Go Deep: How Saw Palmetto Seed Sowing Depth Influences Germination and Seedling Growth

Vânia M. Pereira[1], Thiago Souza Campos[1,2], Patricia Ramalho de Barros[3], Jena Osmani[1], Nancy Bissett[4], Wagner Vendrame[1], and Héctor E. Pérez[1]

Keywords. germination, nursery production, palm seed, seedling quality, seedling growth, sowing depth

Abstract. Saw palmetto is a palm of high ornamental and land restoration value with the potential for commercial production as a result of its phytotherapeutic properties. It is native to the southeastern United States, where green- and silver-leaved forms are found. Nursery production of saw palmetto is based on seed germination. However, seed germination is slow and uneven. Based on communications with nursery growers, deeper seed placement in the substrate yields taller seedlings at marketable size in a shorter period. We investigated the influence of sowing seed depths (1, 2, 4, 6, and 8 cm) on the germination and seedling growth of silver and green forms of saw palmetto. Green saw palmetto seeds germinated 60 days earlier than silver saw palmetto seeds, although final germination percentages were similar (84% and 82%, respectively). Sowing depth influenced significantly the required seed rate overage, with shallow depths (1 cm) necessitating a 30% to 45% increase in seed quantity to compensate for reduced seedling production, whereas sowing at 4 cm reduced overage to 5% to 6%, optimizing seed use and reducing costs. Differences in growth parameters 1 year after sowing were statistically significant for 1-year-old seedlings, with silver plants performing better than green ones. Major differences occurred between the 1- and 8-cm sowing depths with regard to seedling and root length. Plants from seeds sown at 8 cm showed increased plant height and width, and reduced root length compared with those sown at 1 cm. Vigor indices of plants from deeper sowing (2, 4, 6, and 8 cm) were higher than those sown at 1 cm. We conclude that green saw palmetto seeds germinated earlier than silver, but final germination percentages were similar. In addition, sowing at 4 cm optimized seed use and costs, whereas deeper sowing improved plant vigor and growth but reduced root length.

Received for publication 12 Apr 2025. Accepted for publication 23 May 2025.

Published online 5 Aug 2025.

[1]Department of Environmental Horticulture, IFAS, University of Florida, 2550 Hull Road, Room 1529, Gainesville, FL 32611, USA

[2]Department of Agricultural Sciences, Unesp, Via de Acesso Prof. Paulo Donato Castelane, S/N, Vila Industrial, Jaboticabal, SP 14884-900, Brazil

[3]Department of Plant Science and Landscape Architecture, College of Agriculture and Natural Resources, University of Maryland, Plant Sciences Building, 4291 Fieldhouse Dr, College Park, MD 20742, USA

[4]The Natives Inc., 1617 Champagne Road, Davenport, FL 33837, USA

This research was made possible through the support of Indena, Milan, Italy. The financier had no role in the conceptualization of the study or the drafting of this manuscript. The US Department of Agriculture National Institute of Food and Agriculture has also provided support for this study under Hatch project 7001563. Special recognition is due to Joanna Tucker Lima from Montgomery Botanical Center, Coral Gables, FL and Michael and Myron Huffman for providing seed material.

V.M.P. is the corresponding author. E-mail: vmp.pereira@outlook.com.

https://doi.org/10.21273/HORTTECH05671-25

Saw palmetto [*Serenoa repens* (W. Bartram) Small] is a small, shrublike, rhizomatous palm that occurs in the southeastern United States. The saw palmetto range covers the entire state of Florida and extends from southeastern Louisiana to southern South Carolina, USA (Dransfield et al. 2008; Hilmon 1968). Saw palmetto is distributed throughout coastal areas, pinelands, hammocks, and prairies (Fisher and Tomlinson 1973; Hilmon 1968; Orzell et al. 2024). The species exist in two forms: silver and green. The silver form, native to eastern coastal Florida scrub habitats, features a glaucous layer on the leafblades that gives it a blue-green or silver appearance and a typically more compact structure (Dransfield et al. 2008; Essig et al. 2000; Pereira et al. 2025; Moldenke 1967). In contrast, the green form, found throughout inland Florida and southeastern states, has brighter green leaves, a taller and more open growth habit, and tends to grow more vigorously than silver (Pereira et al. 2025).

Saw palmetto is an essential plant for Florida, USA, fauna. It is used as a food source or cover by more than 200 species of wildlife (Maehr and Layne 1996). Moreover, 300 insect species have been recorded to visit saw palmetto inflorescences (Deyrup and Deyrup 2012). In addition to its food source value, saw palmetto also provides fiber, oil, medicinal properties, wax, roof thatch, and high-grade honey (Bennett and Hicklin 1998). The landscape use of saw palmetto started around the 1970s as a result of its high adaptability to different conditions and the wide variability in its growth patterns (Smith 1972). Saw palmetto has a high tolerance for varying soil alkalinity, drought, and salinity. Furthermore, saw palmetto is highly sought to provide great textures for landscapes and is often used in mass plantings under tree canopies or as a border accent. However, transplanting saw palmettos from natural habitats into landscapes is challenging, and post-transplant survival rates are typically low. As a result, it is often recommended to plant nursery-grown seedlings at twice the desired final density to account for expected losses. Once established, however, saw palmetto plants do not require maintenance (Pereira et al. 2025).

Because of the increased ornamental importance of saw palmetto and low transplant recovery, successful nursery propagation techniques are essential to meet demand. Nursery production of saw palmetto relies on seed germination. However, saw palmetto tends to have low and uneven germination and slow seedling growth (Pereira et al. 2025). Studies on how physical and chemical treatments affect saw palmetto seed germination have varying results (Carpenter 1986, 1987; Makus 2006). For example, a 7-d presowing soaking period combined with high-temperature incubation increased germination percentages and speed. The optimum temperature for germination was 35 °C. Differing results have been found after soaking seeds in gibberellic acid (GA). For example, 1000 ppm GA_3 applied to seeds for 24 h did not increase total germination, or reduced days to achieve median germination time. However, when seeds are exposed to 10,000 ppm

$GA_{4,7}$ for 24 h, the percentage and speed of germination increased (Carpenter 1986; Makus 2006). As a fire-adapted species, treatments that expose seeds to smoke have also been evaluated but have not demonstrated benefits for seed germination (Lindon and Menges 2008). In contrast, seeds passing through the digestive system of Florida box turtles had an increase in final germination percentage and germination rate (Liu et al. 2004).

Besides temperature and presowing treatments, sowing depth also plays an important role in palm seed germination. Seeds of *Copernicia berteroana* (Becc.) sown at 1.27 cm displayed the highest germination percentage (79.5%), and an increase in leaf emergence and seedling survival when compared with surface-sown seeds (Murphy et al. 2016). Similarly, seed depth affected germination of *Chrysalidocarpus lutescens.* However, germination varied according to the environmental conditions, as embryo desiccation is a major cause of germination failure. For instance, Broschat and Donselman (1986) suggested placing seeds deeper in the soil because moisture levels are retained at greater depths. Moreover, larger seeds, such as palm seeds, have a smaller surface-to-volume ratio and greater water requirements. Consequently, larger seeds tend to take longer to become fully imbibed (Norden et al. 2009). A common recommendation for sowing palm seeds is to use the diameter of the seed as the sowing depth (Meerow and Broschat 2021).

A frequent practice by Florida, USA, nursery growers is to sow saw palmetto seeds deeper in the substrate, claiming that plants grown from seeds that were sown deep in the substrate will have greater foliar area and achieve marketable size in a shorter amount of time (Bissett N, personal communication). To our knowledge, this practice has not been investigated. Thus, in our study, we evaluate the effect of sowing depths on seed germination and seedling growth 1 year after sowing.

Materials and methods

Seed collection and cleaning. Fruit of silver saw palmetto were collected in Oct 2021 from a population in Gainesville, North Florida, USA (lat. 29.6148°N, long. 82.3767°W); and fruit from the green form were collected in Felda, South Florida, USA (lat. 26.5414°N, long. 81.4352°W). Gainesville and Felda are characterized by US Department of Agriculture plant hardiness zones 9a (–6.7 to –3.6 °C) and 10a (–1.1 to 1.7 °C), respectively (US Department of Agriculture 2023). Fruit of saw palmetto are ellipsoidal to subglobose, dark blue to black at maturity, and consist of a smooth exocarp, fleshy mesocarp, and a thin, papery endocarp containing one seed (Dransfield et al. 2008). Fruit collection occurred at the natural shedding stage by gently shaking the inflorescences inside a net bag. Fruit were depulped (i.e., removal of exocarp and mesocarp) by washing in a ~15-L bucket under flowing water. After washing, the endocarps were dried at ambient temperature and humidity in the laboratory (~22–25 °C; 40%–50% relative humidity), stored in resealable plastic bags on the laboratory bench, and then used within 30 d. Diaspores were discarded if the endocarp was damaged during the cleaning process. Before the experiment was conducted, the endocarp was cracked manually and the seeds were removed. Seeds were sterilized with a 2.26% NaClO solution for 20 min in a platform shaker and were then rinsed three times in deionized water. After sterilization, seeds were soaked in 150 mL deionized water for 24 h on a platform shaker, with 50 seeds/250 mL Erlenmeyer flask (Makus 2006).

Germination. Germination data collection occurred weekly for a year, with germination scored when the cotyledonary petiole displaced the operculum by > 2 mm (Fig. 1A). Any seeds showing signs of deterioration were removed from the experiment and counted as censored observations. Treatments were arranged as a factorial design, with two saw palmetto forms (green and silver) × five sowing depths (1, 2, 4, 6, and 8 cm) (Fig. 1B). A randomized complete block design was used with five blocks. For each block, each treatment combination was replicated in plots of 10 containers, and each container had two seeds on opposite sides of the container (n = 20 seeds per plot × 5 blocks = 100 seeds per treatment combination). Presoaked seeds were sown Nov 2021 in 1.47-L plastic cups (ST40851BTCP; Berry Global Inc., Evansville, IN, USA) filled with a soilless medium (5.5 bark:3.0 peat:1.5 perlite; Promix BX, Premier Tech Horticulture, Quebec, Canada). Six 1-cm-diameter holes were drilled at the bottom of each cup for drainage. All cups were wrapped with two layers of black plastic (Fig. 1C). Plants were grown under controlled conditions in a greenhouse for 1 year and were irrigated manually as needed. Air temperature fluctuated between 22 and 30.5 °C.

Evaluation of growth traits. Seedling data collection occurred 1 year after sowing in Nov 2022 (Fig. 1D). Data collected included seedling length, from the root–shoot connection to the top of the tallest leaf; root length; number of leaves; Chlorophyll Relative Content (CRC) was measured using a SPAD meter (Soil Plant Analysis Development; Minolta Camera Co., Osaka, Japan) from three different areas on each seedling's leaf. Fractional Green Canopy Cover (FGCC) was measured as a percentage using the Canopeo app (Version 1.0; Oklahoma State University, Stillwater, Oklahoma, USA) from an image taken 30 cm above the lateral side of the seedling, which was laid on a table after container removal. A vigor index was used to assess seedling vigor (1 point = poor, 2 points = stunted, 3 points = fair, 4 points = good, 5 points = excellent). Vigor was assessed by considering leaf number and size, presence of pest damage, and nutritional deficiency symptoms. Shoot and root fresh and dry weights were collected. Dry weight was recorded after placing tissues in a forced-air oven at 70 °C for 48 h.

Statistical analysis. Time-to-event analysis was used to assess germination. Germination was coded as one and censored events were coded as zero. Censored events included contaminated seeds and seeds that had not germinated by the end of the experiment. PROC LIFETEST was used to estimate survivor functions using Kaplan–Meier estimates of survival, which were stratified by the covariates of interest (i.e., saw palmetto forms and sowing depth). The Kaplan–Meier estimates were used to generate a median germination time (t_{50}). Germination rate was calculated as $1/t_{50}$. The log-rank statistic was

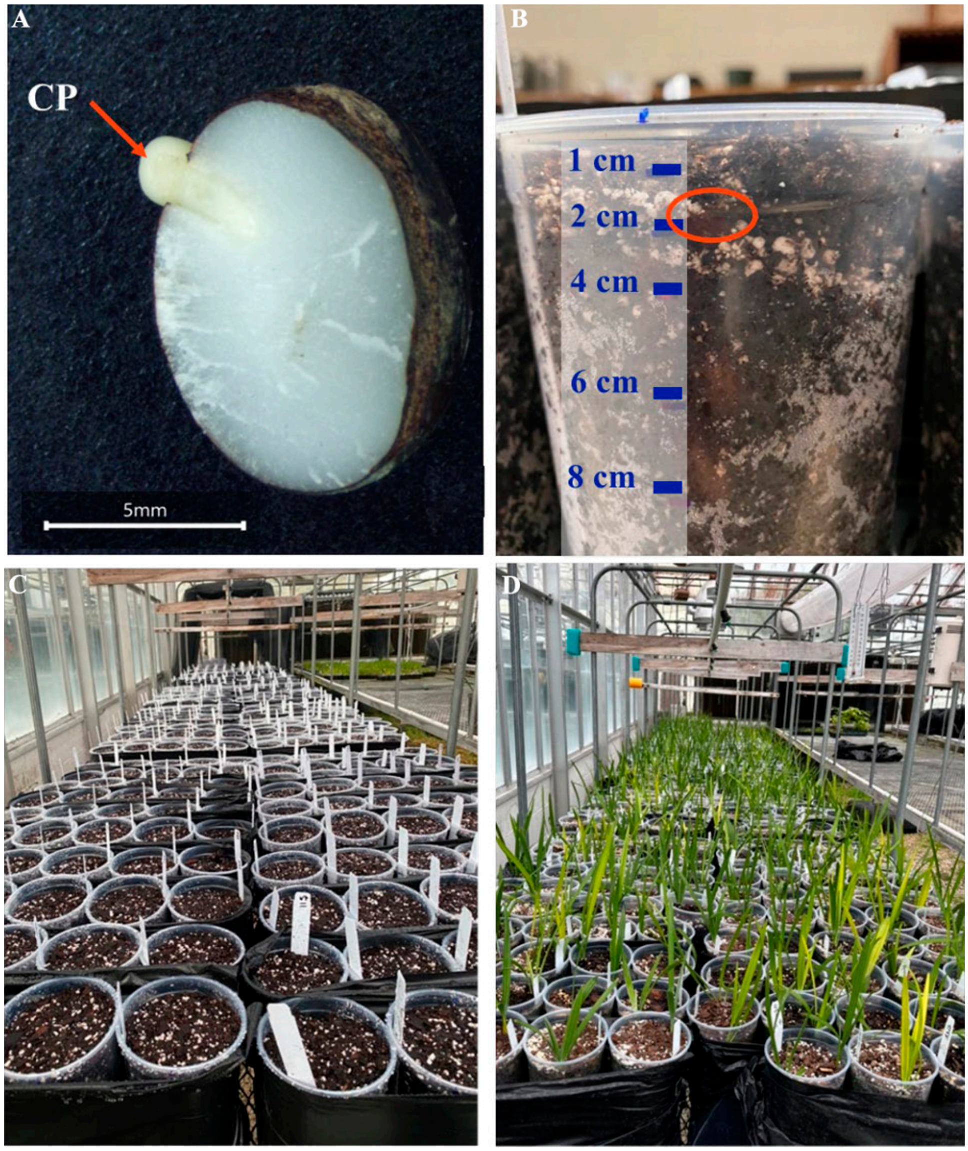

Fig. 1. Silver and green saw palmetto sowing-depth experiment. (A) Germination scored by the cotyledonary petiole (CP) displacing the operculum. (B) Seed placement at 2 cm in the container in the orange circle. Marker dots represent the sowing depths of 1, 2, 4, 6, and 8 cm. (C) Experiment installation in Nov 2021. (D) One year since sowing in Nov 2022.

used to test the null hypothesis that there were no differences in temporal patterns of germination among treatments. Cox regression models were generated to test for treatment effects and used the exact method to account for tied event times (Allison 2011). Violations of the proportional hazards assumption were assessed graphically using Schoenfeld residuals (Allison 2011). When violations occurred, time-dependent covariates (e.g., sowing depth × time) were incorporated into the models. Evaluations of the likelihood of germination were accomplished using orthogonal linear contrasts (Allison 2011). Although a standard does not exist, growers typically calculate a seeding rate overage to compensate for seeds that do not germinate during production. Overages of 10% are common. Therefore, to recommend seeding overages for production, we calculated the percentage change in likelihood of germination using the formula [(HR – 1) × 100], where HR was the hazard ratio generated from orthogonal linear contrasts.

We used analysis of variance (i.e., PROC GLIMMIX) to evaluate seedling growth parameters 1 year after sowing, with block as the random variable and the effects of sowing depth and saw palmetto forms held as fixed variables, and we compared means with the Tukey-adjusted least square means approach ($\alpha = 0.05$). Alternatively, we applied the generalized estimating equation (GEE) approach (i.e., PROC GENMOD) to assess plant vigor for 1-year seedling data given the categorical nature of these data (Stokes et al. 2012). We extended the GEE method to analyze planned comparisons by constructing single degrees of freedom (*df*) orthogonal contrasts for differences in vigor within saw palmetto forms and within sowing depths ($\alpha = 0.05$). We assessed effect sizes on growth parameters by partial η^2, with the following values used as thresholds for different sized effects $\eta^2 = 0.01$, small; $\eta^2 = 0.06$, medium; and $\eta^2 = 0.14$, high (Ben-Shachar et al. 2020). We performed all analyses with SAS v. 9.4 (SAS Institute

Inc., Cary, NC, USA). Days since germination were used as a covariate in all mixed model analyses.

Results

Germination. Stratified plots of Kaplan–Meier estimators revealed considerable variation in temporal germination patterns between saw palmetto forms and within the different sowing depths (Fig. 2). Final germination for green saw palmetto seeds ranged from 79% at the 1-cm sowing depth to ~84% to 87% at the other sowing depths of 2, 4, 6, and 8 cm. Seeds reached the median germination time within 120 to 134 d, with the longer t_{50} for the 8-cm sowing depth (Table 1). Similarly, silver saw palmetto seeds had a lower final germination percentage (61%) when seeds were sown at 1 cm compared with seeds sown between 2 and 8 cm (83%–92%). The median germination time was also ~31% to 44% faster for seeds sown between 2 and 8 cm compared those sown at 1 cm (Table 1). The hypothesis that temporal germination patterns were not different among forms and seed sowing depths was rejected (log-rank $\chi^2{}_2 = 103.3$, $P = < 0.0001$).

Cox regression detected a non-statistically significant saw palmetto forms × sowing depth interaction (Wald $\chi^2 = 5.8$; $P = 0.2095$) on the likelihood of germination. However, the main-effects model revealed statistically significant effects of saw palmetto forms (Wald $\chi^2 = 65.5$; $P < 0.0001$) and seed sowing depth (Wald $\chi^2 = 30.7$; $P < 0.0001$) on the likelihood of germination.

Orthogonal contrasts revealed statistical differences in the likelihood of germination when comparing the main effects of saw palmetto forms and sowing depth. For example, the likelihood of germination for green saw palmetto was 1.8 times greater than the silver form (Supplemental Fig. 1A). With regard to sowing depths, the only statistical difference occurred between seeds sown at 1 cm vs. the remaining sowing depths (Supplemental Fig. 1B). Moreover, when sowing at a depth of 1 cm, a seeding rate overage of 30% to 45% is estimated to achieve the desired number of plants when compared with other depths. As sowing depth increased, the required overage decreased. For instance, at a depth of 4 cm, only 6% more seeds were required (Table 2).

Seedling growth: Form effects. The form × sowing depth interaction was not statistically significant for all growth parameters evaluated. Thus, a main-effects model was used for each response variable. The partial η^2 values indicated a small effect of forms on root length, FGCC, and total dry weight ($\eta^2 = 0.01$–0.03), despite its statistical significance. Root length of the silver form was slightly longer than the green form, by 0.5 cm

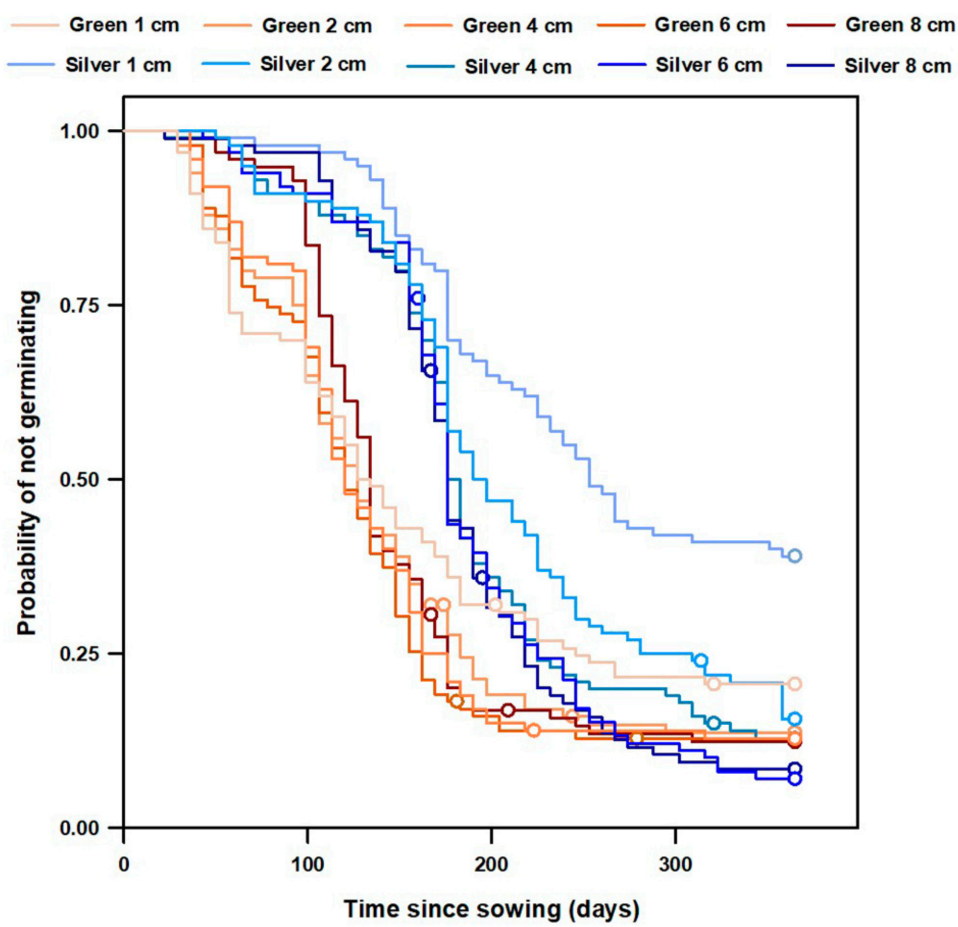

Fig. 2. Kaplan–Meier estimates of survivor functions for green and silver saw palmetto seeds at different sowing depths (1, 2, 4, 6, and 8 cm). The decreasing step function indicates germination taking place. Values closer to zero represent higher germination probabilities. Pointwise, 95% confidence intervals were omitted for clarity. Circles denote censored observations.

Table 1. Germination parameters for green and silver saw palmetto seeds exposed to different sowing depths for 1 year.[i]

Sowing depth (cm)	Final germination (%)	Median germination time (t_{50}), d [95% CI][ii]	Germination rate ($1/t_{50}$)[iii]
Green form			
1	79	130 [113, 169]	0.0076
2	85	127 [106, 148]	0.0078
4	87	120 [113, 141]	0.0083
6	86	120 [106, 134]	0.0083
8	85	134 [127, 148]	0.0074
Silver form			
1	61	253 [225, 351]	0.0039
2	84	193 [176, 225]	0.0051
4	87	179 [176, 190]	0.0055
6	92	176 [176, 190]	0.0056
8	89	176 [169, 190]	0.0056

[i] Germination was counted weekly.
[ii] Median germination time (t_{50}) refers to the 50th percentile of germination or the smallest event time where the probability of germinating earlier is greater than 0.50.
[iii] Germination rate is the inverse of the median germination time.
CI = confidence interval.

(Fig. 3A) ($F_{1,40}$ = 5.52; P = 0.0238). The FGCC percentage was 1.2-fold greater for the silver form than the green (Fig. 3B) ($F_{1,40}$ = 23.32; $P \leq 0.0001$). Similarly, the total dry weight had a small increase of 0.15 g in the silver form than the green form (Fig. 3C) ($F_{1,40}$ = 9.39; P = 0.0039).

For the variables of seedling length, number of leaves, and CRC SPAD, the partial η^2 values indicated a medium effect size of saw palmetto forms (η^2 = 0.06–0.09). Green saw palmetto seedlings were, on average, 2 cm taller than silver seedlings after 1 year since sowing (Fig. 3D) ($F_{1,40}$ = 23.34; $P \leq 0.0001$). The silver form provided 1.25 times more leaves than the green form (Fig. 3E) ($F_{1,40}$ = 65.55; $P \leq 0.0001$). Greater responses for the silver form were also recorded for CRC values compared with the green form (Fig. 3F) ($F_{1,40}$ = 21.67; $P \leq 0.0001$).

Seedling growth: Sowing-depth effects. Partial η^2 values indicated large effect sizes of seed sowing depth on seedling and root length. For example, the final seedling length was 9.5 cm greater for seeds placed at 8 cm rather than 1 cm. In contrast, root length was nearly 6.4 cm smaller at 8 cm than 1 cm (Fig. 4A and B) ($F_{4,40}$ = 42.59; $P \leq 0.0001$ on seedling length and $F_{4,40}$ = 113.07; $P \leq 0.0001$ on root length).

Partial η^2 values indicated a medium effect size of sowing depth on leaf number [η^2 = 0.09; 95% confidence interval (CI), 0.04, 0.1] and a small effect size for CRC (η^2 = 0.05; 95% CI, 0.01, 0.07), FGCC (η^2 = 0.02; 95% CI, 0.0006, 0.03), and total dry mass (η^2 = 0.02; 95% CI, 0.002, 0.02). Leaf number was higher in seedlings grown at shallow depths than in deeper seed placement ($F_{4,40}$ = 16.26; P = ≤ 0.0001). Relative chlorophyll content was ∼10% higher for seedlings sown at 2 cm than seedlings sown at 4, 6, and 8 cm (Table 3) ($F_{4,40}$ = 3.4; P = 0.0173). Alternatively, seedling FGCC percentages at 2 cm were 36% greater than seedlings sown at 1 cm (Table 3) ($F_{4,40}$ = 3.02; P = 0.0289). Fewer statistically significant differences were for total dry mass of seedlings. For example, the only statistical difference in total dry mass occurred for comparisons of seedlings sown at 2 and 8 cm, where seedling dry mass was ∼32% greater in seedlings originating from seeds sown at 2 cm compared with those sown at 8 cm (Table 3) ($F_{4,40}$ = 3.89; P = 0.0093).

Seedling vigor was mostly lower for plants sowed at 1 cm (vigor indices, 1 and 2 points) than for seeds sown deeper (Fig. 5). The GEE approach detected a significant effect of sowing depth (χ^2_4 = 13.23, P = 0.0102) on vigor, but no effect of form or the interaction form × sowing depth (χ^2_1 = 1.08, P = 0.2938 and χ^2_4 = 5.55, P = 0.2355, respectively). However, the sowing depth effect on seedling vigor was small (Cohen's w = 0.11). Single *df* contrasts from the GEE analysis revealed that plant vigor differed statistically between seedlings sown at 1 cm and those sown at deeper depths, but vigor was not statistically different among seedlings from deeper sowing depths (Table 4).

Table 2. Linear orthogonal contrasts for saw palmetto seed sowing depths, hazard ratios, and 95% confidence limits.

Contrast	HR (LCL, UCL)	Percent change[i]
1 cm vs. 2 cm	0.68 (0.54, 0.84)	–32
1 cm vs. 4 cm	0.60 (0.48, 0.75)	–40
1 cm vs. 6 cm	0.56 (0.45, 0.70)	–44
1 cm vs. 8 cm	0.63 (0.50, 0.78)	–37
2 cm vs. 4 cm	0.88 (0.71, 1.10)	–12
2 cm vs. 6 cm	0.83 (0.67, 1.02)	–17
2 cm vs. 8 cm	0.93 (0.75, 1.15)	–7
4 cm vs. 6 cm	0.94 (0.76, 1.16)	–6
4 cm vs. 8 cm	1.05 (0.85, 1.29)	5
6 cm vs. 8 cm	1.12 (0.91, 1.38)	12

[i] Percent change refers to the percentage change in the likelihood of germination and is calculated by (HR – 1) × 100.
HR = hazard ratio; LCL = lower confidence limit; UCL = upper confidence limit.

Discussion

There was a notable distinction in germination timing between seeds of the two saw palmetto forms. Green saw palmetto seeds germinated more than 60 d earlier than silver saw palmetto seeds, regardless of the planting depth. However, growers should consider that the final germination percentage was similar for both forms (84% for green and 82% for silver). Considering the difference between forms and region of seed collection, similar responses have been observed across various species, even in geographically proximate locations (Baskin and Baskin 2014). For instance,

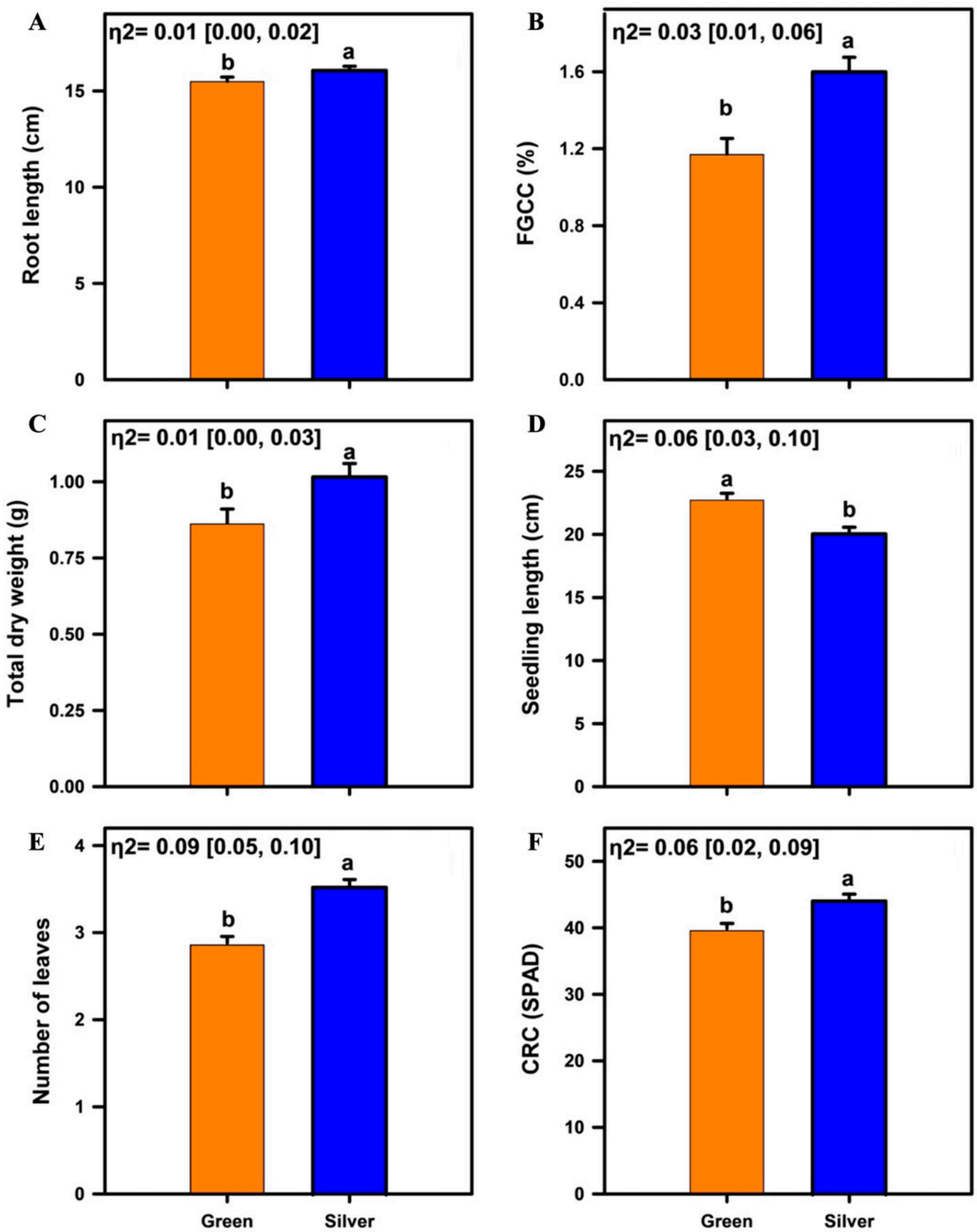

Fig. 3. Plant growth parameters for seeds sown at different depths for saw palmetto seedlings 1 year after sowing, including root length (A), fractional green canopy cover (FGCC) (B), total dry weight (C), seedling length (D), number of leaves (E), and chlorophyll relative content (CRC) (F). Lowercase letters indicate a significant difference between treatments ($P < 0.05$). Eta-squared values denote the effect size of saw palmetto forms in growth parameters and 95% confidence limits. SPAD = soil plant analysis development.

germination synchrony of *Euterpe edulis* (Mart.) seeds was affected by population habitat type (Santos et al. 2023).

The earlier germination of green saw palmettos may be attributed in part to environmental or genetic factors associated with the origin of the seeds. Silver seeds were collected primarily from northern Florida; Green seeds were from southern Florida populations. Located in different climatic conditions. Such differences at the regional level may affect dormancy mechanisms and germination cues (Baskin and Baskin 2014).

When sowing seeds, a common practice is to have a seed overage, which is recommended to achieve the desired number of plants, considering that not all seeds will germinate (Luna et al. 2014; Van Steenis 2013). Seed sowing depth promoted significant differences in the overage percentages. When sowing at shallow depths of 1 cm, growers need to consider a greater seeding overage of 30% to 45% to achieve the final desired number of plants, implying a greater cost to compensate for production losses. As the sowing depth increases, the seeding overage decreases. In our study, sowing at 4 cm reached a threshold with

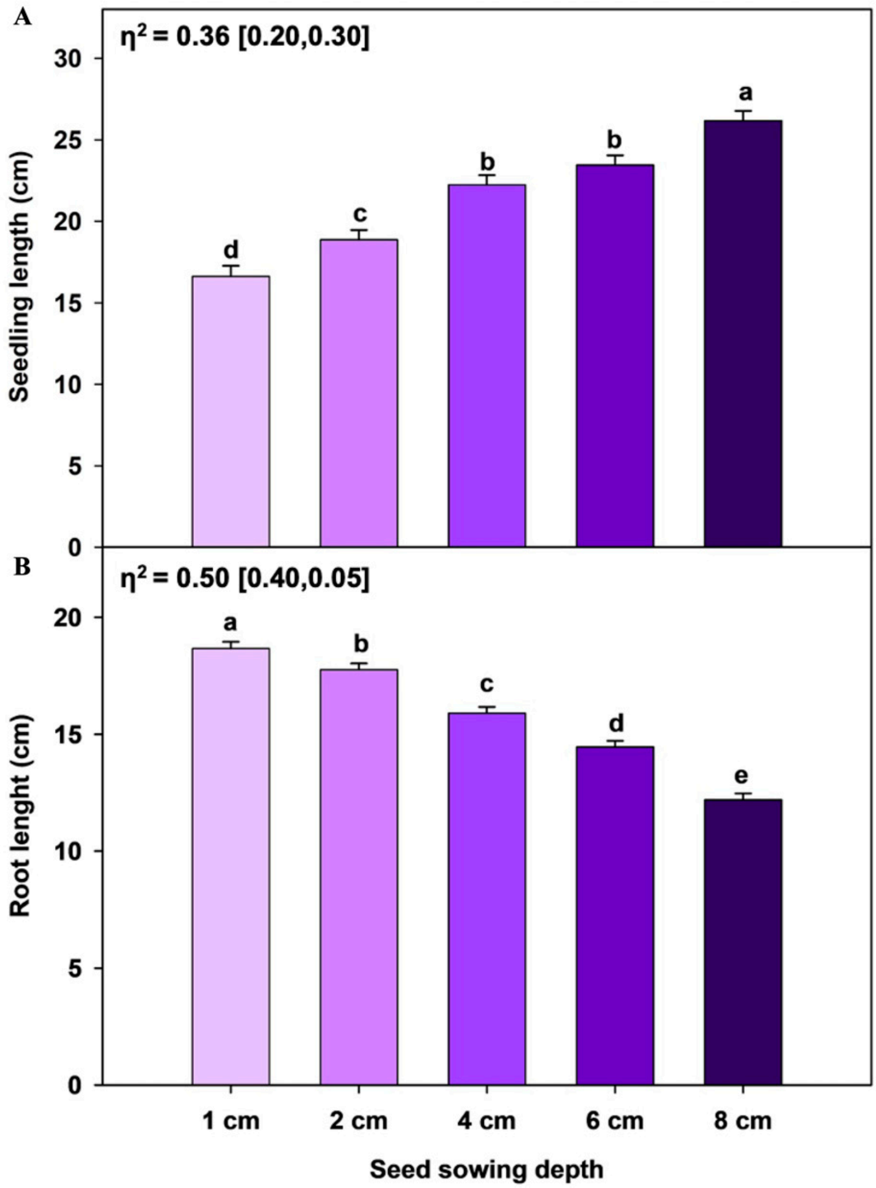

Fig. 4. Average (± standard error) seedling (A) and root (B) length of seeds sown at different depths for saw palmetto seedlings 1 year after sowing. Lowercase letters indicate a significant difference between treatments ($P < 0.05$). Eta-squared values denote the effect size of saw palmetto forms in growth parameters and 95% confidence limits.

the lowest overage percentage of 6%, thus decreasing seed costs and losses.

Considering the small to medium effect of silver and green size differences in seedling growth, growers should consider the market demand for saw palmetto forms. In a commercial setting, leaf coloration plays a significant role in increasing ornamental value (Tang et al. 2020). Silver saw palmetto plants are usually preferred in ornamental settings because of a consumer preference for the blueish leaves (Bonner et al. 2008; Pereira et al. 2025).

Seedling growth after germination was influenced significantly by sowing depth; however, the practical relevance of these effects depends on their magnitude and applicability. Our results confirmed grower observations that increasing sowing depth enhances plant height. Seedlings planted deeper had to overcome more substrate to reach the surface, leading to increased shoot length when measured from the seed connection point. However, this came with a trade-off; deeper sowing reduced root length, likely a result of space constraints within the container. Our study revealed a significant relationship between root and shoot growth (Fig. 4). Seedlings placed at greater depths developed longer shoots but shorter roots, likely reflecting a shift in energy allocation. As the palm invests energy to reach the soil surface, root development may become restricted due to limited space (Renninger and Phillips 2016). While this shoot elongation may facilitate emergence from deeper planting, it poses a greater challenge during transplanting. A reduced root system can limit water uptake and compromise post-transplant vigor (Hodel et al. 2009). Therefore, selecting an appropriate sowing depth that balances shoot and root development is crucial for producing vigorous, transplant-ready seedlings.

A moderate effect was observed for the number of leaves, with seedlings sown at shallow depths (1–2 cm) producing more leaves. However, other growth parameters, such as CRC, FGCC, total dry mass, and overall seedling vigor, showed a small effect with minimal statistical differences between sowing depths. Likewise, the dry mass of *Archontophoenix cunninghamii* palm seedlings provided no differences at different sowing depths of 0, 2, 4, and 6 cm (da Luz 2015). Alternatively, da Silva et al. (2009) observed that sowing *Copernicia prunifera* [(Miller) H. E Moore] at a depth of 2.1 cm increased the dry mass of the aerial part compared with more shallow sowings.

Regarding seedling vigor, although the size effects were minor, sowing at a shallow depth of 1 cm resulted in a greater proportion of seedlings rated as poor or stunted (vigor indices, 1 and 2 points) and fewer seedlings rated as good or excellent (vigor indices, 4 and 5 points). Similarly, seeds of the *Copernicia berteroana* palm sown at 1.27 cm demonstrated superior seedling vigor than surface sowing, revealing the greatest number of visible leaves per seedling after 7 months of growth (Murphy et al. 2016).

Conclusion

Green and silver saw palmetto forms differed in germination timing but not in final germination

Table 3. Saw palmetto seedling growth parameters 1 year after sowing at different depths (1, 2, 4, 6, and 8 cm), including mean estimates (average ± standard error) of leaf number, chlorophyll relative content (CRC) (SPAD values), fractional green canopy cover, and total dry mass.

Depth (cm)	No. of leaves	Chlorophyll relative content (SPAD value)	Fractional green canopy cover (%)	Total dry mass (g)
1	3.4 ± 0.09 ab[i]	42.6 ± 1.12 ab	1.16 ± 0.10 c	0.89 ± 0.05 ab
2	3.6 ± 0.08 a	45.0 ± 1.00 a	1.58 ± 0.09 a	1.10 ± 0.05 a
4	3.3 ± 0.08 b	41.0 ± 1.00 b	1.42 ± 0.09 ab	0.96 ± 0.05 ab
6	2.9 ± 0.08 c	41.0 ± 1.00 b	1.34 ± 0.09 bc	0.93 ± 0.05 ab
8	2.8 ± 0.08 c	41.0 ± 1.00 b	1.41 ± 0.09 a–c	0.83 ± 0.05 b

[i] The same letters in a column indicate no difference in Tukey's adjustment for mean separation at $\alpha = 0.05$. SPAD = soil plant analysis development.

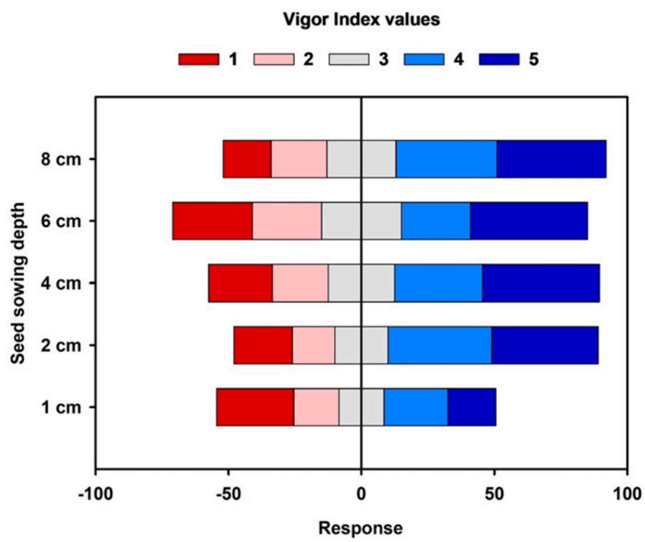

Fig. 5. Vigor indices (1–5) of saw palmetto seed sown at different depths 1 year after sowing. Vigor is ranked from 1 to 5 points (1 point = poor, 2 points = stunted, 3 points = fair, 4 points = good, 5 points = excellent) and is indicated by red, pink, gray, light blue, and blue, respectively.

percentages. Sowing depth influences germination significantly, whereas its effects on seedling growth vary. A sowing depth of ~4 cm optimized germination and promoted the development of vigorous, market-ready plants while minimizing excessive seed use, thereby enhancing production efficiency. Given the variable responses of different growth traits, growers must balance the benefits of deeper sowing for increased plant height against potential trade-offs, such as reduced root length and seedling quality variations. Furthermore, the influence of saw palmetto form and sowing depth on germination should be considered when making decisions regarding optimal seedling production.

Table 4. Single degree of freedom contrast results from the generalized estimating equation approach for the effect of seed sowing depth on plant vigor.

	χ^2 (P value)				
Sowing depth	1 cm	2 cm	4 cm	6 cm	8 cm
1 cm	—	9.78 (0.001)	8.03 (0.004)	4.08 (0.043)	9.77 (0.001)
2 cm	—	—	0.13 (0.715)	1.72 (0.190)	0.00 (0.949)
4 cm	—	—	—	0.92 (0.338)	0.10 (0.757)
6 cm	—	—	—	—	1.63 (0.202)
8 cm	—	—	—	—	—

References cited

Allison P. 2011. Survival analysis using SAS: A practical guide. Biometrics. 67(3): 1182–1182. https://doi.org/10.1111/j.1541-0420.2011.01658_7.x.

Baskin CC, Baskin JM. 2014. Seeds ecology, biogeography, and evolution of dormancy and germination. Elsevier Science. Academic Press, San Diego, CA, USA.

Bennett BC, Hicklin JR. 1998. Uses of saw palmetto (*Serenoa repens*, Arecaceae) in Florida. Econ Bot. 52(4):381–393. https://doi.org/10.1007/BF02862068.

Ben-Shachar MS, Lüdecke D, Makowski D. 2020. Effect size: Estimation of effect size indices and standardized parameters. JOSS. 5(56):2815. https://doi.org/10.21105/joss.02815.

Bonner FT, Karrfalt RP, Bonner FT. 2008. The woody plant seed manual. US Department of Agriculture, Forest Service, Washington, DC, USA.

Broschat TK, Donselman H. 1986. Factors affecting storage and germination of *Chrysalidocarpus lutescens* seeds. J Am Soc Hortic Sci. 111(6):872–877. https://doi.org/10.21273/JASHS.111.6.872.

Carpenter WJ. 1986. Seed germination of *Serenoa repens*, p 158–159. In: Proceedings of the Annual Meeting of the Florida State Horticultural Society. Florida State Horticultural Society, Gainesville, FL, USA.

Carpenter W. 1987. Temperature and imbibition effects on seed germination of *Sabal palmetto* and *Serenoa repens*. HortScience. 22(4):660. https://doi.org/10.21273/HORTSCI.22.4.660.

da Luz PB. 2015. Profundidade de semeadura na emergência e crescimento de plântulas de *Archontophoenix cunninghamii* H. Wendl. & Drude. Magistra. 27(1):54–62.

da Silva FDB, Medeiros Filho S, Bezerra AME, Freitas JBSd, Assunção MV. 2009. Pre-soaking and the depth of sowing in the emergency of *Copercinia prunifera* (Miller) H. E. Moore. Ciência Agron. 40(2):272–278.

Deyrup M, Deyrup L. 2012. The diversity of insects visiting flowers of saw palmetto (Arecaceae). Florida Entomol. 95(3): 711–730. https://doi.org/10.1653/024.095.0322.

Dransfield J, Uhl NW, Asmussen CB, Baker WJ, Harley MM, Lewis CE. 2008. Genera *Palmarum*: The evolution and classification of palms (2nd ed). Royal

Botanic Gardens, Kew, Richmond, Surrey, UK.

Essig FB, Taylor YR, TeStrake D. 2000. Florida's wax palm: The silver form of *Serenoa repens* (Arecaceae). Florida Sci. 63(1):13–16.

Fisher FB, Tomlinson PB. 1973. Branch and inflorescence production in saw palmetto (*Serenoa repens*). Principes. 17(1): 10–19.

Hilmon JB. 1968. Autecology of saw palmetto (*Serenoa repens* (Bartr.) Small) (master's thesis). Duke University, Durham, NC, USA.

Hodel DR, Downer AJ, Pittenger DR. 2009. Transplanting palms. HortTechnology. 19(4):686–689. https://doi.org/10.21273/HORTTECH.19.4.686.

Lindon HL, Menges E. 2008. Scientific note: Effects of smoke on seed germination of twenty species of fire-prone habitats in Florida. Castanea. 73(2):106–110. https://doi.org/10.2179/0008-7475(2008)73[106:EOSOSG]2.0.CO;2.

Liu H, Platt SG, Borg CK. 2004. Seed dispersal by the Florida box turtle (*Terrapene carolina bauri*) in pine rockland forests of the lower Florida Keys, United States. Oecologia. 138(4):539–546. https://doi.org/10.1007/s00442-003-1445-7.

Luna T, Wilkinson KM, Dumroese RK. 2014. Seed germination and sowing options, p 163–183. In*:* Wilkinson K, Landis T, Haase D, Daley B, Dumroese RK, eds. Tropical nursery manual: A guide to starting and operating a nursery for native and traditional plants. US Department of Agriculture, Forest Service, Washington, DC, USA.

Maehr DS, Layne JN. 1996. Florida's all-purpose plant: The saw palmetto. Palmetto. 16(4):6–10, 15, 21.

Makus DJ. 2006. Seed germination methods and establishment of saw-palmetto, Serenoa repens, in South Texas. Acta Hortic. 782:381–385.

Meerow AW, Broschat TK. 2021. Palm seed germination. Eletronic Data Iinformation Source, EP238. Univ. of Florida, IFAS Ext., Gainesville, FL, USA. https://doi.org/10.32473/edis-ep238-2004.

Moldenke H. 1967. *Serenoa repens* (batr.) Small, forma glauca. Phytologia. 14:326–336. https://doi.org/10.5962/bhl.part.18530.

Murphy V, Clase T, Rodríguez-Peña RA, Jiménez-Rodríguez F, Jestrow B, Husby CE, Griffith MP. 2016. Conservation horticulture for yarey palm and buccaneer palm: Substrate and sowing depth affect germination and early seedling growth. HortTechnology. 26(6):811–815. https://doi.org/10.21273/HORTTECH03521-16.

Norden N, Daws MI, Antoine C, Gonzalez MA, Garwood NC, Chave J. 2009. Relationship between seed mass and mean time to germination for 1037 tree species across five tropical forests. Funct Ecol. 23(1):203–210. https://doi.org/10.1111/j.1365-2435.2008.01477.x.

Orzell SL, Bitomský M, Bridges EL, Budach B, Klimešová J, Martinková J, Reed ZE, Raynor SJ. 2024. Florida's fiery subtropical grasslands: Growth forms, belowground organs, and post-fire recovery strategies. Folia Geobot. 58(3–4):209–230. https://doi.org/10.1007/s12224-024-09440-1.

Pereira V, McMillan M, Vendrame W, McCoy K. 2025. Serenoa repens: Saw palmetto: FPS-547 (rev 3). Eletronic Data Iinformation Source, Universityof Florida IFAS Extension, Gainesville, FL, USA. https://doi.org/10.32473/edis-fp547-2025.

Renninger HJ, Phillips NG. 2016. Palm physiology and distribution in response to global environmental change, p 67–101. In: Goldstein G, Santiago LS (eds). Tropical tree physiology: Adaptations and responses in a changing environment. Springer, Cham, Switzerland. https://doi.org/10.1007/978-3-319-27422-5_4.

Santos AS, Braz MIG, Santos de Barros C, Cássia Quitete Portela R, Mattos EA. 2023. Sensitivity of seed germination to water stress in high-altitude populations of a threatened palm species. Plant Biol (Stuttgart). 25(4):593–602. https://doi.org/10.1111/plb.13527.

Smith D. 1972. Palm briefs: Fruiting in the Saw Palmetto. Principes. 16(1):30–33.

Stokes ME, Davis CS, Koch GG. 2012. Categorical data analysis using SAS. SAS Institute, Cary, NC, USA.

Tang Y, Fang Z, Liu M, Zhao D, Tao J. 2020. Color characteristics, pigment accumulation and biosynthetic analyses of leaf color variation in herbaceous peony (*Paeonia lactiflora* Pall.). 3 Biotech. 10(2):76. https://doi.org/10.1007/s13205-020-2063-3.

US Department of Agriculture. 2023. 2023 USDA plant hardiness zone map. Agricultural Research Service, USDA, Washington, DC, USA.

Van Steenis E. 2013. Calculating optimum sowing factor: A tool to evaluate sowing strategies and minimize seedling production cost, p 45–50. In: National Proceedings of the Forest and Conservation Nursery Associations, 2012. USDA Forest Service, Washington, DC.