Original Research Article

Effect of Sowing Method and Seed Rate on Growth and Yield of Carrot (*Daucus carota* L.) in the River Nile State, Sudan

ABSTRACT

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| **Aims:** Carrot (*Daucus carota* L.) is a nutritionally and economically important crop in Sudan, yet its productivity remains low due to suboptimal agronomic practices. Limited research has addressed the combined effects of sowing methods and seed rates under Sudanese conditions. This study evaluated traditional sowing methods, *Sarsaba* (SM₁) and *Madrab* (SM₂), across four seed rates (3.5–18.0 kg ha⁻¹) in River Nile State. The lack of locally validated planting protocols hinders yield optimization, particularly for smallholder farmers. By assessing growth and yield responses, this work identifies optimal practices for sustainable intensification.  **Study Design:** A factorial experiment arranged in a completely randomized block design (CRBD) with four replications.  **Place and Duration of Study:** The experiment was conducted at Hudaiba Research Station, River Nile State, Sudan (17°34′N, 33°56′E; 350 m above sea level), over two winter cropping seasons (2019–2020 and 2020–2021).  **Methodology:** The carrot variety Royal Chantenay 2 was cultivated under ridge-based conditions with uniform irrigation and urea fertilization at 120 kg N ha⁻¹. Treatments included two sowing methods—SM₁ (continuous line sowing on ridge crests) and SM₂ (precision hill sowing at 10 cm spacing)—and four seed rates. Growth and yield parameters assessed were plant density (plants m⁻²), root length (cm), root diameter (cm), marketable yield (kg m⁻²), and total yield (kg m⁻²). Data were analyzed using ANOVA and LSD tests (P= 0.05) via the GRAPES statistical platform.  **Results:** The results showed that the highest seed rate of 18.0 kg ha⁻¹ produced the greatest total yield (5.36 kg m⁻²) and marketable yield (3.49 kg m⁻²), although this rate negatively affected root dimensions, reducing both length and diameter. Conversely, the moderate seed rate of 12.0 kg ha⁻¹ offered a better balance between yield and root quality. Among the sowing methods, *Madrab* (SM₂) significantly improved marketable yield (3.52 kg m⁻²), while *Sarsaba* (SM₁) resulted in larger root dimensions, with a mean length of 14.82 cm and diameter of 2.28 cm. The interaction between sowing method and seed rate was generally non-significant (P > 0.05), except for root length, which was notably enhanced under SM₁ at the lowest seed rate of 3.5 kg ha⁻¹. Additionally, seasonal variation was evident, with higher yields obtained in the second season, likely due to more favorable agroclimatic conditions during that period.  **Conclusion:** The combination of *Madrab* sowing (SM₂) and a moderate seed rate (12.0 kg ha⁻¹) optimizes both yield and root quality, supporting sustainable carrot production under semi-arid conditions similar to those in Sudan’s River Nile State. |

*Keywords: Daucus carota, plant density, root yield, seed rate, sowing method.*

1. INTRODUCTION

Carrot (*Daucus carota* L. ssp. sativus), one of the world’s most widely cultivated root vegetables, plays a vital role in human nutrition and global agriculture. It is particularly valued for its sweet-tasting roots, high in dietary fiber, antioxidants, and provitamin A carotenoids—namely β-carotene and α-carotene—which are essential in combating vitamin A deficiency, a significant cause of childhood blindness in many developing countries (Prohens and Nuez, 2008; Van den Berg *et al.*, 2000). In addition to orange cultivars rich in carotenoids, genetic diversity within carrot includes purple, red, yellow, and white types containing other phytochemicals such as anthocyanins and lycopene, with emerging value in both health promotion and natural food coloring (Stolarczyk and Janick, 2011; Alasalvar *et al.*, 2001; Stintzing and Carle, 2004).

Domesticated in Central Asia, particularly in Afghanistan and Iran, carrots have been selectively bred for centuries, evolving from anthocyanin-rich Eastern types into the carotene-rich Western forms predominant in modern markets (Banga, 1957). The global production increasing from 5.8 million tons in 1961 to over 42 million tons by 2022 (FAOSTAT, 2022), the demand for carrots as a fresh-market and processing crop continues to rise, underscoring the need for agronomic improvements that can sustain high yields and root quality under diverse environmental conditions.

While genetic improvements such as hybrid cultivar development have contributed to yield gains in temperate regions (Simon, 2000), yield stagnation remains a persistent challenge in tropical and subtropical zones, including Sudan. In such environments, agronomic constraints often limit crop performance more than genetic potential. Among the most influential agronomic factors are sowing methods and seed rates, which directly affect plant population density, root uniformity, canopy development, and ultimately yield and marketability (Rubatzky *et al.,* 1999; Simon *et al.,* 2008).

Carrot seeds are small and slow to germinate, making stand establishment highly sensitive to sowing strategy. Broadcast sowing can lead to uneven plant spacing and poor resource use efficiency, while line or precision sowing allows for better seed placement, uniform emergence, and ease of intercultural operations such as thinning and weeding (Bose and Som, 1986). Similarly, inappropriate seed rates may lead to overcrowding, causing competition for nutrients and malformed roots, or underutilization of space and lower yields.

Despite these known dynamics, limited research has addressed the combined effects of sowing methods and seed rates on carrot performance under Sudanese conditions. River Nile State, with its expanding horticultural sector, represents an important region for testing context-specific agronomic practices that can boost productivity and resource efficiency. Understanding how these factors interact under local agroecological conditions is essential for formulating recommendations that are both practical and scalable for smallholder farmers.

Therefore the present study was conducted with an objective to evaluate the effect of different sowing methods and seed rates on the growth parameters and root yield of carrot in the River Nile State of Sudan. By identifying optimal agronomic practices suited to local conditions, this research aims to complement genetic advancements, improve marketable yield, and support sustainable intensification of carrot production in the region.

2. material and methods

**2.1 Descriptions of the Study Area**

The experiment was conducted at Hudaiba Research Station, under the Agricultural Research Corporation. The research station is located in River Nile State, northern Sudan, on the eastern bank of the Nile, just south of the Atbara–Nile confluence. The research station located at latitude 17° 34ʹ N, Longitude 33° 56ʹ E, and altitude 350 m above sea level (Alla-Jabow and Mahgoub, 2017). The region has a hot desert climate with most rainfall during July–September. The winter season along the Nile River, including the River Nile State, is characterized by mild, sunny days and cool nights, with daytime temperatures typically ranging from 20°C to 26°C. Nights can be cool, with temperatures dropping to around 8°C to 12°C. Hudaiba Research Station soil is regarded as class 2 with low N, P and organic carbon with alkaline reaction. The soil is clay in texture (with about 4% sand, 40% silt and 56% clay), the soil physical and chemical parameters are presented in Table 1. The station’s strategic river access makes it essential for developing crop varieties and irrigation practices fit for Sudan’s semi‑arid zones.

**Table 1. Physical and chemical properties of the soil at Hudeiba Research Station**

|  |  |
| --- | --- |
| **Particulars** | **Mean value at depth (0-203 ) cm** |
| Sand (% ) | 4.00 |
| Silt (%) | 40.00 |
| Clay (%) | 56.00 |
| Hydraulic conductivity (cm/hr) | 0.13 |
| Moisture content at wilting point (m3 /m3 ) | 25.00 |
| Moisture content at field capacity (m3 /m3 ) | 46.00 |
| Soil bulk density (g/cm3 ) | 1.76 |
| pH | 7.90 |
| Calcium carbonate (%) | 5.40 |
| Total nitrogen (%) | 0.038 |
| Organic carbon (%) | 0.281 |
| Cation exchange capacity (meq/100g soil) | 53.00 |
| Sodium absorption rate | 7.00 |

*(Source: Alla -Jabow and Mahgoub, 2017)*

**2.2 Experimental Design**

A factorial experiment was conducted using a Completely Randomized Block Design (CRBD) with four replications. The study investigated two factors: sowing methods and seed rates. The first factor examined was the sowing method, which had two levels. The first sowing method, referred to as *Sarsaba* (SM₁) , involves planting seeds in a continuous line along the crest of ridges, directly into shallow furrows, with seeds spaced closely together. This sowing method is commonly known among farmers as “*Sarsaba*”. The second sowing method (SM2) which employs a planting ruler with perforation points spaced at 10 cm apart to ensure uniform and consistent seed spacing of 3 cm deep holes are refer to as “*Madrab* (SM2). The carrot seed variety used for this experiment is Royal Chantenay 2, lot No. 10060, which has a minimum germination rate of 85% and was produced in France. The second factor, seed rate, included four levels SR1, SR2, SR3 and SR4 .These represent 3.5, 6.0, 12.0, and 18.0 kgha-1,respectively. These two factors combined to form eight treatment combinations, each replicated four times, resulting in a total of 32 experimental plots. Each plot is 25 square meters, measured as (5 m × 5 m). Plots were randomly assigned within each block and spaced appropriately to minimize edge effects and cross-treatment interference. The experiment was conducted over two growing seasons: 2019–2020 and 2020–2021, with sowing dates on 13 November 2019 and 12 November 2020, respectively.

Land preparation involved plowing and harrowing to create uniform ridges suitable for carrot cultivation. Seeds were sown according to the designated sowing methods and seed rates. Irrigation was applied regularly through surface irrigation to maintain adequate soil moisture throughout the growing season, while fertilization was carried out uniformly across all plots using Urea fertilizer 46% nitrogen by weight, applied at a rate of 120 kg N ha⁻¹. The following parameters were collected: number of plants per square meter, root length (cm), root diameter (cm), yield parameters, including marketable root yield in kilograms per square meter (kg/m²) and total root yield (kg/m²) were measured and recorded at harvest. Marketable yield was defined as the weight of carrot roots that were straight, undamaged, and met commercial size standards. It was expressed in kilograms per square meter (kg/m²).Total yield included the combined biomass of marketable roots and shoot (green top) weight, also expressed in kg/m².

**2.3 Statistical Analysis**

Data collected from both growing seasons were analyzed using Analysis of Variance (ANOVA), suitable for factorial experiments in CRBD as described in Singh and Chaudhary (1985). The statistical analysis and mean comparisons for main effects and interactions between sowing methods and seed rates was evaluated at the 5% probability level using GRAPES online statistical analysis platform by Gopinath *et al*. (2020).

3. results and discussion

The results presented in Table 2 demonstrate significant variations (P = 0.05) in carrot growth and yield traits due to seed rates, sowing methods, and their interactions. The impact of seed rate was particularly evident in parameters such as number of plants per square meter (plant density), total yield and marketable yield, while its influence on root diameter and length was less consistent across the two seasons.

Increasing seed rate from 3.5 to 18.0 kg ha⁻¹ significantly increased the number of plants per square meter in both seasons. Among the seed rates tested, the highest plant population densities were recorded at the 18.0 kg ha⁻¹ level (SR4), reaching 125.5 and 211.75 plants m⁻² in seasons one and two, respectively, which were statistically significant (P ≤ 0.05). The lowest number of plants per square meter was 49.50 and 85.75 plants m⁻², at the lowest seed rate (SR1) in seasons one and two, respectively. This trend was expected, as higher seed rates naturally increase the plant population per unit area. However, this increase was associated with a reduction in root quality parameters such as shorter roots and smaller root diameter, particularly at the highest rate, indicating intra-specific competition. Total root yield and marketable root yield improved with increased seed rates, reaching a maximum of 5.36 and 3.49 kg per square meter, respectively at 18.0 kg ha⁻¹ in season one. The increased number of plants at higher densities in carrot appears to effectively compensate for any individual plant size reduction, leading to a higher overall root yield. These findings aligns with the conclusions of Salter *et al.* (1979), Oliva *et al*. (1988), Taivalmaa and Talvitie (1997), Mengistu and Yamoah (2010),Tegen and Jembere (2021), Muhie and Yimer (2023) who advocate lower seed rate and wider spacing for quality roots. They reported that higher seed rates in carrots led to increased plant density but reduced individual root size due to competition for nutrients and space. In terms of yield performance, SR4 at 18.0 kg ha⁻¹ produced the highest total root yield (5.36 and 4.85 kg m⁻² across the two seasons) and marketable root yield (3.49 and 3.13 kg m⁻²). Nonetheless, these yield increments came at the expense of reduced root quality traits, specifically root diameter and root length, highlighting the trade-off between quantity and quality at excessive seed densities. The moderate seed rate of 12.0 kg ha⁻¹ (SR3) demonstrated a better balance between yield and quality, with respectable marketable yield (3.28 and 3.59 kg m⁻²) and improved root dimensions.

It is important to use sound sowing/planting methods, which control seed placement, spacing, and depth, that lead to seed savings, improved nutrient utilization, and reduced plant competition, ultimately enhancing yield, root quality, and profitability. In contrast, broadcasting offers less control and can result in uneven stands and wasted seeds. Farmers in River Nile State, north of Khartoum, are adopting *Sarsaba* (SM1) and *Madrab* (SM2) sowing methods rather than seed broadcasting. Each method's supporters cite their own experiences, reporting observations for high-yield crops, better management conditions, and higher marketable quality. The results obtained in Table 2, show that the sowing method significantly affects root diameter, root length, and marketable yield, particularly in Season 2. The *Sarsaba* Method (SM1) resulted in larger root diameters (2.28 cm) and longer roots (14.82 cm) compared to the *Madrab* (SM2). Additionally, the *Madrab* method (SM2) led to higher marketable yields (3.52 kg) in Season two, reflecting better plant spacing and reduced competition. Preferences for carrot root diameter and length vary widely and largely depend on the type of consumer. Household consumers typically prefer slender, medium-sized carrot roots, while the food industry often favors longer carrots with a larger diameter. In Sudan, carrots are primarily consumed fresh by households. These results corroborate those of Muhie and Yimer (2023) and Kepka *et al.* (1977), who observed that precision sowing using evenly spaced holes improved carrot root uniformity and marketable yield under similar conditions. The greater uniformity in the *Madrab* (SM2) is likely enabled by more efficient nutrient use and root development, leading to enhanced quality and productivity. Obdiebube *et al.* (2023) corroborate the significantly influence of planting method especially direct seeding on carrot. Taivalmaa and Talvitie (1997) reported the lowest yield for Single rows sown in ridges which much resemble the *Sarsaba* sowing method (SM1).

Interaction effects between seed rate and sowing method (SR × SM) is not significant for most of the traits across the seasons. The only significant observation recorded was the combination of 3.5 kgha-1 (SR1)seed rate and *Sarsaba* method (SR1 × SM1). This combination is giving the highest root length. Seasonal differences were also observed, with Season 2 generally showing higher values for total and marketable yields, possibly due to improved environmental conditions such as better temperature or rainfall distribution as per Figure 1. The results underline the importance of optimizing both seed rate and sowing method to enhance carrot growth and yield. Moderate seed rates (around 12.0 kg ha⁻¹) combined with precise sowing *Madrab* method (SM2) produced the best agronomic performance. These findings are consistent with prior studies and reinforce the need for context-specific recommendations for carrot cultivation under similar agro-ecological conditions.

**Table 2. Mean performance as affected by seed rate, sowing method, and their interaction in carrot across two seasons**

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Source of Variation** | | **Root Diameter (cm)** | | **Root Length (cm)** | | **Number of Plants per (m2)** | | **Total Yield (Kg/m2)** | | **Marketable Root Yield**  **( Kg/m2)** | |
| **Season 1** | **Season 2** | **Season 1** | **Season 2** | **Season**  **1** | **Season**  **2** | **Season**  **1** | **Season**  **2** | **Season**  **1** | **Season**  **2** |
| **Seed Rate**  **(SR)** | **3.5 kgha-1**(**SR1)** | 2.88 | 2.30a | 16.75 | 14.23 | 49.50b | 85.75c | 4.18bc | 4.46 | 2.98ab | 3.19 |
| **6.0 kgha-1 (SR2)** | 2.58 | 2.16a | 16.03 | 13.34 | 70.00b | 161.25b | 3.68c | 4.98 | 2.54b | 3.43 |
| **12.0 kgha-1 (SR3)** | 2.67 | 1.85b | 15.54 | 12.75 | 110.63a | 187.75ab | 4.96ab | 5.46 | 3.28a | 3.59 |
| **18.0 kgha-1 (SR4)** | 2.26 | 2.05ab | 14.69 | 13.88 | 125.50a | 211.75a | 5.36a | 4.85 | 3.49a | 3.13 |
| **Mean** | **2.60** | **2.09** | **15.75** | **13.55** | **88.91** | **161.63** | **4.55** | **4.94** | **3.07** | **3.33** |
|  | ***LSD p =0.5*** | **NS** | **0.27** | **NS** | **NS** | **31.35** | **39.96** | **0.86** | **NS** | **0.66** | **NS** |
| **Sowing Method (SM)** | ***Sarsaba*** (**SM1)** | 2.79 | 2.28a | 16.23 | 14.82a | 99.69 | 148.31 | 4.43 | 4.78 | 2.91 | 3.15b |
| ***Madrab* (SM2)** | 2.40 | 1.91b | 15.27 | 12.28b | 78.13 | 174.94 | 4.66 | 5.10 | 3.23 | 3.52a |
| **Mean** | **2.60** | **2.09** | **15.75** | **13.55** | **88.91** | **161.63** | **4.55** | **4.94** | **3.07** | **3.33** |
| ***LSD p =0.5*** | **NS** | **0.19** | **NS** | **1.14** | **NS** | **NS** | **NS** | **NS** | **NS** | **0.33** |
| **Interaction**  **(SR × SM)** | **SR1 × SM1** | 3.08 | 2.55a | 17.50 | 15.65 | 59.00 | 82.25 | 4.39 | 4.65 | 3.03 | 3.23 |
| **SR1 × SM2** | 2.69 | 2.05c | 16.00 | 12.80 | 40.00 | 89.25 | 3.98 | 4.28 | 2.94 | 3.15 |
| **SR2 × SM1** | 2.70 | 2.18abc | 15.88 | 14.05 | 74.50 | 149.00 | 3.50 | 4.96 | 2.33 | 3.33 |
| **SR2 × SM2** | 2.46 | 2.15bc | 16.18 | 12.63 | 65.50 | 173.50 | 3.86 | 5.00 | 2.75 | 3.54 |
| **SR3 × SM1** | 2.82 | 1.90cd | 16.08 | 13.25 | 125.75 | 186.00 | 4.86 | 4.98 | 3.15 | 3.19 |
| **SR3 × SM2** | 2.53 | 1.80cd | 15.00 | 12.25 | 95.50 | 189.50 | 5.07 | 5.95 | 3.42 | 4.00 |
| **SR4 × SM1** | 2.57 | 2.48ab | 15.48 | 16.33 | 139.50 | 176.00 | 4.98 | 4.53 | 3.14 | 2.85 |
| **SR4 × SM2** | 1.95 | 1.63d | 13.90 | 11.43 | 111.50 | 247.50 | 5.74 | 5.18 | 3.84 | 3.40 |
| **Mean** | **2.60** | **2.09** | **15.75** | **13.55** | **88.91** | **161.63** | **4.55** | **4.94** | **3.07** | **3.33** |
| ***LSD p =0.5*** | **NS** | **0.39** | **NS** | **NS** | **NS** | **NS** | **NS** | **NS** | **NS** | **NS** |

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

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

4. Conclusion

This study demonstrated that both sowing method and seed rate significantly influence the growth and yield of carrot (*Daucus carota* L.) under the agroecological conditions of River Nile State, Sudan. Among the tested treatments, the highest seed rate of 18.0 kg ha⁻¹ (SR4) led to the greatest total and marketable root yields across both seasons. However, this yield increase came at the expense of reduced root length and diameter, highlighting a trade-off between yield quantity and root quality at high plant densities. Conversely, the moderate seed rate of 12.0 kg ha⁻¹ (SR3) provided a more favorable balance between yield and desirable root characteristics, suggesting its suitability for both commercial productivity and market quality.

With respect to sowing methods, the precision-based “*Madrab*” method (SM2) enhanced marketable yield and improved root uniformity, particularly in the second season. This reflects the benefit of controlled seed spacing and depth in minimizing intra-specific competition and maximizing nutrient use efficiency. Although the “*Sarsaba*” method (SM*1*) showed advantages in root diameter and length, it was less consistent in delivering higher marketable yields.

The findings underscore the importance of optimizing both seed rate and sowing technique for carrot cultivation in semi-arid, irrigated environments. Specifically, the combination of the *Madrab* sowing method and a seed rate of 12.0 kg ha⁻¹ is recommended for achieving a favorable compromise between yield volume and marketable root quality. These recommendations provide practical value for extension services and farmers seeking to improve carrot production efficiency in similar agro-climatic zones of Sudan.

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.

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, proof-reading, 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.

References

Alasalvar, C., Grigor, J. M., Zhang, D., Quantick, P. C., and Shahidi, F. (2001). Comparison of volatiles, phenolics, sugars, antioxidant vitamins and sensory quality of different colored carrot varieties. *Journal of Agricultural and Food Chemistry*, *49*(3), 1410–1416. <https://doi.org/10.1021/jf000595h>.

Alla-Jabow M. K., and Mahgoub Z. B. (2017). Crop Water Productivity and Crop Coefficients of Lentil (*Lens Culinaris* M.) Under Different Irrigation Regimes. *U. of K. J. Agric. Sci. 25*(1), 1- 19.

Banga, O. (1957). Origin of the European cultivated carrot. *Euphytica,* *6*(1), 54–63. https://doi.org/10.1007/BF00027657

Bose, T.K., and Som, G.M. (1986) Vegetable Crops in India. Naya Prokash, Calcatta, India, 567-569.

FAOSTAT 2022. World Food and Agriculture – Statistical Yearbook 2022. Rome. <https://doi.org/10.4060/cc2211en>

Gopinath, P. P., Parsad, R., Joseph, B., Adarsh, V. S. (2020). GRAPES: General Rshiny Based Analysis Platform Empowered by Statistics. https://www.kaugrapes.com/home. Version 1.0.0. <https://doi.org/10.5281/zenodo>. 4923220

Kepka, A., Umiecka, L., and Fajkowska, H. (1977). The influence of row spacing and plant density in rows on the yield of carrots and root quality. In *Symposium on the Timing of Field Vegetable Production 72* (pp. 217-224).

Mengistu, T., and Yamoah, C. (2010). Effect of sowing date and planting density on seed production of carrot (*Daucus carota* var. sativa) in Ethiopia. *African Journal of Plant Science*, *4*(8), 270-279.‏

Muhie, S. H., and Yimer, H. S. (2023). Growth and yield performance of carrot (*Daucus carota* L.) as influenced by plant population density under irrigation conditions. *Advances in Horticultural Science*, *37*(3), 307–315. <https://doi.org/10.36253/ahsc-14158>

Obdiebube, E. A., Okolie, H., Obasi, C., Ndukwe, O. O., Muojiama, S., Eche, P., and Umeh, O. A. (2023, March). Effect of Planting Methods on the Growth and Yield of Carrot (*Daucus carota* L) in Humid Tropical Zone. In *e-Proceedings of the Faculty of Agriculture International Conference* (pp. 84-90).

Oliva, R. N., Tissaoui, T., and Bradford, K. J. (1988). Relationships of Plant Density and Harvest Index to Seed Yield and Quality in Carrot. *Journal of the American Society for Horticultural Science*, *113*(4), 532-537. [https://www.doi.org/10.21273/ JASHS.113.4.532](https://www.doi.org/10.21273/%20JASHS.113.4.532)

Prohens, J., and Nuez, F. (Eds.). (2008). Vegetables II: Fabaceae, Liliaceae, Solanaceae, and Umbelliferae (Vol. 2). Springer. https://doi.org/10.1007/978-0-387-74110-9

Rubatzky, V. E., Quiros, C. F., and Simon, P. W. (1999). Carrots and related vegetables Umbelliferae. CABI Publishing. https://www.cabidigitallibrary.org/ doi/full/10.5555/ 19990309628

Salter, P. J., Currah, I. E., and Fellows, J. R. (1979). The effects of plant density, spatial arrangement and time of harvest on yield and root size in carrots. *The Journal of Agricultural Science*, *93*(2), 431-440.

Simon, P. W. (2000). Domestication, historical development, and modern breeding of carrot. *Plant breeding reviews*, 157-190.

Simon, P. W., Freeman, R. E., Vieira, J. V., Boiteux, L. S., Briard, M., Nothnagel, T., ... and Kwon, Y. S. (2008). Carrot. In Vegetables II: Fabaceae, Liliaceae, Solanaceae, and Umbelliferae (pp. 327-357). New York, NY: Springer New York.

Singh, R.K. and Chaudhary, B.D. (1985) Biometrical Method in Quantitative Genetics Analysis. Kalyani Publishers, New Delhi.

Stintzing, F. C., and Carle, R. (2004). Functional properties of anthocyanins and betalains in plants, food, and in human nutrition. *Trends in Food Science and Technology*, *15*(1), 19–38. https://doi.org/10.1016/j.tifs.2003.07.004

Stolarczyk, J., and Janick, J. (2011). Carrot: History and iconography. *Chronica Horticulturae*, *51*(2), 13–18. <https://www.actahort.org/chronica/pdf/ch5102.pdf#page=13>

Taivalmaa, S. L., and Talvitie, H. (1997). The effects of ridging, row-spacing and seeding rate on carrot yield. *Agricultural and Food Science*, *6*(5-6), 363-369.

Tegen, H., and Jembere, M. (2021). Influences of spacing on yield and root size of carrot (*Daucus carota* L.) under ridge-furrow production. *Open Agriculture*, *6*(1), 826-835.

Van den Berg, H., Faulks, R., Granado, H., Hirschberg, J., Olmedilla, B., Sandmann, G., Southon, S., and Stahl, W. (2000). The potential for the improvement of carotenoid levels in foods and the likely systemic effects. *Journal of the Science of Food and Agriculture*, *80*(7), 880–912.