Original Research Article

Effects of Season, Sowing Method and Planting Date on Growth and Yield Components of Pumpkin (*Cucurbita moschata* Duch. ex Poir.)

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ABSTRACT

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| **Aims:** The study aimed to evaluate the effects of seasonality, sowing methods and planting dates on the growth and yield components of pumpkin (*Cucurbita moschata* Duch.) under Sudanese agro-climatic conditions, with the objective of identifying optimal practices for improved productivity.**Study Design:** The experiment followed a factorial arrangement in a Randomized Complete Block Design (RCBD), comprising two sowing methods and three planting dates across two winter growing seasons.Place and Duration of Study: The research was conducted at Al-Hudeiba Agricultural Research Station, River Nile State, Sudan, over two winter cropping seasons: 2019–2020 and 2020–2021.**Methodology:** Two sowing methods—one-side and two-side—were tested alongside three sowing dates (November 4, 14, and 24). A local *Cucurbita moschata* cultivar was grown under standard management. Data were collected on lateral branches, leaves, flowers, fruit set percentage, fruit number, and fruit yield per plant. Statistical analysis was performed using ANOVA with means separated via LSD at the 5% level.**Results:** Significant seasonal differences were found, with the 2020–2021 season yielding superior performance. The one-side sowing method significantly improved fruit yield. November 14 sowing consistently produced higher values in most traits. The best combination (Y2 × SM1 × SD2) resulted in maximum fruit yield and vegetative growth.**Conclusion:** Aligning sowing method and planting date with seasonal conditions can significantly enhance pumpkin productivity in Sudan. The one-side sowing method and mid-November (14 November) planting are recommended for optimal yield. These findings support climate-responsive agronomic strategies for sustainable vegetable production in arid and semi-arid regions. |

***Keywords****: Agronomic practices, Climatic variability, Cucurbita moschata, Planting date, Sowing method, Yield components*

### **INTRODUCTION**

Pumpkin (*Cucurbita moschata* Duch.) is a vital traditional vegetable crop in Sudan, appreciated for its nutritional value, culinary versatility, and adaptability to diverse agro-ecological zones. It is widely consumed across the country in both savory and sweet dishes. Commonly, pumpkin is prepared with meat, sautéed onions, tomato sauce, and local spices, and is served with *kisra*—a fermented sorghum flatbread. It is also used in sweet preparations with sugar and milk, or as an ingredient in cakes and pastries, reflecting its integral role in Sudanese cuisine.

The crop is cultivated across various regions in Sudan, including the Northern State, River Nile State, Blue Nile State and Gedaref—particularly in Al-Mafaza and Al-Hawata along the Rahad River, as well as Kordofan State and Central State, which are identified as the most important production area for various pumpkin landraces. These areas offer favorable conditions such as irrigated land, fertile alluvial soils, and supportive infrastructure, which collectively contribute to pumpkin's prominence in both local consumption and its potential in export markets. In 2020, Sudan produced 33,396 tons of pumpkin on 2010 hectares (Ali *et al*., 2022; Hassan *et al.,* 2024).

Despite its prevalence, there is no improved cultivar for commercial cultivation in Sudan; production relies on local accessions and landraces, referred to as *baladi* varieties, which are typically named after their regions of origin. These *baladi* types are noted for their resilience to pests, diseases, and suboptimal management conditions (Ulrich *et al.,* 2022). Pumpkin cultivation is well-suited to Sudan’s winter cropping season, with optimal sowing occurring between October and November. The crop performs best in light sandy-loam soils, particularly those found in alluvial areas along riverbanks.

Pumpkin plays a critical role in food security, income generation, and sustainable farming systems in both semi-arid and irrigated zones such as Gezira, Sennar, North Kordofan, and Blue Nile States. Despite its wide distribution and socio-economic importance, productivity remains below potential due to suboptimal agronomic practices—especially sowing methods and planting dates that do not align with climatic suitability.

Sowing method and planting date are key agronomic factors influencing pumpkin growth, development, and yield. The choice of sowing technique—flat sowing, ridging, or pit planting—affects root establishment, soil moisture dynamics, and nutrient availability. Likewise, the timing of planting must align with optimal environmental conditions, including temperature, rainfall, and photoperiod, to maximize phenological efficiency, particularly during flowering and fruit set (Oloyede & Adebooye 2013; Sadia *et al.* 2023; Kakoli *et al.,* 2025). However, limited empirical research has examined these interactions in Sudan, resulting in a reliance on traditional practices and inconsistent yields.

Globally, studies in tropical and subtropical climates have shown that optimized sowing and planting dates can enhance growth and yield components such as fruit number, size, seed weight and protein (Latifi, *et al.,* 2012; Oloyede & Adebooye 2013; Sawale *et al.,* 2022; Sadia *et al.,* 2023). Therefore, identifying agronomic practices tailored to Sudanese conditions is crucial for achieving higher productivity and more sustainable pumpkin farming.

This study aims to investigate the effects of different sowing methods and planting dates on the growth and yield components of *Cucurbita moschata* under Sudanese agro-climatic conditions. This research provides location-specific recommendations to enhance farm profitability and guide agricultural extension

1. **MATERIALS AND METHODS**

**2.1 Experimental Site**

The study was conducted at the Al-Hudeiba Agricultural Research Station, located in the city of El-Damer, River Nile State, Sudan. This research station is part of the National Agricultural Research Corporation network and specializes in Nile Valley agriculture. The site is classified with a hot desert climate (BWh), with temperatures typically ranging from 23 °C to 36 °C throughout the year. However, temperatures can occasionally drop to 8 °C or rise as high as 46 °C. The average annual precipitation is approximately 34 mm, with only five rainy days each year exceeding the 1 mm threshold.

**2.2 Experimental Design**

 The experiment was conducted using a factorial arrangement in a Randomized Complete Block Design (RCBD) with four replications. The study included three factors: Season (A), Sowing Method (B), and Sowing Date (C). Factor A, Season, had two levels corresponding to two winter growing seasons—2019–2020 and 2020–2021—each extending from November to April. Factor B, the Sowing Method, included two levels: SM1 (one-side sowing method) and SM2 (two-side sowing method). Factor C, Sowing Date, comprised three levels SD1 ,SD2 and SD3: 4 November, 14 November, and 24 November respectively. The 12 treatment combinations resulting from the factorial arrangement (2 × 2 × 3) were randomly allocated within each of the four blocks, resulting in a total of 48 experimental units.

Each experimental unit measures five by five meters and contains two raised beds, each 2.5 meters wide and five meters long. Planting took place on specified dates during both the 2019 and 2020 growing seasons. A local cultivar *“Al-damar baladi”* of *Cucurbita moschata* , commonly grown in the region, was used. The seeds were hand-sown to a depth of 5 cm, with three seeds planted per hill, which were later thinned to one healthy plant at the two-leaf stage. During land preparation, cured manure was applied two weeks before planting at a rate of five tons per hectare and incorporated during the rotavation process. Phosphorus was supplied in advance using triple super phosphate (TSP) at a rate of 50 kg per hectare to promote strong root development and early plant establishment. Nitrogen was later provided through urea (46% N), applied at a total rate of 90 kg per hectare, split into two equal applications; the first was applied three weeks after sowing to support vegetative growth, and the remaining half was applied at the flowering stage to sustain plant vigour and fruit development.

**2.3 Data collection & statistical analysis**

Data were collected on six traits including, the number of lateral branches, number of leaves per plant, number of flowers per plant, fruit set per cent, number of fruits per plant and fruit yield per plant (kg).  The experiment was conducted using a factorial arrangement and the results were subjected to analysis of variance (ANOVA) to evaluate the main and interaction effects of the studied factors as detailed in Singh and Chaudhary (1987). Statistical analysis was done using GRAPES 1.1.0, online software developed by Gopinath *et al.,* (2021), to test the significance of main effects (Years, sowing method and sowing date) and their interactions. Means were separated using Least Significant Difference (LSD) at the 5% probability level.

1. **RESULTS AND DISCUSSION**

The climatological data for the two seasons, along with the deviation of the 2020-2021 season from the 2019-2020 season, are recorded in Table 1 and Figure 1, respectively. The analysis of variance (ANOVA) presented in Table 2 shows the mean square values for key growth and yield traits of pumpkin (Cucurbita spp.), influenced by year (Y), sowing method (SM), sowing date (SD), and their interactions. The mean performance across different factors and their interaction were assessed for statistical significance and presented in Table 3a and 3b respectively.

**Table 1. Monthly Climatological Parameters for Atbara–Damar, River Nile State, Sudan (November 2019 – April 2021)**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Year** | **Month** | **Mean Temp (°C)** | **Min Temp (°C)** | **Max Temp (°C)** | **Rainfall (mm)** | **RH (%)** |
| **2019-2020** | **Nov** | 23.0 | 20.1 | 35.0 | 0.0 | 36.0 |
| **Dec** | 22.0 | 16.1 | 31.9 | 0.0 | 34.0 |
| **Jan** | 21.0 | 14.7 | 30.5 | 0.0 | 27.0 |
| **Feb** | 23.0 | 15.1 | 31.9 | 0.0 | 29.0 |
| **Mar** | 25.0 | 18.0 | 35.5 | 0.0 | 21.0 |
| **Apr** | 28.0 | 21.7 | 39.7 | 1.0 | 35.0 |
| **Season Average**  | **23.7** | **17.6**  | **34.1** | **0.17** | **30.33** |
| **2020-2021** | **Nov** | 28.1 | 21.0 | 35.2 | 0.7 | 38.0 |
| **Dec** | 24.5 | 17.0 | 31.7 | 0.0 | 35.0 |
| **Jan** | 23.2 | 15.6 | 30.7 | 0.0 | 22.0 |
| **Feb** | 25.0 | 16.8 | 32.6 | 0.0 | 28.0 |
| **Mar** | 28.7 | 20.3 | 36.5 | 0.1 | 36.0 |
| **Apr** | 31.9 | 24.1 | 40.4 | 0.0 | 30.0 |
| **Season Average**  | **26.9** | **19.1** | **35.1** | **0.1** | **31.5** |

**Figure 1. Mean deviations in climate variables (2020–2021 vs. 2019–2020)**

*Note: Monthly differences in mean, minimum, and maximum temperature (°C), rainfall (mm), and relative humidity (%) during the dry season (November to April), calculated as 2020–2021 values minus those of 2019–2020.*

**3.1 Influence of years on growth and yield parameters**

The analysis of variance (ANOVA) in Table 2. revealed highly significant differences (p < 0.01 or p < 0.001) between the two growing years, 2019–2020 and 2020–2021, for all measured parameters. The second year (2020–2021) Mean performance in Table 3a showed superior performance in most traits, including the number of lateral branches per plant (3.75), the number of leaves per plant (91.08), the number of flowers per plant (63.54), the number of fruits per plant (5.46), and the fruit yield per plant (6.89 kg). These findings indicate that environmental differences between the two cropping seasons (2019–2020 and 2020–2021) substantially influenced the growth and productivity of pumpkin. Season (2020–2021) was more favourable for pumpkin growth and yield. Similar findings were reported by Oloyede & Adebooye (2013), who noted that inter-annual climatic variations significantly affect pumpkin productivity, with warmer and more stable conditions enhancing yield. Variability in climatic conditions—particularly rainfall distribution, temperature, and light intensity—likely contributed to these differences. However, it is important to mention that the fruit set percentage (%) was the least favorable trait in the 2020–2021 season. Despite this year showing a higher number of flowers (63.54 compared to 30.46 in 2019–2020), the lower fruit set percentage indicates that factors such as sex ratio imbalance, environmental stress, and resource competition likely contributed to flower abortion and thus reduced fruit set. Climatological data (Table 1) show that the 2020–2021 season was warmer than 2019–2020, conditions which favored pumpkin growth and yield. The superior vegetative growth observed during 2020–2021, evidenced by increased leaf production, (91.08) leaves per plant viz (73.38) in 2019-2020, likely intensified the competition for assimilates between vegetative and reproductive sinks. This heightened vegetative sink strength may have limited resource allocation to developing fruits, resulting in fewer fruits setting despite the abundance of flowers. However, the fruits that did develop were larger and heavier, leading to higher overall yield. This pattern reflects the source–sink relationship and allometric growth principles, where biomass partitioning shifts depending on internal demands and environmental conditions, affecting fruit number and size (Marcelis, 1996). Thus, the lower fruit set percentage in 2020–2021 can be understood as a trade-off arising from high flower production without adequate resource allocation for fruit development.

**3.2 Effect of sowing method on growth and yield parameters**

The sowing method had no significant effect on most traits, including number of fruits per plant. However, the one-side sowing configuration significantly influenced the fruit yield per plant (p < 0.05), resulting in an average of 6.56 kg per plant as shown in Table 2 and 3a respectively. This suggests that, although the number of fruits per plant was not significantly different, the one-side sowing configuration increased fruit weight, leading to higher overall yield. This may be attributed to reduced competition for resources, allowing the plants to produce heavier fruits. Similar outcomes were reported by Obiadalla-Ali *et al.* (2009) and Sure *et al.* (2012) who observed that raised bed planting in pumpkin enhanced yield by improving root zone microclimate and reducing waterlogging.

**3.3 Effect of sowing date on growth and yield parameters**

The sowing date significantly influences several traits, as shown in Table 3a. Highly significant effects were observed for the number of lateral branches (4.19\*\*\*), the number of flowers per plant (858.06\*\*), the fruit set percentage (123.93\*\*), the number of fruits per plant (20.021\*), and fruit yield per plant (kg) (32.71\*). This indicates that the sowing date plays a critical role in aligning pumpkin growth stages with favourable environmental conditions. Table 3 shows that the sowing date of November 14 significantly impacts the number of lateral branches (4.06), the number of flowers per plant (55.31), the number of fruits per plant (5.38), and fruit yield per plant (6.79 kg). On the other hand, an early sowing date of November 4 results in a significantly higher fruit set percentage and is statistically comparable to the November 14 sowing date for traits such as the number of fruits per plant (4.69) and fruit yield per plant (5.81 kg). This suggests that early or optimally timed sowing can enhance vegetative development and improve reproductive success by avoiding extreme temperatures, rainfall and high humidity during flowering (Latifi *et al.,* 2012; Oloyede & Adebooye , 2013). In Bangladesh, sowing time significantly affected the incidence and severity of cucumber mosaic virus (CMV) on pumpkin, as well as overall yield. An early sowing on October 25th resulted in lower disease incidence and severity, and higher yield, compared to a later sowing on November 5th (Sadia *et al.* 2023).

In Nigeria, studies on *Cucurbita pepo* suggested that early planting is beneficial because delayed planting led to a significant reduction in fruit yield and protein content. Crops that experienced less rainfall, moderately high temperatures, and more sunshine generally showed higher fruit yield and protein levels (Oloyede & Adebooye 2013).This is especially important for temperature-sensitive crops like pumpkin, where thermal and photoperiodic stress can significantly reduce fruit set and seed development. across various tropical and subtropical regions, evidence strongly supports that strategic adjustments to sowing and planting dates, often favoring earlier periods or specific seasonal windows, can significantly boost pumpkin and squash yields, enhance fruit quality, accelerate plant maturity, and help mitigate disease incidence, largely by leveraging optimal environmental conditions for growth and pollination (Mohamed, 2011; Latifi *et al.,* 2012; Oloyede & Adebooye 2013; Sumathi & Srimathi (2013); Sawale 2022; Sadia *et al.* 2023; Kakoli *et al.,* 2025).

**Table 2. Analysis of variance for the growth and yield parameters as affected by year (Y), sowing methods (SM), seed date (SD), and their interactions for the field experiments conducted in 2019–2020 and 2020–2021.**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Source of Variation** | **Number of Lateral Branches per Plant** | **Number of Leaves per Plant** | **Number of Flowers per Plant** | **Number of Fruits per Plant** | **Fruit Set Percentage (%)** | **Fruit Yield per Plant (kg)** |
| **Years (Y)** | 3\*\* | 15.274\*\*\*  | 13134.083\*\*  | 52.083\*\* | 131.341\*\* | 89.059\*\* |
| **Sowing Methods (SM)** | 0 ns | 0.528ns | 0.333ns  | 18.750ns | 61.653ns  | 51.258\* |
| **Sowing Dates (SD)** | 4.1875\*\*\* | 3.281ns  | 858.063\*\* | 20.021\* | 123.927\*\* | 32.711\* |
| **Y × SM** | 0.3333 ns | 7.063\*\*  | 396.750ns | 56.333\*\* | 52.041ns  | 94.265\*\* |
| **Y × SD** | 0.4375 ns | 10.165\*\*\*  | 1171.896\*\* | 47.896\*\*\* | 117.716\*\* | 76.556\*\*\* |
| **SM × SD** | 0.1875 ns | 1.525ns | 711.271\* | 28.563\*\* | 22.212ns  | 47.699\*\* |
| **Y × SM × SD** | 0.2708 ns | 3.332\* | 380.438ns | 29.021\*\* | 38.406ns  | 48.059\*\* |

*ns: non-significant, \* significant at p = 0.05, \*\* significant at p < 0.01 and \*\*\*significant at p < 0.001*

**Table 3a. Mean performance for the growth and yield parameters as affected by main effect of year (Y), sowing methods (SM), seed date (SD), conducted in 2019–2020 and 2020–2021.**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Treatments** | **Number of Lateral Branches per Plant** | **Number of Leaves per Plant** | **Number of Flowers per Plant** | **Number of Fruits per Plant** | **Fruit Set Percentage (%)** | **Fruit Yield per Plant (kg)** |
| **Season (Y)** |  |  |  |  |  |  |
| Year (2019-2020) -Y1 | 3.25b | 73.38b | 30.46b | 3.38b | 11.34a  | 4.16b  |
| Year (2020-2021) -Y2 | 3.75a | 91.08a | 63.54a  | 5.46a | 8.03 b | 6.89a |
| LSD at p= 0.05 | **0.323** | **9.218** | **7.459** | **1.273** | **2.460** | **1.596** |
| **Sowing Methods (SM)** |  |  |  |  |  |  |
| One-sided sowing (SM1) | 3.5 | 83.88 | 46.92 | 5.04  | 10.82  | 6.56a |
| Two-sided sowing (SM2) | 3.5 | 80.58  | 47.08  | 3.79  | 8.55  | 4.49b  |
| LSD at p= 0.05 | **NS** | **NS** | **NS** | **NS** | **NS** | **1.596** |
| **Sowing Date (SD)** |
|  4 November (SD1) | 3.38b | 82.75 | 41.50b | 4.69ab | 12.74a  | 5.81ab |
| 14 November (SD2) | 4.06a | 89.06  | 55.31a  | 5.38a | 9.02b | 6.79a  |
|  24 November (SD3) | 3.06b | 74.88 | 44.19b | 3.19b | 7.30b | 3.97b  |
| LSD at p=0.05 | **0.396** | **NS** | **9.135** | **1.559** | **3.013** | **1.954** |

*Values followed by different letters within a column are significantly different at* P *= 0.05; 'NS' indicates a non-significant difference.*

* 1. **Interaction Effects (Year × Sowing method × Sowing Date)**

Several interaction were presented by the ANOVA, as shown in Table 3b, were statistically significant, highlighting the complexity of the pumpkin's response to combined agronomic and seasonal variables. The interaction between years and sowing methods (Y × SM) significantly affected the number of leaves per plant, the number of fruits per plant, and the fruit yield per plant (kg). The result recommended the 2020-2021 season with the one-side sowing method (Y2 x SM1) combination for optimal performance in these three traits. This suggests that the effectiveness of the sowing method varies depending on seasonal conditions.

Similarly, the interaction between year and sowing date (Y × SD) had significant effects on number of leaves per plant, number of flowers per plant ,number of fruits per plant , fruit set percentage and fruit yield (kg), reflecting the influence of environmental dynamics on optimal sowing time. The results recommend the 2020-2021 season with sowing date 14 November as the best optimum performance for number of leaves per plant, number of flowers per plant, number of fruits per plant and fruit yield (kg).

Moreover, the sowing method × sowing date (SM × SD) interaction significantly affected number of flowers per plant, number of fruits per plant and fruit yield (kg). The results recommend one side sowing (SM1) and the 14 November sowing date combination as the best performing combination across the three traits. This implies that the combination of planting time and method plays a crucial role in regulating reproductive parameters, which are closely tied to final yield.

The three-way interaction among years, sowing methods, and sowing dates (Y × SM × SD) significantly influenced the number of leaves, the number of fruits per plant, and the fruit yield per plant (in kilograms). The combination of the 2020-2021 season, one-side sowing method, and a sowing date of November 14 (Y2 × SM1 × SD2) was identified as the best combination, as it resulted in a higher number of leaves, fruits per plant, and fruit yield per plant. Previous studies have reported broader three-way interactions that include "year" alongside sowing-related parameters, such as fixed late sowing dates, planting dates, or combinations of spacing and treatments. This indicates that environmental conditions, which can vary from year to year, can indeed influence the outcomes of specific cultivation practices (Harrelson *et al*., 2008; Abdel-Rahman *et al.,* 2012).

Overall, the results indicate that pumpkin performance is governed by complex and seasonally dependent agronomic relationships. These findings support the G × E × M framework (Genotype × Environment × Management) proposed by Slafer *et al.* (2014) and further discussed by Jaenisch *et al*. (2022) and Cooper et al. (2022). This framework emphasizes that crop performance is influenced by a combination of biological and environmental factors. In this context, year-to-year variability stands out as the primary factor affecting yield variation, while the sowing date and its interaction with the sowing method offer strategic opportunities to enhance productivity.

**Table 3b. Mean performance for growth and yield parameters as affected by main effect of year (Y), sowing methods (SM), sown date (SD), conducted in 2019–2020 (Y1) and 2020–2021 (Y2)**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Interaction** | **Number of Lateral Branches per Plant** | **Number of Leaves per Plant** | **Number of Flowers per Plant** | **Number of Fruits per Plant** | **Fruit Set Percentage (%)** | **Fruit Yield per Plant (kg)** |
| **Interaction Y × SM** |  |  |  |  |  |  |
| Year 1 | SM1 | 3.17 | 69.00c | 27.50 | 2.92b | 11.43 | 3.79b |
| SM2 | 3.33 | 77.75bc | 33.42 | 3.83b | 11.25 | 4.53b |
| Year 2 | SM1 | 3.83 | 98.75a | 66.33 | 7.17a | 10.21 | 9.32a |
| SM2 | 3.67 | 83.42b | 60.75 | 3.75b | 5.86 | 4.45b |
| LSD at p= 0.05 | **NS** | **13.04** | **NS** | **1.8** | **NS** | **2.26** |
| **Interaction Y × SD** |  |  |  |  |  |  |
| Year 1 | SD1 | 3.25 | 79.50bc | 31.13c | 5.25b | 17.50a | 6.43b |
| SD2 | 3.88 | 65.88c | 29.00c | 2.50c | 8.78b | 3.08c |
| SD3 | 2.63 | 74.75bc | 31.25c | 2.38c | 7.74b | 2.97c |
| Year 2 | SD1 | 3.50 | 86.00b | 51.88b | 4.13bc | 7.98b | 5.18bc |
| SD2 | 4.25 | 112.25a | 81.63a | 8.25a | 9.27b | 10.50a |
| SD3 | 3.50 | 75.00bc | 57.13b | 4.00bc | 6.85b | 4.98bc |
| LSD at p = 0.05 | **NS** | **15.97** | **12.92** | **2.21** | **4.26** | **2.76** |
| **Interaction SM × SD** |  |  |  |  |  |  |
| SM1 | SD1 | 3.25 | 79.63 | 38.37b | 4.88b | 14.82 | 6.32b |
| SD2 | 4.13 | 95.63 | 62.88a | 7.50a | 10.53 | 9.75a |
| SD3 | 3.13 | 76.38 | 39.50b | 2.75b | 7.11 | 3.60b |
| SM2 | SD1 | 3.50 | 85.88 | 44.63b | 4.50b | 10.66 | 5.29b |
| SD2 | 4.00 | 82.50 | 47.75b | 3.25b | 7.52 | 3.83b |
| SD3 | 3.00 | 73.38 | 48.88b | 3.63b | 7.49 | 4.35b |
| LSD at p = 0.05 | **NS** | **NS** | **12.92** | **2.21** | **NS** | **2.76** |
| **Interaction Y × SM × SD** |  |  |  |  |  |  |
| Y1× SM1× SD1 | 3.00 | 71.50bc | 25.25 | 4.25bcd | 18.17 | 5.51bcd  |
| Y1× SM2× SD1 | 3.50 | 87.50b | 37.00 | 6.25b | 16.84 | 7.35b  |
| Y1× SM1× SD2 | 3.75 | 58.75c | 28.75 | 2.25d | 7.92 | 2.93d |
| Y1× SM2× SD2 | 4.00 | 73.00bc | 29.25 | 2.75cd | 9.64  | 3.24cd  |
| Y1× SM1× SD3 | 2.75 | 76.75bc | 28.50 | 2.25d | 8.22 | 2.94d  |
| Y1× SM2× SD3 | 2.50 | 72.75bc | 34.00 | 2.50cd | 7.27 | 3.00d |
| Y2× SM1× SD1 | 3.50 | 87.75b | 51.50 | 5.50bc | 11.47 | 7.14bc |
| Y2× SM2× SD1 | 3.50 | 84.25b | 52.25 | 2.75cd | 4.49  | 3.23cd  |
| Y2× SM1× SD2 | 4.50 | 132.50a | 97.00 | 12.75a | 13.15 | 16.58a |
| Y2× SM2× SD2 | 4.00 | 92.00b | 66.25 | 3.75bcd | 5.39 | 4.42bcd  |
| Y2× SM1× SD3 | 3.50 | 76.00bc | 50.50 | 3.25bcd | 6.00 | 4.25bcd  |
| Y2× SM2× SD3 | 3.50 | 74.00bc | 63.75 | 4.75bcd | 7.70 | 5.70bcd |
| LSD at p < 0.05 | **NS** | **22.581** | **NS** | **3.118** | **NS** | **3.91**  |
| Mean | **3.5** | **82.23** | **47** | **4.42** | **9.69** | **5.52** |
| CV % | **15.73** | **19.09** | **27.02** | **49.07** | **43.24** | **49.20** |

*Values followed by different letters within a column are significantly different at* P *= 0.05; 'NS' indicates a non-significant difference.*

**4. CONCLUSION**

This study demonstrates that seasonal variability, sowing methods, and planting dates significantly influence the growth and yield of pumpkin (*Cucurbita moschata*) under Sudanese conditions. The 2020–2021 growing season outperformed 2019–2020 in key traits such as lateral branches, leaves, flowers, fruit number, and yield, highlighting the impact of climatic factors on productivity. However, the lower fruit set percentage in 2020–2021 suggests that excessive flower production does not always translate to higher yields, possibly due to environmental stressors or resource competition.

To optimize pumpkin yields, farmers should adopt the one-side sowing method (SM1) and target a sowing date of November 14. This combination (Y2 × SM1 × SD2) consistently produced the highest number of leaves, fruits per plant, and overall yield. While early sowing (November 4) may enhance fruit set, mid-November (November 14) sowing showed better overall yield and aligns better with favorable environmental conditions for balanced vegetative and reproductive growth.

Future research should explore the interactions between irrigation regimes, nutrient management, and sowing dates to refine cultivation strategies. Evaluating the performance of diverse local pumpkin genotypes under these optimized practices could unlock higher yield stability and climate resilience. By integrating these findings with targeted agronomic interventions, Sudan’s pumpkin production can achieve greater sustainability and profitability. This study underscores the importance of the G × E × M (Genotype × Environment × Management) framework in tailoring practices to local conditions, offering a roadmap for both farmers and researchers to enhance pumpkin productivity in similar agro-climatic regions. The findings provide actionable insights for immediate application while highlighting critical areas for further investigation to support long-term agricultural resilience.

Ethical approval

All authors declare that no human participants or animals were involved in this study. The research was conducted solely on plant material under field conditions.

COMPETING INTERESTS DISCLAIMER:

Authors have declared that they have no known competing financial interests OR non-financial interests OR personal relationships that could have appeared to influence the work reported in this paper.

DISCLAIMER (ARTIFICIAL INTELLIGENCE):

The author(s) hereby declare that generative AI technologies and digital tools, including Grammarly Version 1.2.169.1689, released June 19, 2025 and Zotero 7.0.19, were used solely for reference management, proofreading, and language editing. All content and ideas presented in the manuscript were entirely generated by the author(s), without AI assistance in writing or data interpretation.

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