Research Article

Optimizing Sowing Dates for Enhanced Growth and Development of *Salvia hispanica* L. in Western Morocco During the Spring Season

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Abstract | This study investigated the impact of sowing dates on the phenological development, growth performance, and seed quality of *Salvia hispanica* L. under semi-arid conditions in Western Morocco. Five sowing dates (March 12, April 2, April 23, May 14, and May 28) were evaluated in a randomized complete block design. Results demonstrated that sowing date significantly influenced all measured parameters ($p < 0.05$). Sowing on 14 and 28 May resulted in superior performance across most traits. The days to emergence decreased from 23.8 for the early sowing to 15.3 for these optimal late sowings, and the flowering time was reduced from 55.7 days to 41.2 days. Plant height reached approximately 104 cm in the plants sown latest versus 73.6 cm in those sown early. Seed yield increased from 930.7 kg/ha to 1251.9 kg/ha, while oil content increased from 31.8% to 33.5%, and omega-3 fatty acid content increased from 34.4% to 36.2%. Strong positive correlations ($r = 0.92$–1.00) were observed among LAI, plant height, biomass and seed nutritional components. In contrast, phenological traits such as days to emergence and flowering showed perfect negative correlations ($r = -1.00$) with yield and quality indices. These findings highlight that the sowing window between 14 and 28 May aligns best with environmental conditions in the region, optimizing chia growth, yield, and seed quality for sustainable production in Mediterranean semi-arid climates.

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Introduction

Salvia hispanica L., commonly known as chia, is an annual herbaceous plant belonging to the Lamiaceae family. Native to Central and Southern Mexico, it has garnered increasing attention in recent years due to its high nutritional value, particularly its rich content of omega-3 fatty acids, dietary fiber, protein, and bioactive compounds (Jukić *et al*., 2023). Due to increasing consumer demand for plant-based nutrients and functional foods, chia seed has become a vital crop with economic and health relevance across the globe. Countries like Morocco, where climate change and soil degradation are ongoing major challenges, introduction of climate resilient crops such as chia seed presents an opportunity to diversify agricultural systems and improve food security (Bouhlali *et al*., 2022).

Among main agronomic factors influencing chia seed productivity, sowing time also plays an critical role in determining its growth cycle, phenological development and yield components. Time of sowing decides how crop coordinates with environmental factors such as temperature, photoperiod and soil moisture that directly impact seed germination, vegetative growth, flowering, seed maturation and indirectly yield (Pramanik *et al*., 2022; Amjad *et al*., 2024). Chia plant is very sensitive to photoperiod, fluctuations in temperature and time of sowing are crucial for ensuring optimal development of both vegetative and reproductive phases (Ramos-Castellá *et al*., 2023).

Mediterranean climates, like found in western Morocco, drastic climate changes like shifting rainfall patterns, increasing temperatures and shortening growing seasons is major limiting factor for chia production. These environmental changes are compelling farmers for adaptation of modern agronomic practices like selection of appropriate chia cultivar and adjustments in sowing dates (El Yamani *et al*., 2023; Saqib *et al*., 2025). Although chia shows potential for cultivation in such environments due to its moderate drought tolerance and relatively short life cycle, there is a lack of region-specific agronomic data for farmers.

Previously reported studies in subtropical and semi-arid environment, results indicated that both early and late sowing of chia can affect both vegetative and reproductive attributes and indirectly yield (Rana *et al*., 2021). However, extent to which these findings apply to Moroccan agro-climatic zones remains unclear due to different environmental conditions and regional variation in season. Furthermore, fluctuations in temperature and photoperiod across sowing duration may lead to failure in flowering or seed setting, ultimately reducing yield.

Current study was therefore designed to investigate the impact of different sowing dates on growth cycle and developmental behavior of *Salvia hispanica* L. cultivated under field conditions in western Morocco. The primary objective is to determine the optimal planting window that ensures maximum vegetative development, efficient flowering, and favorable seed formation, thereby contributing to improved agronomic practices and sustainable chia production in the region.

Materials and Methods

A field trial was conducted in Mnasra, Kenitra Province (34.36°N, 6.55°W; ~12 m a.s.l.), Western Morocco, under Mediterranean climatic conditions. The surface soil (0–20 cm) was sandy, slightly alkaline, low in EC, and poor in organic matter. The experiment employed a randomized complete block design (RCBD) with three replications, assessing five sowing dates: March 12, April 2, April 23, May 14, and May 28, 2024. Each 3 × 1.5 m plot had five rows with 30 cm × 50 cm spacing. Certified *Salvia hispanica* L. seeds (FLORAGARDEN, Morocco) were sown at 3 kg ha^{-1} and 1–2 cm depth, based on previous chia agronomy (Muntean *et al*., 2014).

Crop management

The field was prepared with disc harrowing and leveling, followed by the incorporation of 20 t ha^{-1} of well-decomposed sheep manure. Irrigation was applied biweekly; weeds were manually controlled. No chemicals were used, following sustainable practices.

Data collection and analysis

Growth stages (emergence, flowering, maturity) were recorded per BBCH scale (Meier, 2001). Growth metrics (height, branches, LAI) were measured from 10 plants per plot. Yield and biomass were assessed at maturity; harvest index (HI) was computed as yield/biomass × 100. Seed oil was extracted via Soxhlet with petroleum ether; protein was measured by Kjeldahl; omega-3 content was determined through GC, following methylation (Martínez-López *et al*., 2023). AOAC (2000) methods were used for biochemical analyses. Weather data were sourced from ORMVAG, Kenitra. ANOVA and LSD tests (5% level) were applied using SPSS v25.0. Correlation analysis followed Gomez and Gomez (1984).

Results and Discussion

Effect of sowing dates on phenological development of salvia hispanica L.

The phenological response of *Salvia hispanica* L. was markedly influenced by sowing date under the agro-climatic conditions of Western Morocco. A progressive delay in sowing from SD1 to SD5 resulted in a consistent reduction in the number of days required to reach emergence, flowering, and maturity.

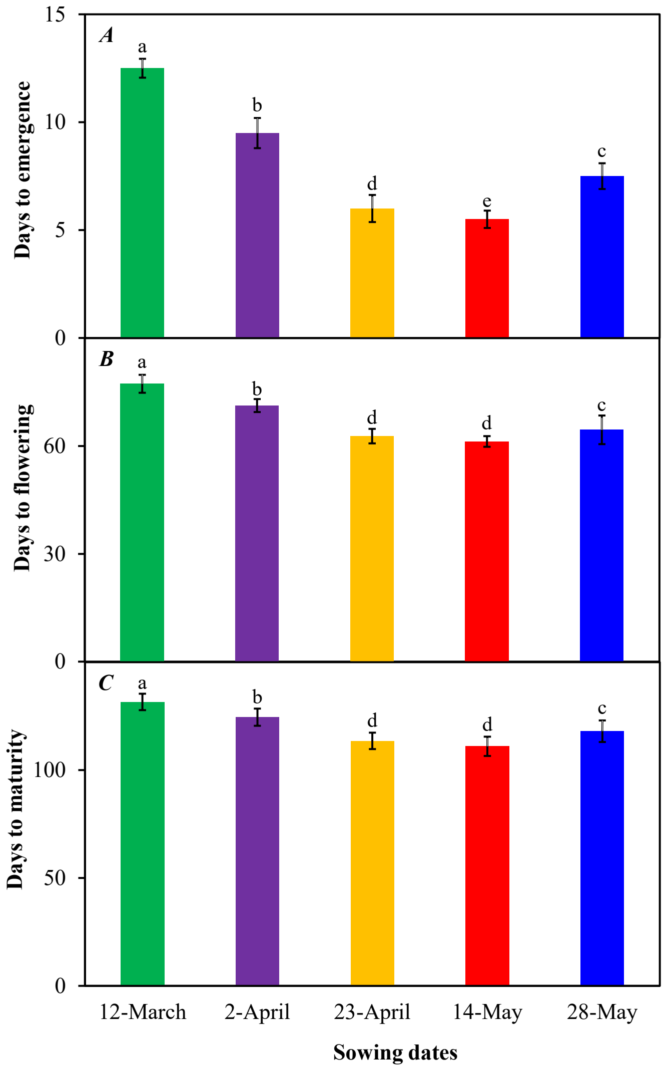

Figure 1: *Effect of sowing dates on days to emergence (A), days to flowering (B), and days to maturity (C) in chia. Each bar represents the mean value of four replications, while the vertical bars indicate standard error of the mean (SEM), showing variability among replications.*

Days to emergence

The sowing date had a significant effect on the emergence time of chia. Seeds sown on 12 March exhibited the longest emergence period (23.8 ± 0.4 days), followed by 9 April (19.5 ± 0.6 days). A considerable reduction in emergence time was observed for 14 May (15.9 ± 0.5 days) and 28 May (15.3 ± 0.3 days) (Figure 1 A). However, a slight increase was recorded for 28 May (17.4 ± 0.4 days). These results indicate that sowing in 14 and 28 May favored faster germination, likely due to more favorable soil temperature and moisture conditions.

Days to flowering

Chia plants sown on 12 March required the longest duration to flowering (68.2 ± 0.6 days), followed by 9 April (64.3 ± 0.5 days). In contrast, a significant reduction was noted in 14 May (60.5 ± 0.5 days) and 28 May (59.7 ± 0.4 days) sowings (Figure 1 B). A minor increase in flowering duration was recorded for the 28 May sowing (61.8 ± 0.6 days). The progressive reduction in flowering time with delayed sowing until 14 May suggests a temperature-driven acceleration in developmental rate. However, the increase for the last sowing date may reflect suboptimal conditions or stress during the reproductive stage.

Days to maturity

The number of days to maturity followed a trend similar to flowering. The 12 March sowing reached maturity at 96.2 ± 0.7 days, while sowings on 2 April and 23 April matured at 92.8 ± 0.6 and 88.3 ± 0.6 days, respectively (Figure 1 C). The 14 May sowing showed the shortest maturity duration (87.6 ± 0.5 days). However, a slight delay was again observed for the 28 May sowing (89.9 ± 0.6 days). These results indicate that earlier sowing prolonged the growth period, whereas moderate delay (until early May) shortened the crop cycle without adverse effects. Late sowing in late May slightly extended the maturity period, likely due to heat stress or photoperiodic influence.

Plant height (cm)

Sowing date exerted a significant influence on plant height in chia. The tallest plants were observed when sowing was carried out on 14 May (104.8 ± 2.1 cm) and 28 May (103.9 ± 1.9 cm), reflecting favorable conditions during the vegetative phase. In contrast, earlier sowings such as 12 March (78.3 ± 1.8 cm) and 2 April (84.6 ± 2.0 cm) resulted in markedly shorter plants (Figure 2A). A moderate decline in height was recorded for the 23 April sowing (91.3 ± 1.7 cm). These results suggest that environmental factors such as increasing temperature and photoperiod during 14 and 28 May contribute positively to stem elongation and biomass accumulation.

Number of branches per plant

Branching patterns were similarly affected by sowing date. The number of primary branches per plant was significantly higher in the 14 May (20.3 ± 0.6) and 28 May (21.1 ± 0.5) treatments, indicating enhanced vegetative proliferation under these sowing conditions. Early sowings, namely 12 March (14.2 ± 0.4) and 2 April (14.5 ± 0.3), exhibited reduced branching, possibly due to slower initial growth under cooler temperatures (Figure 2A).

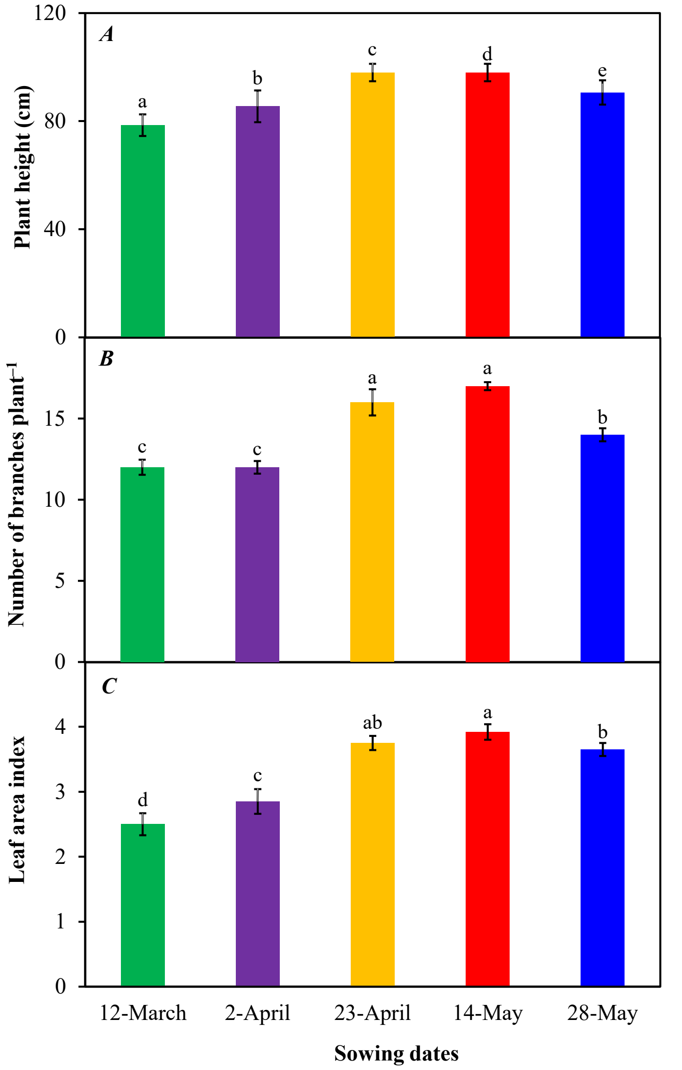

Figure 2: *Effect of sowing dates on plant height (A), number of branches plant^{-1} (B), and leaf area index (C) of chia. Each bar represents the mean value of four replications, while the vertical bars indicate standard error of the mean (SEM), showing variability among replications.*

Leaf area index (LAI)

The leaf area index, a key indicator of canopy development and light interception efficiency, was significantly influenced by sowing date. Maximum LAI values were recorded in sowings on 14 May (4.1 ± 0.1) and 28 May (4.3 ± 0.1), reflecting enhanced leaf expansion and favorable vegetative growth during this window (Figure 2A). Lower LAI values were associated with 12 March (2.3 ± 0.1) and 2 April (2.7 ± 0.1) sowings. These patterns suggest that the sowing on 14 and 28 May creates an optimal microclimate for leaf development and canopy establishment in chia.

Seed yield

Seed yield of chia was progressively increased with delayed sowing, from 930.7 kg/ha (March 12) to a maximum of 1251.9 kg/ha (May 28). (Figure 3A). This trend suggests that later sowings likely coincided with more favorable climatic conditions like optimal temperature, day length, and reduced early-season moisture stress leading to improved reproductive development and seed filling.

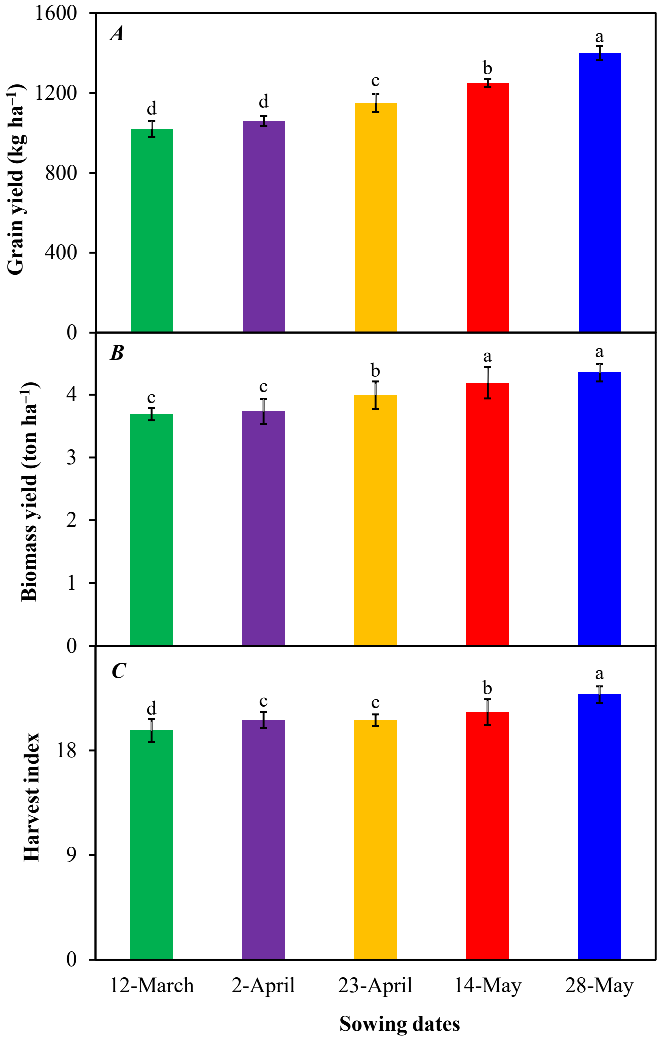

Figure 3: *Effect of sowing dates on seed yield (A), biomass yield (B), and harvest index (C) of chia. Each bar represents the mean value of four replications, while the vertical bars indicate standard error of the mean (SEM), showing variability among replications.*

Biomass yield

Total biomass yield also increased with delayed sowing, from 3.9 t ha^{-1} (12 March) to 4.6 t ha^{-1} (28 May). The rise in vegetative biomass reflects improved crop establishment and canopy development under later sowing conditions (Figure 3B). Enhanced vegetative growth may be attributed to better synchronization of the crop's vegetative phase with optimal sunlight and temperature conditions during between 14 and 28 May.

Harvest index

The harvest index (HI), representing the efficiency of biomass conversion into economic yield, showed a gradual increase from 23.7% (12 March) to 26.7% (28 May) (Figure 3C). Although the differences were moderate, they indicate that later sowings not only enhanced overall biomass but also improved assimilate partitioning toward reproductive organs.

Effect of sowing dates on biochemical development of salvia hispanica L.

Protein content

Protein content increased significantly with delayed sowing. The lowest protein level (approximately 34.8%) was recorded for the 12 March sowing, while the highest value (39.6%) was observed for the 28 May sowing (Figure 4A). A steady rise was noted between sowing dates, with intermediate values for 2 April (36.1%), 23 April (37.3%), and 14 May (38.5%). Statistical groupings (denoted by different letters) confirm that each later sowing date led to a significant improvement in seed protein concentration.

Oil content

Oil content followed a similar pattern. Seeds sown on 12 March contained the lowest oil content (around 20.9%), while the maximum value (23.7%) was recorded for the 28 May sowing (Figure 4B). Intermediate sowing dates 2 April, 23 April, and 14 May resulted in oil contents of 21.7%, 22.2%, and 22.8%, respectively. Each increase across sowing dates was statistically significant, indicating that later sowing enhances lipid accumulation in chia.

Omega-3 content

The omega-3 content also exhibited a gradual increase with delayed sowing. The 12 March treatment recorded 33.8%, while the highest value (36.4%) was found on 28 May. Intermediate sowings 2 April, 23 April, and 14 May yielded 34.2%, 34.8%, and 35.4%, respectively (Figure 4C). Though the numerical changes were modest, statistical analysis showed significant differences, suggesting that environmental conditions associated with later sowings favorable omega-3 fatty acid biosynthesis.

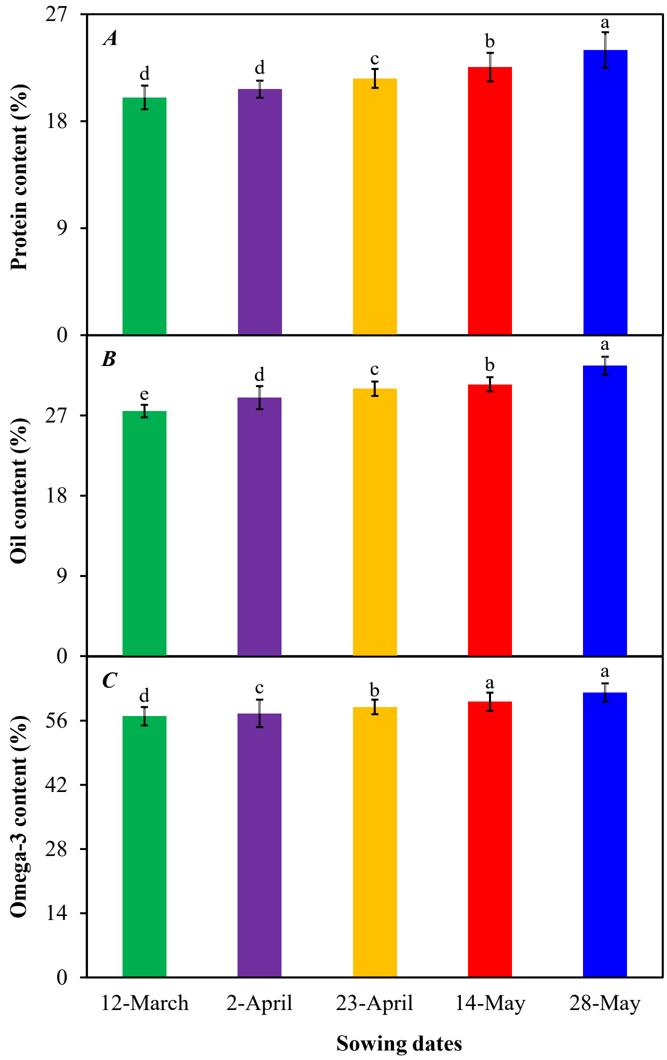

Figure 4: *Effect of sowing dates on protein content (A), oil content (B), and omega-3 content (C) of chia. Each bar represents the mean value of four replications, while the vertical bars indicate standard error of the mean (SEM), showing variability among replications.*

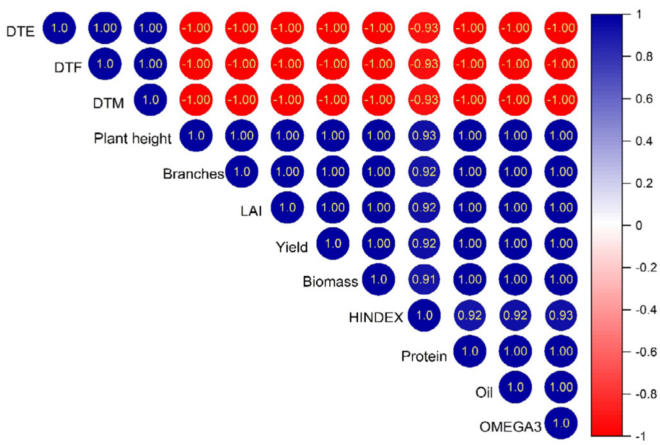

Figure 5: *Pearson correlation among the studied attributes. DTE=days to emergence, DTF=days to flowering, DTM= days to maturity, LAI= leaf area index, HINDEX= harvest index.*

Trait correlations in salvia hispanica l. under varying sowing dates

The correlation matrix analysis demonstrated strong and significant relationships among key morphological, phenological, and biochemical traits of *Salvia hispanica* L. cultivated under different sowing dates in Western Morocco. Days to emergence (DTE), days to flowering (DTF), and days to maturity (DTM) showed a perfect negative correlation with multiple yield and quality parameters. Specifically, DTE, DTF, and DTM were negatively correlated with yield (r = -1.00), biomass (r = -1.00), harvest index (r = -1.00), protein content (r = -1.00), oil content (r = -1.00), and omega-3 fatty acids (r = -1.00). This pattern indicates that delayed phenological development leads to a substantial decline in both yield and seed quality attributes.

In contrast, strong positive correlations were observed among several agronomic traits. Plant height exhibited a high positive correlation with LAI (r = 1.00), yield (r = 0.93), biomass (r = 0.93), harvest index (r = 0.92), protein content (r = 0.92), oil content (r = 0.92), and omega-3 levels (r = 0.92). Similarly, LAI was positively correlated with yield (r = 1.00), biomass (r = 1.00), and seed quality traits such as protein (r = 1.00), oil (r = 1.00), and omega-3 (r = 1.00), demonstrating the importance of canopy development in enhancing photosynthetic capacity and assimilate allocation. Yield showed perfect positive correlations with biomass (r = 1.00), harvest index (r = 1.00), protein (r = 1.00), oil (r = 1.00), and omega-3 content (r = 1.00), indicating that improvements in yield are strongly associated with enhanced nutritional and economic value.

Sowing time significantly affects chia (*Salvia hispanica* L.) phenology, as evidenced by variations in days to emergence, flowering, and maturity across planting dates. Early sowing on 12 March extended the crop duration, whereas later sowings in May accelerated development. Days to emergence declined from 23.8 to 15.3 days with delayed sowing, likely due to higher soil temperatures and improved moisture availability, supporting findings by Martínez-Cuenca *et al.* (2022). Likewise, flowering and maturity were hastened in plants sown on 14 May and 28 May (flowering: 60.5 and 59.7 days; maturity: 88.3 and 87.6 days), compared to 68.2 and 96.2 days under early sowing. This trend aligns with Pradhan *et al.* (2023), who highlighted the role of accumulated growing degree days and photoperiod in advancing reproductive development. A slight delay in flowering (61.8 days) and maturity (89.9 days) under 28 May sowing may be linked to terminal heat or photoperiod stress, as similarly noted by Hernández-Hernández *et al.* (2024).

Sowing date significantly influenced chia (*Salvia hispanica* L.) growth parameters, including plant height, number of branches per plant, and leaf area index (LAI). The tallest plants were observed in the 14 May (104.8 cm) and 28 May (103.9 cm) sowings, suggesting that optimal thermal conditions during early vegetative growth promoted internodal elongation. These findings align with Ali *et al.* (2023), who reported that sowing during warmer periods enhanced chia height and biomass accumulation.

Branch number also peaked on 14 May (20.3) and 28 May (21.1), likely due to better assimilate availability and extended vegetative duration. Similar trends were noted by Hernández-Hernández *et al.* (2024), who found that delayed sowing within an optimal window improves branching and canopy structure. The highest LAI values 4.1 (14 May) and 4.3 (28 May) reflect vigorous canopy development, enhancing light interception and photosynthesis. Da Silva *et al.* (2022) emphasized the role of favorable sowing windows in maximizing LAI and vegetative growth. In contrast, early sowings (e.g., 12 March) had lower LAI (2.3) and height (78.3 cm), likely due to suboptimal early-season temperatures. A slight reduction in growth was observed with the 23 April sowing, with plant height (91.3 cm) and LAI (3.8) decreasing, possibly due to late-season stress and shortened vegetative phases (Martínez-Cuenca *et al.*, 2022).

Variation in seed yield, biomass and harvest index across sowing dates reflects critical influence of planting time on chia productivity. The highest seed yield (1251.9 kg ha^{-1}) and biomass yield (4.6 t ha^{-1}) were measured with the 28 May sowing, while the lowest values (930.7 kg ha^{-1} and 3.9 t ha^{-1}, respectively) were observed with 12 March sowing. This indicates that later sowing aligned better with favorable environmental conditions particularly temperature and light availability during reproductive phase, improving assimilate accumulation and partitioning. Harvest index also improved slightly with delayed sowing, increasing from 23.7% to 26.7%, suggesting more efficient conversion of biomass into economic yield under late sown conditions. These findings emphasize that optimal sowing timing improves not only total biomass but also proportion allocated to seeds. Similar observations were made by Mendoza-García *et al.* (2023), who reported that adjusting sowing time in chia improves yield components by associating phenological stages with optimal climatic conditions, particularly during flowering and grain filling.

Findings demonstrate that delayed sowing significantly improves the protein, oil, and omega-3 fatty acid content of chia seeds. These enhancements are likely associated with more favorable environmental conditions such as optimal temperature, longer photoperiod, and extended seed-filling periods in late spring. The increase in protein content with later sowing agrees with the observations of Jamboonsri *et al.* (2020), who reported that moderate heat stress during seed development enhances protein biosynthesis in chia. Similarly, oil content increased significantly with later sowings, which aligns with the results of Olivos-Lugo *et al.* (2021), suggesting that longer exposure to sunlight and mild temperatures during late phenological stages supports enhanced lipid accumulation in *Salvia hispanica*. Significantly, the steady rise in omega-3 fatty acids, particularly α-linolenic acid, is consistent with the findings of (Zúñiga-López *et al*., 2023; Ahmad *et al*., 2025), who described that late-season sowing increases omega-3 content due to enhanced enzymatic activity in the desaturation pathway under moderate thermal conditions. These results collectively highlight potential role of sowing time in shaping chia's nutritional quality. Delaying sowing until late May optimizes the seed's biochemical composition, offering practical implications for producers targeting high value functional food markets.

The correlation analysis highlights the pivotal role of sowing dates in optimizing the agronomic and biochemical traits of *Salvia hispanica* L. Negative correlations between phenological traits (DTE, DTF, DTM) and key performance indicators such as yield, biomass, oil, and omega-3 content ($r = -1.00$) suggest that delayed development adversely affects crop productivity. Similar outcomes were reported by Ramirez-Lopez *et al.* (2022), emphasizing the risk of late-season stress on chia. Conversely, strong positive correlations were observed between LAI, plant height, and yield components, indicating that enhanced vegetative growth supports better yield and seed quality. These results align with Maheshwari *et al.* (2023), who noted enhanced resource use and assimilate partitioning under optimal planting times. Yield's perfect correlation with oil, protein, and omega-3 content further confirms simultaneous enhancement in quantity and quality, as supported by Zhou *et al.* (2023) and Azeem *et al.* (2024).

Conclusions and Recommendations

Optimal sowing time significantly enhances the growth, yield, and nutritional composition of *Salvia hispanica* L. in Western Morocco. Sowing between 14 and 28 May provides the best alignment of phenology with environmental conditions, promoting greater biomass accumulation, higher seed yield, and improved oil and omega-3 content. Early planting is therefore recommended as a key strategy for maximizing chia productivity in semi-arid Mediterranean regions.

Acknowledgements

The authors have no conflicts of interest regarding this investigation.

Novelty Statement

This study provides the first comprehensive analysis of how sowing date variations influence the growth cycle duration of chia (*Salvia hispanica*) in North Morocco during the Spring season, a region with understudied agro-climatic conditions. Our findings offer region-specific guidelines to optimize chia cultivation enhancing yield stability under mediterranean climates.

Author's Contribution

Aicha Rossafi: Conducted research, data collection and write-up, interpretation of data
Soukaina Njili: Conceptualization, designing, supervision
Mohamed Rossafi: Analysis of data and arrangement of tabulated data and statistical analysis
Mohammed Ouhssine: Helped in format setting and citations, validation of the manuscript

Generative AI or AI assisted technology statement
The authors declare that no generative AI or AI-assisted technology was used in the writing or editing of this manuscript.

Conflict of interest

The authors have declared no conflict of interest.

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