corn. This study mainly explored the traditional yield parameters but also investigated the effects of SD and PD on glucose, fructose and sucrose content, which are critical determinants of sweetness and overall consumer acceptability. By integrating both agronomic and nutritional quality assessments, our research provides a more comprehensive understanding of how optimal SD and PD can enhance both yield and grain quality in the HHH region.

MATERIALS AND METHODS

The experiment was conducted in Leida Mountain, Fengyang County, Chuzhou City, Anhui Province (N: 32°52′39.57″, E: 117°33′32.18″), representative of the HHH plain's agricultural conditions. The region has a humid subtropical climate with an annual average temperature of 16 °C as illustrated in Figure 2, precipitation of 925 mm, and yellow loam soil that is classified as medium fertility. Soil characteristics include pH 6.5, organic matter (14.56 g/kg), available nitrogen (71.93 mg/kg), phosphorus (19.16 mg/kg), and potassium (231.28 mg/kg), making it ideal for sweet corn cultivation.

The sweet corn variety Fengtian 188 (FT188), provided by the Anhui University of Science and Technology, was used in this study. FT188 is a regionally developed hybrid bred specifically for the HHH plain. It is a medium-maturity cultivar with stable performance under a wide range of sowing dates and plant densities. The findings derived from FT188 are likely applicable to other sweet corn hybrids with similar growth characteristics cultivated in temperate regions. The experiment employed a randomized complete block design (RCBD) with two factors: SD and PD. The SDs included SD1 (25th April), SD2 (10th May), SD3 (25th May), and SD4 (10th June), while the PDs were PD1 (3000 plants/667 m^2), PD2 (3500 plants/667 m^2), and PD3 (4000 plants/667 m^2). ^{2}). Each of the 12 treatment combinations (4 sowing dates × 3 planting densities) was replicated three times, resulting in 36 plots in total. Each plot measured 6.67 m^2, with 60 cm inter-row spacing and standard plant spacing based on the assigned density. Ten ears were randomly sampled from each individual plot for biochemical and yield analysis.

Meteorological data for the experimental site were sourced from the Meteorological Data Sharing Service System (https://data.cma.cn, accessed on April 24, 2024). Field agronomic traits, including cob weight, 100-grain weight, and the number of grains per row, were measured during the growth period. Sampling was conducted 21 days after pollination. At each sampling stage, 10 ears of FT188 were randomly selected from each treatment for indoor biochemical analyses.

Indicators and methods

Biochemical analyses were performed to quantify grain fructose (UV method), glucose (glucose oxidase method), sucrose (UV colorimetric method), starch and vitamin C (colorimetric method). Each measurement followed standardized protocols, using 10 ears harvested from each treatment combination for SD and PD.

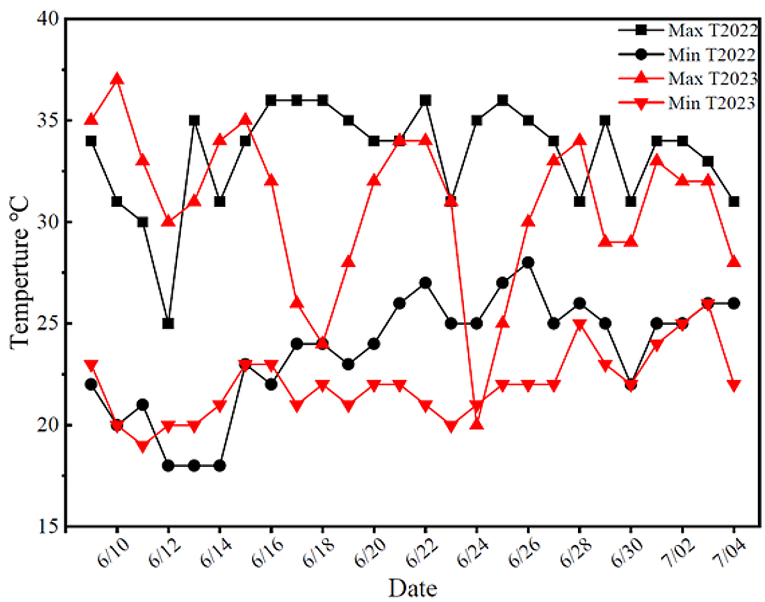

Figure 1. Maximum and minimum temperature tasseling to harvesting stage in 2022 and 2023 at the experimental station

Statistical analysis

Data were analyzed using SPSS software (version 19.0, SPSS Inc., Chicago, IL, USA) through analysis of variance (ANOVA) with a univariate general linear model to evaluate the effects of SD and PD on all measured traits. Graphical visualizations were created using OriginPro 2019 to represent the results.

RESULTS

Effects of different SD and PD on yield traits of sweet corn

100 kernel weight

The ANOVA results confirmed that SD and PD significantly affected the 100-kernel weight (Table 1). Among all treatments, SD1 combined with PD1 consistently yielded the highest 100-kernel weight, achieving 39.87 g in 2022 and 34.13 g in 2023. These values were significantly higher as compared to other SDs and densities. PD3 generally produced lower kernel weights than PD1 and PD2. Kernel weights were notably higher in 2022, with the highest value of 41.70 g observed for SD2-PD1, highlighting favorable growth conditions in this year.

Cob weight

With increasing plant density (3.000–4.000 plants per 667 m²), the cob weight of sweet corn showed a gradual decline, ranging from 65.20 g to 142.70 g per plant. The maximum cob weight (142.70 g) was recorded in 2023 for SD1-PD1, significantly higher than other combinations. Similarly, in 2022, the highest cob weight was observed for SD1-PD2 with 117.01 g, which is outperforming than other combinations but with smaller differences. As the sowing period was delayed, cob weight exhibited a trend of first increasing and then decreasing. For instance, at density of 3.500 plants per 667 m² in 2023, cob weight ranged between 81.83 g and 140.00 g per plant. This indicates a significant influence of SD and PD on cob weight. In general, SD1 showed consistent higher cob weight across treatments, with plant densities PD1 and PD2 performing

Table 1. Comparison of different ear treats of sweet corn grown under different SDs and PDs in 2022 and 2023

		2022				2023			
PD	SD	100 kernels weight (g)	Cob weight (g)	Ear length (cm)	Number of grains in a row	100 kernel weights (g)	Cob weight (g)	Ear length (cm)	Number of grains in a row
3000	4.25	39.87±0.28b	88.95±0.07a	22.02±0.53b	40.67±1.16a	34.13±0.90a	142.70±0.46a	23.53±1.19a	46.67±1.53a
	5.10	41.70±0.06a	71.66±0.34d	22.72±0.08a	40.00±1.73a	33.23±0.21ab	95.20±0.87c	21.30±0.10b	41.67±2.52ab
	5.25	39.43±0.20c	86.26±0.19b	20.54±0.23c	33.33±1.53b	34.23±0.12a	84.90±0.66d	21.00±0.62b	42.33±5.13ab
	6.10	28.28±0.09d	83.25±0.29c	19.43±0.29d	40.00±1.00a	32.10±1.56b	101.00±0.44b	20.90±1.14b	37.33±2.08b
3500	4.25	31.45±0.05c	117.01±0.14a	20.20±0.27b	40.67±1.16a	32.57±0.29b	140.00±0.85a	23.07±0.78a	44.67±1.16a
	5.10	29.98±0.09d	67.72±0.04d	21.37±0.15a	37.67±1.53b	32.90±0.26b	82.67±0.80c	20.90±0.61b	38.33±2.89b
	5.25	35.80±0.25b	83.87±0.37c	19.44±0.16c	35.00±1.00c	36.10±0.26a	81.83±0.57c	19.90±0.46b	41.33±2.52ab
	6.10	39.61±0.08a	96.98±0.11b	19.24±0.20c	40.67±1.16a	28.50±1.56c	86.90±0.62b	20.13±1.53b	40.67±3.06ab
4000	4.25	35.21±0.22b	115.19±0.20a	23.73±0.32a	42.67±1.53a	35.00±0.82a	95.00±0.60a	22.73±1.31a	47.00±1.00a
	5.10	34.44±0.20c	65.20±0.37d	21.33±0.58b	37.33±1.53c	35.80±0.17a	86.73±0.49b	21.57±2.57a	39.67±1.53b
	5.25	36.48±0.27a	102.98±0.37b	19.66±0.19d	38.00±2.00bc	32.20±0.17b	77.43±0.67c	22.13±2.31a	41.00±4.36b
	6.10	32.00±0.05d	82.32±0.17c	20.48±0.47c	40.67±1.16ab	30.20±1.56c	86.90±1.42b	20.13±3.45a	37.33±3.79b
	ANOVA								
	Year	***	***	*	***	***	***	*	***
	SD	***	***	***	***	***	***	***	***
	PD	***	***	NS	NS	***	***	NS	NS
	Year*SD	***	***	NS	***	***	***	NS	***
	Year*PD	***	***	NS	NS	***	***	NS	NS
	SD * PD	***	***	NS	NS	***	***	NS	NS
	year*PD*SD	***	***	NS	NS	***	***	NS	NS

Note: NS: Non-significant, *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

well through the years. On the other hand, the plant density PD3 drop back behind. The date-density combination SD1-PD2 contained one of the larger cob weights in both years, thereby strengthening its edge as one of the most considered dates and plant densities to sow.

Ear length

Means of ear length tested were significant for SD and PD, where SD1-PD2 yielded the longest ear length across treatments. In 2023, maximum ear length of 22.80 cm was recorded for SD1-PD2, which significantly outperformed combinations involving later SDs and higher densities. Similarly, in 2022, SD1-PD2 yielded the highest ear length of 22.72 cm. This shows the implication of early sowing SD1 and medium density PD2 towards the effect on ear length.

Number of grains in a row

Grain count per row showed significant variation between different SDs, with SD1 always producing the highest number. The highest value was obtained in 2023 for SD1-PD3, with 45 grains per row, which was statistically higher than the other treatments. In 2022, the maximum value of 40.67 grains per row for SD1-PD3 sustained its supremacy in performance. PD3 generally expected more grains per row, whereas SD1 turned out to be the best SD.

ANALYSIS OF VARIANCE IN THE NUTRITIONAL CHARACTERISTICS OF SWEET CORN

Sugar content

Glucose content

The analysis of variance (ANOVA) revealed that SD and PD significantly affected glucose content (Table 2). In 2023, glucose levels at low PD (PD1) were consistently low, ranging from 4.06 to 9.04 mg/g. A notable increase was observed at medium density (PD2), with levels ranging from 9.04 to 116.74 mg/g. The glucose content peaked at high PD (PD3) levels, ranging from 116.74 to 188.50 mg/g. SD3 and SD4 generally exhibited higher glucose levels across both years. Specifically, the highest glucose content was recorded with the combination of SD3 and PD3, with values reaching up to 345.35 mg/g in 2023. Furthermore, the interaction analysis indicated that glucose levels in 2023 were consistently higher than those in 2022 across all combinations of SD and PD. The highest glucose content was notably achieved in 2023, highlighting the significant impact of SD and PD on glucose levels.

Fructose content

Although the effect of SD on fructose content was significant but PD had insignificant effect (Table 2). The interaction analysis of SD and PD indicated that the highest fructose content was achieved using the combination of SD4 and PD3. In 2022, this combination yielded a fructose level of 148.9733 mg/g, whereas in 2023, the same combination produced 56.8500 mg/g. SD1 also showed relatively high fructose level, but SD4 consistently provided superior results, particularly during the 2022 growing season. The data suggest that, overall, higher fructose levels were observed in 2022 than in 2023, with SD4-PD3 being the most effective combination for achieving high fructose content.

Sucrose content

The ANOVA results confirmed that SD and PD significantly affected sucrose content (Table 2). SD1 and SD4 yielded higher sucrose content in both years. In 2022, SD1-PD3 (4000) achieved a sucrose level of 113.43 mg/g, whereas SD4-PD3 reached 131.01 mg/g. PD3 consistently showed the highest sucrose content across all SDs and both growing seasons, with notable values of 130.92 mg/g for SD3 (5.25) and 131.01 mg/g for SD4 in 2022. Generally, the highest sucrose level was observed in 2022 as compared to 2023 across all combinations, with values of 130.88 mg/g for SD4-PD1 and 130.69 mg/g for SD4-PD2 in 2022. The interaction analysis of SD and PD indicated that the combination of SD1 and PD3 is best for achieving a higher sucrose content, as seen with values of 113.43 mg/g in 2022 and 102.43 mg/g in 2023 (Table 2).

Starch content

The analysis of starch content across different and SDs for 2022 and 2023 revealed significant variation primarily influenced by SD. In 2023, starch content in PD1 consistently increased from 2.03 to 3.55 mg/g fresh weight. Similarly, at PD2,

Table 2. Effects of SD and PD on sweet corn nutrient traits in 2022 and 2023

		2022			2023		
PD	SD	Glucose	Fructose	Sucrose	Glucose	Fructose	Sucrose
	4.25	11.69±2.08b	62.08±11.82b	112.80±0.05d	4.06±3.24d	28.35±0.05d	48.50±0.30d
3000	5.10	21.73±2.63a	100.22±13.54a	115.18±0.05c	9.04±0.22c	36.71±0.13c	69.98±0.17b
	5.25	19.97±3.20a	48.23±8.62b	128.14±0.86b	116.74±0.13b	45.53±0.60b	67.72±0.46c
	6.10	21.67±2.13a	101.02±19.22a	130.88±0.22a	188.50±0.49a	76.17±0.15a	101.30±0.35a
	4.25	9.02±1.13b	74.95±4.41b	113.49±0.15d	4.39±3.52d	30.90±0.22d	140.26±0.23a
3500	5.10	20.93±0.88a	80.69±6.46ab	115.22±0.11c	56.20±0.21c	34.73±0.13c	80.52±0.31c
	5.25	21.17±0.87a	37.23±8.63c	130.16±0.17b	290.91±0.74a	66.90±0.49b	66.86±0.91d
	6.10	18.30±2.71a	98.77±16.34a	130.69±0.24a	249.57±0.44b	77.30±0.23a	105.14±0.35b
	4.25	13.15±1.84c	100.24±2.96b	113.43±0.20c	4.26±3.42d	18.51±0.14c	102.43±0.10b
4000	5.10	27.83±0.66a	32.32±3.60c	115.67±0.02b	42.89±0.20c	51.35±0.05b	78.80±0.17c
	5.25	20.66±1.41b	41.27±9.99c	130.92±0.41a	345.35±0.91a	50.99±0.42b	76.09±0.59d
	6.10	16.62±3.12bc	148.97±26.98a	131.01±0.11a	158.56±0.40b	56.85±0.19a	114.41±0.73a
	ANOVA						
	Year	***	***	***	***	***	***
	SD	***	***	***	***	***	***
	PD	***	NS	***	***	NS	***
	Year*SD	***	***	***	***	***	***
	Year*PD	***	*	***	***	*	***
	SD * PD	***	***	***	***	***	***
	year*PD*SD	***	***	***	***	***	***

Note: NS: Non-significant, *p < 0.05, **p < 0.01, ***p < 0.001.

the starch content rose steadily from 2.0932 in SD1 to 3.4742 in SD4. For PD3, the starch content increased substantially from 1.9248 for SD1 to 3.5487 for SD4. In contrast, the 2022 data showed lower overall starch content, with PD1 rising from 0.0707 on SD1 to 0.3067 on SD4, PD2 peaking at 0.2963 on SD3 before dropping to 0.0733 on SD4, and PD3 increasing from 0.0653 on SD1 to 0.304 on SD3 and then decreasing to 0.0167 by SD4.

The best combination for consistently achieving high starch level was observed in 2023 with PD3 achieving 3.5487 mg/g fresh weight on SD4. The ANOVA result, presented in Table 3, indicate that SD significantly affected starch level ($p < 0.001$), whereas PD did not. These results suggest that SD is more important than PD in optimizing starch content (Figures 1 A and B). Based on the data, SD4 consistently resulted in the highest starch content across the PDs, indicating that it is the optimal SD for maximizing starch levels.

Vitamin C content

ANOVA revealed that only the effect of SD on vitamin C content was significant (Table 3). SD1 (4.25) showed a more consistent performance throughout both years, particularly for PD3 (4000) and PD1 (3000) in 2022, with values such as 7.5333 for PD3 and 4.3433 for PD1. SD4 (6.10) had the highest vitamin C level, especially at higher densities (PD3, PD1); however, it was less consistent across years, with the highest value of 8.1600 at PD3 in 2022. SD2 (5.10) and SD3 (5.25) generally exhibited lower vitamin C level, such as 0.8333 and 2.3100 respectively in 2022. PD3 consistently showed high vitamin C content along with SD1, with notable value in 2022. The interactive analysis of SD and PD suggested that the combination of SD1 and PD3 resulted in the highest and most consistent vitamin C content. Vitamin C was generally higher in 2022 than in 2023, with SD1-PD3 combination showing values of 7.5333 in 2022 and 2.1033 in 2023 (Figures 2 C and D).

Correlation coefficients between sweet corn's different agronomic and nutrient characteristics

Correlation analysis among agronomic and quality traits revealed significant relationships

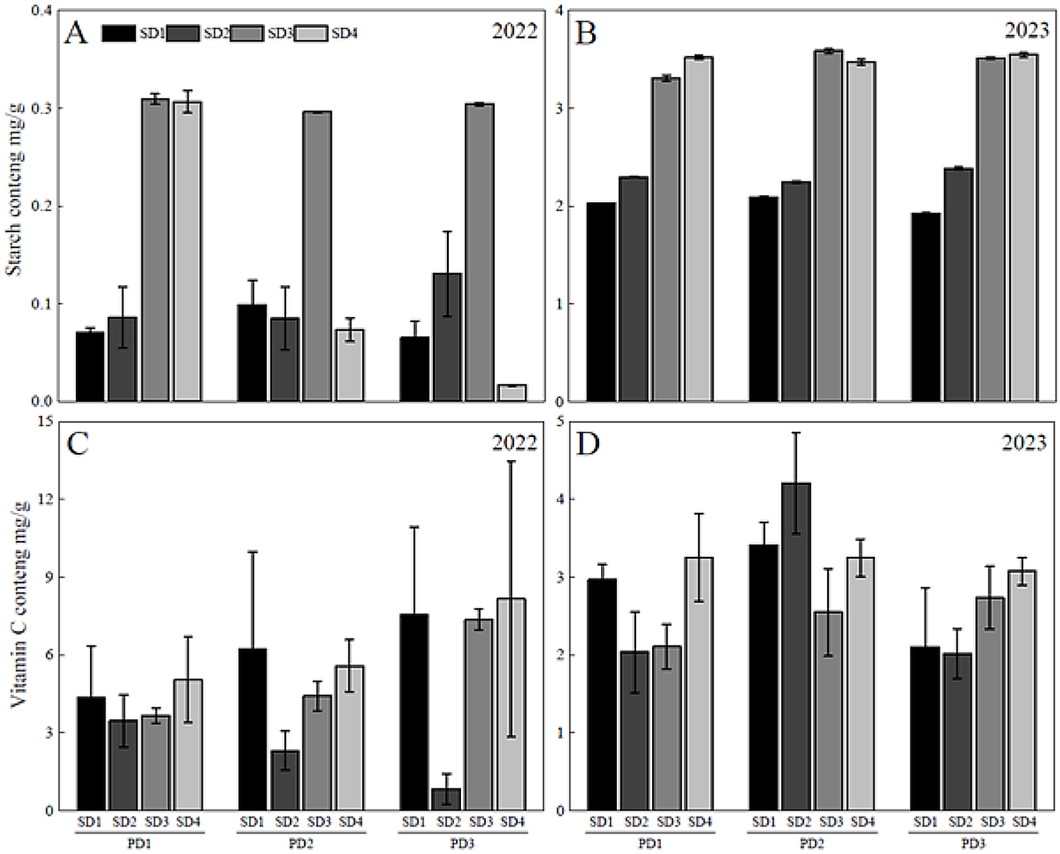

Figure 2. Effects of SD and PD on starch and Vitamin C content (mg/g) in 2022–23.

Table 3. ANOVA for starch and vitamin C content(mg/g)

ANOVA	Vitamin C	Starch content
Year	***	***
SD	**	***
PD	NS	NS
Year*SD	*	***
Year*PD	NS	***
SD * PD	NS	***
year*PD*SD	NS	***

Note: NS: Non-significant, *p < 0.05, **p < 0.01, ***p < 0.001.

(Table 4). The weight of 100 kernels was negatively correlated with glucose content (r = -0.288*), indicating that glucose content tends to decrease as kernel weight increases. Cob weight exhibited a significant positive correlation with ear length (r = 0.307**) and the number of grains in a row (r = 0.475**), suggesting that heavier cobs are associated with longer ears and more grains per row. Fructose content was positively correlated with sucrose (r = 0.361**) and Vitamin C (r = 0.501**), indicating that higher fructose levels are associated with increased sucrose and Vitamin C content. Sucrose also showed a significant negative correlation with glucose (r = -0.398**), implying that higher sucrose levels correspond to lower glucose level. Vitamin C was positively correlated with sucrose (r = 0.383**) and negatively correlated with fructose (r = -0.236*), further highlighting the interrelated nature of these biochemical traits. The number of grains in a row was positively correlated with ear length (r = 0.509**), indicating that ears with more rows of grains tend to be longer.

For maximizing both yield and nutritional quality, the combination of late sowing (May 25, SD4) and higher PD (4000 plants/667 m², PD3) appears most beneficial, as it ensures high sugar content and vitamin C levels while achieving acceptable yields. Conversely, early sowing (April 25, SD1) with a moderate PD may be more suitable when prioritizing cob and kernel weight.

DISCUSSION

Agronomic strategies to counter the adverse effects of climate variability on corn growth

Table 4. Correlation coefficients between different agronomic characters and nutrient content of sweet corn

Correlation coefficient	100-kernels weight (g)	Cob weight (g)	Fructose	Sucrose	Glucose	Vitamin C	Ear length (cm)	Number of grains in a row
Weight of 100 kernels (g)	1.000							
Cob weight (g)	-0.046	1.000						
Fructose	-0.069	-0.207	1.000					
Sucrose	0.065	-0.06	0.361**	1.000				
Glucose	-0.288*	-0.267*	0.008	-0.398**	1.000			
Vitamin C	0.039	0.203	0.501**	0.383**	-0.221	1.000		
Ear length (cm)	0.128	0.307**	-0.175	-0.236*	-0.147	-0.134	1.000	
Number of grains in a row	-0.062	0.475**	-0.112	-0.333**	-0.05	-0.062	0.509**	1.000

Note: correlation coefficients marked with one star (*) are significant at the 0.05 level, and those marked with two stars (**) are significant at the 0.01 level.

depend on local agricultural conditions, which strongly influence SD (Wang, 2013). SD management is a crucial aspect of crop planning, as it modifies crop phenology and adapts growth stages to environmental conditions. Sugar accumulation in sweet corn is particularly sensitive to planting time and geographic location, as SD influences carbohydrate metabolism, enzyme activity, and the starch-to-sugar conversion process (Waha et al., 2012). Several studies have investigated the effects of sowing date on the glucose content of sweet corn (Zakir et al., 2025) examined the influence of sowing time and cultivar selection on yield and shelf life under the agro-climatic conditions of Multan, highlighting its impact on sugar accumulation. Similarly, Sidahmed et al. (2024) reviewed various agricultural factors affecting sweet corn yield, reporting that optimized sowing dates contribute to higher sugar content in grain. Additionally, Sanaev et al. (Sanaev et al., 2024) assessed the growth performance of different sweet maize varieties and hybrids across various planting periods and schemes, analyzing sugar content in both wet and dry grains to determine optimal planting strategies.

Our ANOVA results confirmed that SD significantly affects glucose levels ($p < 0.001$, Table 1). Late sowing (May 25, SD4) at high plant density (4000 plants/667 m^2) resulted in the highest glucose accumulation (Ma et al., 2017). Similar findings by Maresma et al. (Maresma et al., 2019) were reported in a three-year study on maize under Mediterranean conditions, where late sowing led to increased forage yield, grain humidity, and plant height. The observed negative correlation between glucose levels and cob weight ($p < 0.05$), 100-grain weight ($p < 0.05$), and sucrose content ($p < 0.01$) (Table 3) suggests a possible trade-off in carbohydrate partitioning. Previous research by Liu et al. (Liu et al., 2023) has shown that maize grain yield is strongly impacted by plant density, planting patterns, and soil properties, influencing carbohydrate distribution. Previous research by Djaman et al. has shown that maize grain yield is strongly impacted by plant density, planting patterns, and soil properties, influencing carbohydrate distribution. As sowing is delayed, metabolic shifts favor the conversion of sucrose and starch into reducing sugars such as glucose, enhancing sweetness at the expense of grain weight and cob development. This trend may be attributed to enzymatic activities, such as increased invertase and amylase activity, which facilitate sucrose hydrolysis and starch degradation under prolonged grain-filling periods and elevated temperatures. Similar metabolic shifts have been observed by Wang et al. (Wang et al., 2024) in post-harvest studies, where stress-induced enzymatic activity (e.g., catalase, glutathione reductase, and ascorbate peroxidase) contributes to sugar stability and accumulation *Weissella cibaria* DA2 CFS study.

SD also had a significant effect on fructose content ($p < 0.001$, Table 1), with the highest fructose levels observed in SD4-PD3 (148.9 mg/g and 56.8 mg/g in 2022 and 2023, respectively). Interestingly, early sowing (SD1) also resulted in elevated fructose content. This apparent contradiction may be explained by differences in sugar metabolism at various growth stages. In early sowing conditions, higher photosynthetic efficiency and moderate temperatures might enhance initial fructose accumulation due to more efficient carbon fixation.

The impact of SD on sucrose content was significant ($p < 0.001$, Table 1), though this contrasts with the findings of Mandić et al. (Mandić et al., 2020), who reported no significant effect. This discrepancy could stem from differences in cultivars, climatic conditions, and experimental designs. The highest sucrose content (140 mg/g) was recorded in SD1 in 2023, while SD4 also showed increased sucrose accumulation. A possible explanation is that early sowing (SD1) benefits from optimal photosynthetic activity and moderate temperatures, promoting higher sucrose synthesis, while late sowing (SD4) may induce stress conditions that activate sucrose accumulation as an osmo-protectant.

In contrast, starch accumulation exhibited a different pattern. A study in Serbia found that late sowing reduced starch content (Wang et al., 2023), whereas our results indicate that SD4 increased starch levels. The highest starch content (3.55 mg/g) was observed at high PD (4000 plants/667 m²) during SD4 (Rahmani et al., 2015; Rahuma, 2018). This variation may be attributed to regional climatic differences affecting starch biosynthesis pathways. Higher temperatures and prolonged grain-filling periods in late sowing might lead to increased starch accumulation through the upregulation of starch synthase and branching enzymes. Contrariwise, under certain conditions, heat stress can inhibit starch biosynthesis, leading to lower starch content in some studies. These enzymatic and metabolic shifts warrant further investigation into the genetic and physiological factors influencing carbohydrate partitioning under different sowing conditions.

The effect of SD on vitamin C content was highly significant ($p < 0.001$, Table 3). SD4 exhibited the highest vitamin C levels; however, year-to-year variations suggest a strong influence of environmental factors, particularly temperature and solar radiation. Higher temperatures and prolonged sunlight exposure during later sowing dates may have enhanced ascorbic acid synthesis, contributing to increased vitamin C accumulation. Conversely, early sowing (SD1) consistently produced higher vitamin C content at high PD (Figures 2C and 2D), possibly due to optimal temperature and radiation levels favoring enzymatic activity. Additionally, SD1 resulted in the highest cob weight (117 g, 140 g) in both years (Ashok Kumar, 2009), aligning with prior studies (Miya et al., 2018). Similarly, SD1 led to the longest ear length (22.80 cm), corroborating previous findings (Bhatt, 2012). PD significantly influenced sweet corn yield and nutrient quality in this study. Growth, development, and morphology are highly responsive to PD variations (McAllan and Phipps, 1977). Miya et al. reported that lower PD increases sugar content, whereas (Farsiani et al., 2011) found that higher PD enhances sugar accumulation. Our results align with the latter, as increased PD (PD1 to PD3) led to higher glucose levels (Table 1). At low PD (PD1), glucose content was 11.6 mg/g and 4.0 mg/g in 2022 and 2023, respectively, while the highest levels (20.6 mg/g and 345.6 mg/g) were observed at PD3. The increase in sugar accumulation at higher PD may be attributed to improved photosynthetic efficiency and increased source-to-sink translocation. Higher PD can enhance light interception and canopy photosynthesis, optimizing carbohydrate synthesis and partitioning toward grain filling. Sucrose content was also significantly affected by PD ($p < 0.001$, Table 1), with PD3 consistently yielding the highest sucrose content across SDs in both years.

Plant density significantly influenced various agronomic traits, particularly starch content, with PD3 (4000 plants/667 m²) exhibiting the highest levels, aligning with Lente et al. (Lente and Pepó, 2011). Conversely, vitamin C content was not significantly affected by PD, though PD3 consistently maintained higher values across all SDs. Cob weight generally decreased with increasing PD, likely due to intensified competition for resources, as reported in previous studies (Shah et al., 2021; Ye et al., 2023). However, in 2022, PD3 combined with SD1 resulted in the highest cob weight (115.19 g), indicating that early sowing may mitigate resource competition effects at higher densities. Ear length was also significantly influenced by PD ($p < 0.05$, Table 1), with PD1 (3000 plants/667 m²) producing the longest ears, supporting earlier findings (Koca and Canavar, 2014). Notably, the number of grains per row remained statistically unchanged across PD treatments, suggesting that kernel formation is more strongly regulated by sowing date rather than plant density. This was particularly evident in SD1 at moderate densities, where the highest values were recorded, reinforcing the role of early sowing in optimizing grain development.

Late sowing (SD4: May 25) combined with high PD (4000 plants/667 m²) was the most effective strategy for maximizing yield and nutrient quality, leading to the highest glucose, sucrose, and starch levels, along with increased vitamin C content under optimal conditions. However, in resource-limited environments, early sowing (SD1: April 25) at lower densities (PD1: 3000 plants/667 m²) may be a viable alternative, maintaining high kernel and cob weights while ensuring sufficient sugar accumulation. These findings provide practical guidelines for farmers to optimize sweet corn production by adjusting SD and PD strategies based on regional climatic conditions. In cooler regions with shorter growing seasons, early sowing with moderate densities may help maximize kernel development, whereas warmer climates may favor later sowing with higher plant densities for enhanced yield and quality.

CONCLUSIONS

This study investigated the influence of SD and PD on the yield and qualitative traits of sweet corn *Fengtian 188* in the HHH region. The findings demonstrated that early sowing (April 25) improved cob and kernel weight, making it optimal when maximizing yield is the priority. Conversely, late sowing (May 25) with high density (4000 plants/667 m²) favored sugar, starch, and vitamin C accumulation, suggesting this treatment is best when nutritional quality is desired. In Particular, early sowing contributed to improved yield parameters and nutrient accumulation, while higher planting density was particularly effective in enhancing sugar and vitamin C content. These results underscore the importance of adopting agronomic strategies that integrate early sowing and optimal planting densities to improve sweet corn productivity and quality. This study provides a framework for improving sweet corn cultivation practices in the HHH region, offering practical recommendations for local farmers and agricultural policymakers. Future research should investigate the dynamic changes in vitamin and nutrient content across different developmental stages of sweet corn.

Acknowledgments

The authors would like to acknowledge Anhui Science and Technology University for providing the facilities and support necessary to conduct this research. We gratefully acknowledge the contributions of Yao Huang, Yulin Yu and Haibing Yu for their assistance with this project. Special thanks to Xinxin Cheng for their invaluable guidance and supervision throughout this work. We also thank Umair Habib for his assistance with writing, Wang Dongxi and Sun Tao for their help with data analysis.

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