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RESEARCH ARTICLE

Effect of pre-sowing treatments on germination, growth and yield of carrot (*Daucus carota* L.) in a forest-savanna transition Zone of Edo State, Nigeria

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ABSTRACT

A field experiment was conducted at the Crop Unit, Teaching and Research Farm, Faculty of Agriculture, Ambrose Alli University, Ekpoma, to evaluate the effects of pre-sowing treatments on carrot germination, growth, and yield. The treatments involved two varieties (Touchun and Nantes) and four pre-sowing treatments: no priming (control), Hydro, Hallo, and Sand Matric Priming, resulting in eight treatment combinations. The experiment was arranged in a 2 x 4 factorial design within a Randomized Complete Block Design (RCBD), replicated three times. Data collected included germination percentage, plant height, number of leaves/plants, total leaf area/plant, stem girth, root length, root diameter, and root yield. Analysis of variance (ANOVA) at a 5% significance level was used to analyze the data, with mean separation by Duncan's Multiple Range Test. The results showed that pre-sowing treatment significantly ($P \le 0.05$) reduced seed germination time, with Hydro-treated seeds emerging 50% earlier than untreated seeds. Nantes variety germinated earlier than Touchun. While the variety had no significant effect on growth parameters, Touchun produced taller plants with thicker stems. Pre-sowing treatment influenced plant height and total leaf area, with Sand Matric Priming resulting in taller plants and thicker stems. However, pre-sowing treatments did not significantly affect root yield. Touchun treated with Hydro and Hallo is recommended for early germination and improved root production in this locality.

Keywords: carrot, germination, growth, pre sowing treatment, yield

INTRODUCTION

Carrot (*Daucus carota* L.), 2n = 18, is a highly nutritious cool-season root vegetable, classified as a biennial species and belonging to the family Umbelliferae (Sita et al., 2017). The genus *Daucus*, to which carrot belongs, is one of the largest genera in the Umbelliferae family, with over 25 species (Zhang et al., 2018). Carrots are a rich source of beta-carotene and are among the top 10 vegetable crops worldwide in terms of production area and market value (Zhang et al., 2018). Carrot originated in South Asia, in regions now known as Afghanistan, Iran, and Pakistan (Singh et al., 2016). Carrot production continues to rise globally, including widespread cultivation in Africa, particularly in Nigeria, where it is primarily grown in the northern regions, such as Zaria, Sokoto, Kano, and Jos (FAOSTAT, 2019).

Carrots thrive in cool weather and require optimal climate and soil conditions for good flavor development. They are known for slow germination, which can be further delayed at low temperatures. Consequently, pre-sowing treatments are often necessary to enhance seed germination and reduce the lag time between sowing and seedling emergence. These treatments ensure uniform germination and healthy plant stands (Jabran et al., 2018).

Pre-sowing treatments, such as seed priming, have become important techniques for improving seed germination under abiotic stress conditions, due to their low cost and simplicity (Puthur, 2018). Seed priming involves controlled hydration in solutions containing organic or inorganic substances, which prevents premature radical emergence and prepares the seeds for better performance once sown (Bajpai et al., 2017). Recent research has shown that seed priming can improve seedling growth, particularly under sub-optimal conditions, and promote better seedling establishment (Han et al., 2017).

Hydro-priming, halo-priming, and sand matric priming have all shown positive effects on seed germination and plant growth (Khan et al., 2016; Alam et al., 2019). Hydro-priming, for example, involves soaking seeds in water, which enhances seedling vigor and reduces the time to emergence (Mahmoodi et al., 2018). Halo-priming, which involves soaking seeds in inorganic salts like NaCl and KNO3, has been shown to improve seedling vigor and establishment, especially in soils affected by salinity (Khan et al., 2016). Similarly, sand matrix priming accelerates seed germination in cold soil conditions, making it useful for carrot production (Mereddy, 2015).

Seedling establishment is crucial for successful crop production, as it ensures proper plant density and, consequently, higher yield per hectare. Poor seed germination can lead to gaps in crop canopies, allowing weeds to compete with crops for resources such as light, water, and nutrients (Mureithi et al., 2016). Therefore, understanding and implementing the best pre-sowing methods for carrot cultivation is essential for achieving optimal germination, growth, and performance.

MATERIALS AND METHODS

Sources of Planting Materials

Two varieties of carrot: Touchun and Nantes used for this study were obtained from the National Institute for Horticultural Research and Training (NIHORT).

Experimental Location

The field experiment was carried out during the 2023 cropping season at the Teaching and Research Farm, Faculty of Agriculture, Ambrose Alli University, Ekpoma (latitude $6^{o}45'$N and longtitude $6^{0}09'$E) with an altitude of approximately 370m above the sea level. The annual rainfall is approximately 1200mm to 1500mm and a mean temperature of 30.5^{0}C. Ekpoma experiences relative humidity of about 75% (Siloko and Siloko, 2023).

Land Preparation

Land preparation involved clearing of the experimental plot, removal of debris, field layout and demarcation into plots. Individual plots were 3 m x 2 m, with spacing of 1m and 1.5 m between adjacent plots within and between replicates, respectively. The entire experimental plot was 16m x 24m to give a total land area of $384m^2$ (0.01ha).

Experimental Designs and Layout

Each of the two varieties of carrot, Touchon and Nantes, was subjected to four (4) pre-sowing treatments thus: No priming (control), Hydro priming, Hallo priming and Sand matric priming in a 2x4 factorial scheme fitted into a Randomized Complete Block Design (RCBD). There were thus, eight (8) treatment combinations replicated three times giving 24 plots.

Planting Time

Planting took place on 29th May, 2023. Three seeds each of the two carrot varieties were sown per hole on prepared beds at Spacing of 50cm x 25cm inter- and intra-row. Thinning to one plant per stand was effected at three weeks after planting. Thus, giving an equivalent population density of 80,000 plants/ha. Weeds were controlled manually with hoe at 3, 5 and 7 weeks after planting. Subsequent weeding, when necessary, was done by roughing.

Data Collection and Analysis

Data were collected on both vegetative and reproductive growth traits. The vegetative traits included seedling emergence (germination percentage), plant height (cm), number of leaves per plant, leaf area per plant (cm^2), and stem girth (cm). Reproductive traits were monitored at harvest and included yield components and yield (t/ha).

Data Analysis

The collected data were subjected to statistical analysis using Analysis of Variance (ANOVA) to determine the effects of different pre-sowing treatments and carrot varieties on the various growth and yield parameters. A 2 x 4 factorial design was used, with the two varieties (Touchun and Nantes) and four pre-sowing treatments (No priming, Hydro-priming, Halo-priming, and Sand Matric Priming) as the factors. The experiment was laid out in a Randomized Complete Block Design (RCBD) with three replications.

ANOVA was performed at a 5% significance level to assess the main effects and interactions of the varieties and pre-sowing treatments.Duncan's Multiple Range Test (DMRT) was used for mean separation to identify significant differences between the treatment combinations. Genstat 12th Edition (VSN International, 2009) software was used for the statistical analysis of the data.The assumptions of normality and homogeneity of variance were tested before the analysis. When significant differences were found, mean values were separated using Duncan's Multiple Range Test (DMRT). All data were analyzed for both vegetative growth and yield parameters to assess the effects of the treatments on carrot growth and productivity.

RESULTS AND DISCUSSION

The findings indicate that varietal differences did not significantly influence the time to 50% germination, suggesting that inherent genetic variation between Nantes and Touchon may not be a major determinant of early germination under the tested conditions. This aligns with previous studies reporting that varietal effects on germination are often less pronounced compared to pre-sowing treatments (Alam et al., 2019; Jabran et al., 2018). Although insignificant, Nantes attained 50% germination approximately two days earlier than Touchon, which may reflect subtle physiological differences in seed vigor (Singh et al., 2016).

Pre-sowing treatments, however, had a clear impact on germination dynamics. Hydro-priming delayed germination substantially (11 days compared to 15 days in the control), consistent with reports that excessive hydration can sometimes reduce seed vigor under certain conditions (Mahmoodi et al., 2018). In contrast, sand matric priming and halo-priming showed moderate delays (4–5 days), but their interaction with variety produced variable outcomes. For instance, Nantes seeds treated with sand matric priming reached 50% germination in about 12 days, whereas Touchon under the same treatment required nearly 29 days. This variability highlights the importance of genotype × treatment interactions, as documented in earlier work on carrot and other crops (Mereddy, 2015)

Interestingly, untreated seeds of both varieties reached 50% germination in about 15 days, which was comparable to or slightly later than some priming treatments. This suggests that while priming can accelerate emergence under certain conditions, its effectiveness is not universal and may depend on both the crop variety and environmental context (Bajpai et al., 2017; Zhang et al., 2018). The observed delays with hydro-priming reinforce the need for optimizing treatment duration and intensity to avoid detrimental effects (Table1).

Table 1. Effect of Pre-Sowing Treatment on Days to 50% Germination of Carrot

Treatments	Days to 50% germination
Touchun	20.9
Nantes	19.1
SEM±	3.1^{ns}
Pre-sowing treatment	
Control	25.8^{a}

Distilled water	15.2^{b}
Hallo treatment	18.7^{ab}
Sand matric priming	20.3^{ab}
SEM±	3.9*
Variety x Pre-sowing treatment	
Touchun X 0	26.0^{a}
Touchun X H2O	15.3^{b}
Touchun x NaCl	13.3^{b}
Touchun x SMP	29.0^{a}
Nantes X 0	25.7^{a}
Nantes X H2O	15.0^{b}
Nantes x NaCl	24.0^{a}
Nantes x SMP	11.7^{b}
SEM±	3.2*

Values with same letter(s) in columns are not significantly different using Duncan's New Multiple Range Test at 5% level of probability; v: Variety; PST: Pre-sowing treatment; ns: not significant; SEM: Standard error of means;

Plant height (cm)

Sand matric priming as a pre-sowing treatment produced the tallest carrot seedlings (36.9cm) which though comparable with the other pre-sowing treatments, significantly ($P \leq 0.05$) increased the control plants. The control plants which were shortest, were comparable with the Hydro and Hallo treated plants (Table 2).

Table 2. Effect of Pre-Sowing Treatment on the Plant Height (cm) of Two Varieties of Carrot

Treatments	Weeks after planting (WAP)		
	5	7	9
Touchun	6.53	16.9	32.3
Nantes	7.69	16.43	31.4
SEM±	0.62ns	1.58ns	3.25ns
Pre-sowing treatment			
Control	6.93	18.17	25.76^{b}
Distilled water	6.85	17.23	31.17^{ab}
Hallo treatment	6.68	16.68	33.72^{ab}
Sand matric priming	7.98	14.57	36.88^{a}
SEM±	0.95ns	2.19ns	4.03*
Variety x Pre-sowing Treatment			
Touchun X 0	6.57^{b}	18.50	26.30^{ab}
Touchun X H2O	6.50^{b}	19.13	31.10^{ab}
Touchun x NaCl	7.03^{b}	17.87	38.00^{ab}
Touchun x SMP	6.03^{b}	12.10	33.87^{ab}
Nantes X 0	7.30^{b}	17.83	25.22^{b}
Nantes X H2O	7.20^{b}	15.33	31.23^{ab}
Nantes x NaCl	6.33^{b}	15.50	29.43^{ab}

Nante x SMP s x SMP	9.93^{a}	17.03	39.90^{a}
SEM±	1.05*	3.02ns	5.81*

Values with same letter(s) in columns are not significantly different using Duncan's New Multiple Range Test at 5% level of probability; v: Variety; PST: Pre-sowing treatment; ns: not significant; SEM: Standard error of means.

Table 3. Effect of Pre-sowing treatment on the number of leaves/plants of two varieties of carrot

Treatments	Weeks after planting (WAP)		
	5	7	9
Touchun	3.97	6.24	10.17
Nantes	4.55	6.86	11.12
SEM±	0.30ns	0.41ns	0.84ns
Pre-sowing treatment			
Control	3.6^{b}	6.15^{b}	9.90
Distilled water	4.2^{ab}	6.05^{b}	10.43
Hallo treatment	4.833^{a}	7.483^{a}	11.28
Sand Matric Priming	4.4^{ab}	6.517^{ab}	10.95
SEM±	0.39*	0.52*	1.25ns
Variety x Pre-sowing treatment			
Touchun X 0	3.2^{b}	6.3^{ab}	9.53
Touchun X H2O	3.533^{b}	5.667^{b}	9.43
Touchun x NaCl	5^{a}	7.2^{ab}	12.13
Touchun x SMP	4.133^{ab}	5.8^{b}	9.57
Nantes X 0	4^{ab}	6^{b}	10.27
Nantes X H2O	4.867^{a}	6.433^{ab}	11.43
Nantes x NaCl	4.667^{a}	7.767^{a}	10.43
Nantes x SMP	4.667^{a}	7.233^{ab}	12.33
SEM±	0.43*	0.70ns	1.71ns

Values with same letter(s) in columns are not significantly different using Duncan's New Multiple Range Test at 5% level of probability; v: Variety; PST: Pre-sowing treatment; ns: not significant; SEM: Standard error of means;

Total leaf area/plant (cm^2)

The results presented in Table 4 show that leaf area per plant increased progressively from 5 to 9 weeks after sowing (WAS). Variety did not significantly influence leaf area at any sampling period, confirming earlier reports that varietal differences in carrot growth are often less pronounced compared to seed treatment effects (Alam et al., 2019). Nevertheless, Nantes consistently exhibited slightly higher leaf area values than Touchon across all sampling periods, suggesting a modest varietal advantage in vegetative growth (Sita et al., 2017).

Pre-sowing treatments significantly ($P \leq 0.05$) affected leaf area at 9WAS, with Hallo priming producing the greatest increase (105.6%), followed by hydro-priming (57.5%) and sand matric priming (57.0%). These findings are consistent with previous studies showing that priming enhances seedling vigor and leaf expansion by improving water uptake and metabolic activation (Bajpai, Pandey, & Singh, 2017; Mahmoodi, Ranjbar, & Khalil, 2018). The ranking of treatment effectiveness (Hallo ≥ Hydro ≥ Sand matric priming) suggests that osmotic regulation through halo-priming may provide more sustained benefits for leaf development compared to hydro- or sand matric priming (Khan et al., 2016).

The interaction between variety and pre-sowing treatment was significant at 5, 7, and 9WAS, highlighting the importance of genotype × treatment effects. For example, Nantes treated with sand matric priming produced the highest leaf area (36.8 cm^2 at 5WAS), whereas untreated Nantes plants had the lowest (11.9 cm^2). Similarly, Touchon plants showed substantial increases in leaf area when treated: 49.0% with hydro-priming, 176.4% with halo-priming, and 61.8% with sand matric priming. These results underscore the variability in treatment response across varieties, echoing findings by Mereddy (2015) that priming effects are strongly influenced by seed genotype and environmental conditions.

Overall, the study demonstrates that while varietal differences in carrot leaf area are minor, pre-sowing treatments significantly enhance vegetative growth, particularly at later stages. The strong interaction effects suggest that priming strategies should be tailored to specific carrot varieties to maximize leaf area development and, ultimately, crop productivity (Puthur, 2018; Zhang, et al., 2018).

Table 4. Effect of Pre-Sowing Treatment on the Leaf Area (cm^2)/Plant of Two Varieties of Carrot

Treatment	Weeks after planting (WAP)		
	5	7	9
Touchun	19.10	172.00	114.3
Nantes	20.80	182.00	121.9
SEM±	4.64ns	27.10ns	293.90ns
Pre-sowing treatment			
Control	16.32	177.90	762^{b}
Distilled Water	16.85	197.10	120.0^{ab}
Hallo Treatment	17.23	184.40	156.7^{a}
Sand Matric Priming	29.38	147.40	119.6^{ab}
SEM±	5.91ns	38.70ns	304.00*
Variety x Pre-sowing Treatment			
Touchun X 0	20.73^{ab}	192.20	665^{b}
Touchun X H_2O	12.43^{b}	223.80	991^{ab}
Touchun x NaCl	21.13^{ab}	171.50	183.8^{a}
Touchun x SMP	22.00^{ab}	99.60	107.6^{ab}
Nantes X 0	11.90^{b}	163.70	858^{ab}
Nantes X H_2O	21.27^{ab}	170.30	140.8^{ab}
Nantes x NaCl	13.33^{b}	197.40	129.5^{ab}
Nantes x SMP	36.77^{a}	195.20	131.6^{ab}
SEM±	7.65*	53.70ns	444.40*

Values with same letter(s) in columns are not significantly different using Duncan's New Multiple Range Test at 5% level of probability; v: Variety; PST: Pre-sowing treatment; ns: not significant; SEM: Standard error of means.

Stem girth (cm)

The stem girth of both varieties increased over time from 5WAS to 9WAS. Pre-sowing treatment had no significant ($P \geq 0.05$) effect on the stem girth (cm) of the two carrot varieties throughout the period of sampling. (Table 5) Similarly, there was no varietal effect on the stem girth (cm) of the carrot plants. None was significant ($P \geq 0.05$) variety × priming treatment interaction on the stem girth (cm) of the two varieties of carrot from 5-9 WAS. At 9WAS, the stem girth (cm) of carrot varied from 4.20cm to 5.43cm in Touchun pre-sown treated with Hydro and Hallo, respectively. Across the three major variety factors: pre-sown treatments, and interactions between variety and pre-sowing priming (Table 5).

Table 5. Effect of Pre-Sowing Treatment on the Stem Girth (cm) of Two Varieties of Carrot

Treatment	Weeks after planting (WAP)		
	5	7	9
Touchun	3.2[a]	4.49[a]	4.79[a]
Nantes	2.87[b]	4.27[a]	4.6[a]
SEM±	0.22ns	0.27ns	0.39ns
Pre-sowing treatment			
Control	3.05[ab]	4.42[a]	4.47[a]
Distilled Water	3.25[a]	4.35[a]	4.42[a]
Hallo Treatment	2.95[b]	4.52[a]	4.87[a]
Sand Matric Priming	2.90[b]	4.25[a]	5.03[a]
SEM±	0.33ns	0.41ns	0.56ns
Variety x Pre-sowing Treatment			
Touchun X 0	3.50[a]	4.97[a]	4.67[a]
Touchun X H_2O	3.07[ab]	4.17[ab]	4.20[ab]
Touchun x NaCl	3.27[a]	4.97[a]	5.43[a]
Touchun x SMP	2.97[ab]	3.87[b]	4.87[a]
Nantes X 0	2.60[b]	3.87[b]	4.27[a]
Nantes X H_2O	3.43[a]	4.53[a]	4.63[a]
Nantes x NaCl	2.63[b]	4.07[b]	4.30[a]
Nantes x SMP	2.83[ab]	4.63[a]	5.20[a]
SEM±	0.43ns	0.48ns	0.82ns

Values with same letter(s) in columns are not significantly different using Duncan's New Multiple Range Test at 5% level of probability; v: Variety; PST: pre-sowing treatment; ns: not significant; SEM: standard error of means.

Components of yield and yield (t/ha)

Root length (cm)

Root length was not significantly affected by either variety or pre-sowing treatment alone. However, the interaction between variety and pre-sowing treatment significantly influenced root length (Table 6). Touchon roots were marginally longer than Nantes, with about a 1 cm difference. Untreated plants and those subjected to halo-priming or sand matric priming averaged approximately 6 cm in root length, while hydro-primed plants produced slightly longer roots (about 7 cm). These findings suggest that hydro-priming may enhance root elongation, consistent with earlier reports that hydration-based priming can stimulate early root growth by improving water uptake and metabolic activity (Mahmoodi et al., 2018).

Root diameter (cm)

No significant differences were observed in root diameter between the two carrot varieties, nor was there a significant interaction between variety and pre-sowing treatment (Table 6). Pre-sowing treatments did not significantly ($P \geq 0.05$) affect root diameter. The control, hydro-priming, and sand matric priming treatments produced comparable root diameters, all slightly lower than halo-priming, which yielded the broadest roots. This outcome aligns with previous studies suggesting that osmotic priming can enhance root thickness by improving nutrient mobilization and cell expansion (Khan et al., 2016).

Root yield

Pre-sowing treatments did not significantly ($P \geq 0.05$) affect overall root yield, nor was there a significant variety × treatment interaction (Table 6). Touchon produced slightly higher yields (7.64 t/ha) compared to

Nantes (7.03 t/ha). The control, hydro-priming, and sand matric priming treatments resulted in comparable yields, all significantly lower than halo-priming, which produced the highest yield (8.27 t/ha). This finding supports earlier work showing that halo-priming can improve crop yield under stress conditions by enhancing seedling vigor and resource allocation (Alam et al., 2019).

Table 6. Effect of Pre-Sowing treatment on the Components of yield and yield of carrot

Treatments	Root length (cm)	Root diameter (cm)	Root yield t/ha
Touchun	6.56	4.61	7.64
Nantes	5.95	4.88	7.03
SEM±	0.28ns	0.28ns	1.20ns
Pre-sowing treatment			
Control	5.90	4.53	6.52
Distilled Water	6.57	4.87	6.78
Hallo Treatment	6.25	4.95	8.27
Sand Matric Priming	6.31	4.62	7.78
SEM±	0.44ns	0.42ns	1.74ns
Variety x Pre-sowing Treatment			
Touchun X 0	6.53[ab]	4.87	8.17
Touchun X H2O	6.53[ab]	4.83	7.63
Touchun x NaCl	6.47[ab]	4.70	8.13
Touchun x SMP	6.72[a]	4.03	6.63
Nantes X 0	5.27[b]	4.20	4.87
Nantes X H2O	6.60[ab]	4.90	5.93
Nantes x NaCl	6.03[ab]	5.20	8.40
Nantes x SMP	5.90[ab]	5.20	8.93
SEM±	0.56*	0.55ns	2.53ns

Values with same letter(s) in columns are not significantly different using Duncan's New Multiple Range Test at 5% level of probability; v: Variety; PST: Pre-sowing treatment; ns: not significant; SEM: Standard error of means.

CONCLUSION

The results of this study showed that pre-sowing treatments significantly reduced the germination period. Seeds that received the Hydro treatment emerged 50% earlier than those in the other treatment and were significantly taller than untreated plants. The variety planted did not affect carrot vegetative parameters. Touchun had a thicker, taller stem than Nantes. Although Nantes varieties had slightly higher leaf number/plant and total leaf area/plant, they had comparable foliage formation to the Touchun variety. Nantes carrot treated with Sand matric priming produced the tallest plants, while Touchun carrot treated with Hallo produced the thickest stem, indicating a strong interaction between varieties × pre-sowing priming treatment on vegetative characters. Hallo, pre-sown treated carrots produced the highest number of leaves/plant and total leaf area/plant, while the untreated pre-sown seeds produced plants with the least number of leaves and total leaf area. The pre-sowing treatment applied did not show a significant effect on the root yield and yield components of the two carrot varieties. In the control crops, Touchun had a slight yield advantage over Nantes. Nantes seeds pre-sown with sand matrix priming had a higher yield (8.93 tons/ha), while the control, untreated Nantes seeds, produced the least yield (4.87 tons/ha). The yield obtained from treatment with Sand matric priming on Nantes was 83.4% higher than that of others and was therefore recommended.

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AUTHORS CONTRIBUTION

All the authors contributed equally to this work. All authors read and approved the final manuscript.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

Not Applicable

CONSENT FOR PUBLICATION

Not Applicable

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AVAILABILITY OF DATA AND MATERIALS

All datasets analyzed and described during the present study are available from the corresponding author upon reasonable request.

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