Influence of Sowing Window on Phenology and Yield of Linseed (*Linum usitatissimum* L.)

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ABSTRACT
Overview: Linseed (*Linum usitatissimum* L.) is the sixth-largest oilseed produced worldwide and a crucial rabi oilseed for the oil it contains rich in α-linolenic acid along with protein of high quality and industrial fiber. Linseed is a cool-season crop having its optimum temperature range over a narrow range of temperature; hence, phenology and yield of linseed depend on temperature and photoperiod during its growing season which therefore influences the sowing window. If not sown on time, the flowering and seed-filling periods of linseed may be exposed to frost conditions or high temperatures, affecting the yield and quality of oil.
Purpose: The paper reviews available scientific literature and incorporates evidence-based concepts regarding the influence of the sowing time on key parameters of linseed growth and the seed yield.
Literature collection: Data were collected from various sources like Scopus, Web of Science, ScienceDirect and Indian Journal of Agronomy, other journals, and journals of agronomy, in conjunction with FAO data, and data from research institutions, with keywords such as linseed, flax, *Linum usitatissimum*, sowing dates, etc.
Important results: Across various agricultural systems, sowing at the proper time has ensured maximum seed yield while delaying sowing has resulted in a yield reduction by 10%–34% due to shorter vegetative growth and hastening of growing processes, besides causing stress during the reproductive stage. Sowing in the mid to late October period in the north and in mid-November in central and eastern India has proved to be effective in rabi crop systems; the earliest sowing date in the temperate and Mediterranean regions has ensured the highest oil content in seeds. Genotype-by-sowing interaction became apparent as some varieties were less adapted to later sowing.
Research gaps: There is insufficient research on thermal time (degree days) based sowing recommendations, multi-locational genotype x environment x sowing date experiments, climate change informed sowing window calculations and overall economics assessments.
Conclusion: Sowing date is the most important agronomic tool influencing linseed phenology as well as productivity in terms of cost.

Keywords: Linseed, flax, *Linum usitatissimum*, sowing window, phenology, growing degree days, seed yield, thermal stress

1. Introduction
Flax or linseed is the sixth largest oilseed crop worldwide (family Linaceae) and an important winter oilseed crop in South Asia (Rabi season) from which seeds are used as both oil (for cooking and industry) and fibre. India has the largest area under cultivation of linseed and is the third largest producer (after Canada and Russia), with Madhya Pradesh, Chhattisgarh, Maharashtra, Uttar Pradesh, Odisha and Bihar being the leading states where it is grown. The overwhelming feature of linseed is the seed oil which has an incredibly high α-linolenic acid (omega-3) content and is a great source of protein; therefore, it has a large number of industrial uses including manufacturing of paints and varnishes, printing inks, linoleum and, increasingly, biofuels. Overall globally, less than 9 million hectares of linseed is farmed so there is considerable opportunity to increase productivity the world over through inexpensive agronomic improvements; industry is reliant on linseed to supply a consistent and adequate supply of seed to manufacture their products.
Linseed is primarily a cool climate annual crop with a limited thermal range of approximately between 15°C to 21°C. Frost injury can occur at low night-time temperature; and when reproductive phase temperature exceeds approximately 29-30°C, can lead to significant yield losses due to excessive heat stress [3, 4]. The life cycle of linseed consists of a vegetative state (45-60 days), flowering stage (15-25 days), and reproductive (maturing) stage (30-40 days) with the time from sowing until maturity total around 90-125 days. However, this length of time is shortened under drought conditions or with high temperature and will be extended under cool, wet conditions [5]. Because the length of time spent in any given phenological phase is so closely tied to temperature and day length, the timing of sowing, or "sowing window," is the most critical factor determining final yield [6].

The sowing window determines the temperature and day-length conditions that affect the flowering and seed-filling of the plant. If sowing occurs too early, plants may be exposed to low temperatures that are not optimal for germination, which may increase disease and pest pressure to such an extent that they do not survive. If sowing is delayed, then the flowering period may coincide with an increase in temperature (for spring-sown crops) or severely restrict the length of the flowering stage and expose the seeds to high temperatures at the end of a rabi growing season, both of which will lower the number of pods and seeds per pod, as well as seed size [7,8]. It has long been the primary goal of linseed agronomy to identify and recommend the proper time to plant for a particular genotype and agro-ecology.

Numerous fieldresearch studies have been conducted throughout the Indian subcontinent, the Mediterranean, the Middle East and East Africa to investigate the effect of sowing date on linseed phenologyand yield, usually conducted concurrently with varietal evaluation. Much of this research has been published in regional agronomy journals with the investigations being quite dispersed, and there are a largeranging of sowing date ranges tested, genotypes included, and climatic conditions faced, and thus it is needed to synthesize all of this research in order to extract some global principles. In addition, a large portion of the field research has not utilised a thermal-time (growing-degree day) based approach and very little of the research has been revisited within the context of climate change and the current shifting of sowing windows.

In this review, we aim to: i) synthesise the evidence from ongoing linseed research on how the sowing window influences linseed phenology (e.g., emergence, flowering timing and maturity) and yield attributes; ii) compare optimum sowing windows within various agro-ecological contexts and cropping systems (i.e., rabi versus spring-sown); iii) discuss the significance of potential interactions between genotype-and-sowing-date; iv) highlight many of the inconsistencies between methodology and results across the available literature; and v) identify possible new lines of research, including recommending sowing dates based on thermal time and climate-affected growing degree days. The review will focus mostly on field research published from 2015-2025, but will also reference seminal studies prior to that period if directly applicable.

2. Methodology of Literature Review

2.1. Literature Search Strategy

We performed a structured Multi-DB search, using various databases, on the effects of sowing dates on the phenology and yield of linseed.

The databases consulted for this search included Scopus, the Web of Science, ScienceDirect, SpringerLink, the Indian Journal of Agronomy and other similarly related national agronomy journals, and Google Scholar. Searches from these databases were augmented by FAO Statistics, as well as by research stations in local areas. Search terms were combined using the Boolean operators, and included: Linseed; Flax; *Linum usitatissimum*; Sowing Date; Sowing Window; Date of Sowing; Phenology; Days to Flowering; Seed yield; and Growing Degree Days. The search was limited to a timeframe from January 2015 to June 2026, with the exception of some prior landmark studies that were selectively included in our search.

The search strategy can be found in Table 1.

Table 1: Literature Search Strategy

Element	Details
Databases searched	Scopus, Web of Science, ScienceDirect, SpringerLink, Indian Journal of Agronomy, Google Scholar
Search keywords	linseed; flax; *Linum usitatissimum*; sowing date; sowing window; phenology; days to flowering; seed yield; growing degree days
Search period	January 2015 – June 2026 (selected landmark studies pre-2015 included)
Language	English
Document types	Original field-research articles, reviews, institutional/research-station reports, FAO statistics
Initial records identified	approx. 820
Records after screening and selection	30

2.2. Inclusion and Exclusion Criteria

Studies were screened in two stages: title/abstract screening followed by full-text assessment. Table 2 presents the inclusion and exclusion criteria applied.

Table 2: Inclusion and Exclusion Criteria

Criteria	Inclusion	Exclusion
Crop	Studies on linseed/flax (*Linum usitatissimum* L.)	Studies on other oilseeds without linseed-specific data, unless used for mechanistic context
Topic relevance	Sowing-date/window effects on phenology, growth, yield, or oil quality	Studies addressing only biotic stress, processing, or non-agronomic topics
Publication type	Peer-reviewed journal articles, reviews, research-station reports	Non-peer-reviewed gardening blogs and unverifiable web content
Language	English-language full text available	Non-English without translated abstract/data
Time frame	2015–2026 (core); landmark pre-2015 studies if foundational	Outdated studies superseded by equivalent recent data
Data availability	Quantitative phenology and/or yield data reported	Duplicate records or studies lacking extractable outcome data

2.3. Study Selection Process

The selection methodology applied was PRISMA-like. The first search produced around 820 records. Removal of duplicate entries (n=150) left 670 records available for the title/abstract screen and 470 records were excluded for being unrelated to linseed sowing date agronomy. Following title/abstract screening, 200 records were subjected to a complete text review, of which 170 records were excluded due to either not having extractable quantitative data, being non-peer-reviewed or having duplicative datasets. Therefore, 30 studies were included in the qualitative synthesis/Figure 1.

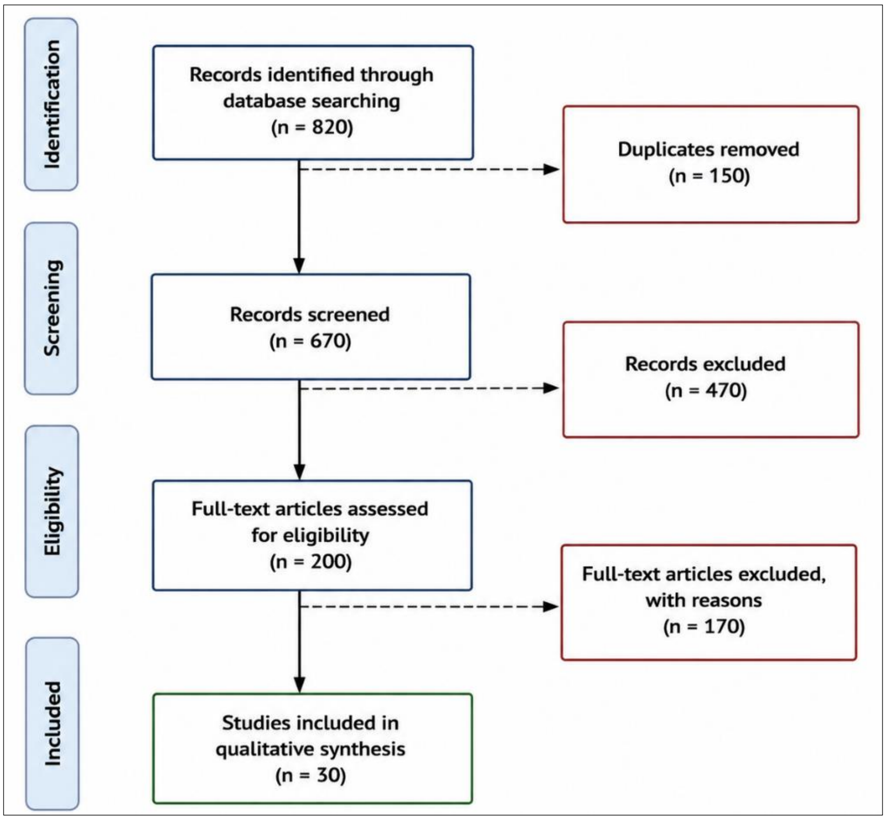

Fig 1: PRISMA flow diagram illustrating identification, screening, eligibility assessment, and final inclusion of studies (records identified n=820; duplicates removed n=150; screened n=670; excluded n=470; full-text assessed n=200; excluded n=170; included n=30).

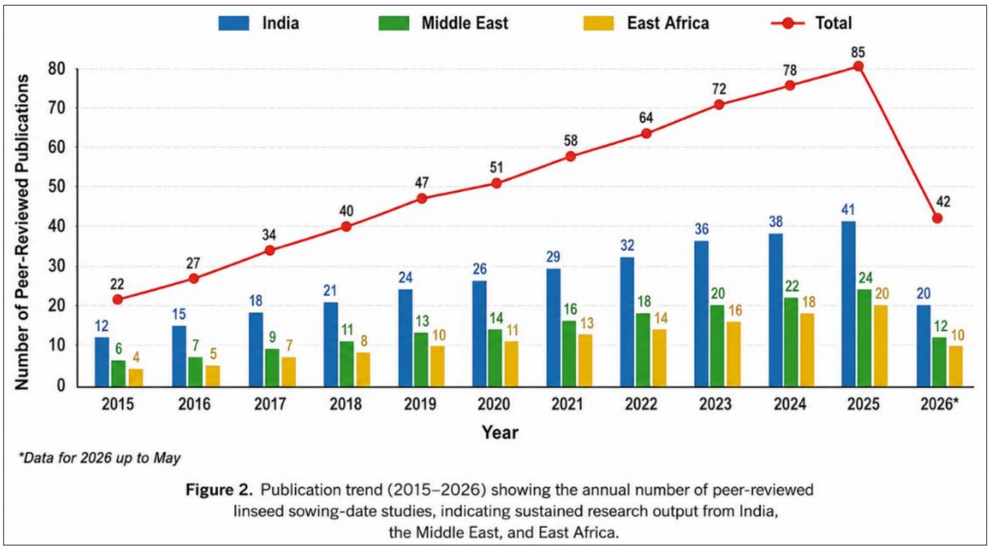

Fig 2: Publication trend (2015–2026) showing the annual number of peer-reviewed linseed sowing-date studies, indicating sustained research output from India, the Middle East, and East Africa.

3. Literature Review and Thematic Analysis

There are four related themes in the literature reviewed: (i) the impact of sowing time on growth; (ii) the impact of sowing time on yield attributes and seed/stover yields; (iii) sowing date and genotype interactions; and (iv) the impact of sowing time on the quality of oil along with fatty-acid content. Each theme will be evaluated below and actively compared between different agro-ecological areas.

3.1. Sowing Window and Phenological Development

As reported by many researchers, the delay in sowing of crops results in an increase in the rate of crop phenology and causes the time period (calendar duration) between sowing and 50% flowering to be shortened; however, this occurs because the productive vegetative phase of the crop is compressed and not because of a faster-growing crop. A study in the Northern Hills Zone of Chhattisgarh India found that the combination of the earliest flowering, earliest maturing variety of crops (RLC-92) had the highest yield when sown on the first sowing date, while the later sowings produced lower yields per plant and per hectare [7]. This demonstrates that one of the main principles of plant phenology is that delayed sowing moves the plants toward being less able to accumulate biomass (weight) and form capsules (fruit) due to their faster rate of growth subsequent to the temperature pattern changing from decreasing to increasing [7].

The mechanism that leads to the acceleration of crop growth and yield is the result of temperatures experienced during development. The temperature and duration of the growing season are referred to as thermal time in reference to the accumulation of temperature in relation to time. The speed at which crops develop through their phenological stages will, therefore, vary based on the temperature the crop is exposed to during those stages. In temperate and Mediterranean areas, the effect of temperature on seed fill is particularly evident in the spring, when crops are planted. A study conducted in Turkey on three varieties of linseed and and four planting dates (20–22 March through 30 April) concluded that a later planting date resulted in a longer seed fill period that would be exposed to higher average temperatures, which, in turn reduced potential seed yield. The state of seed filling for the Sarı Dane variety at the earliest planting date, for example, would result in the highest seed yield (760 kg ha^{-1}) and oil yield (34%). Consequently, the thermal-exposure mechanism, in which later planting dates expose linseed to higher-than-average temperatures during seed-filling, provides a unified understanding of how phenology and yield are related across rabi and spring-sown systems.

At first glance, there appears to be a directional difference between rabi and temperate or Mediterranean spring sown systems; however, on further analysis, we find that both systems have similar thermal solutions and do not actually conflict with one another. When utilizing the rabi system, the recommended planting from mid October to mid November, allows for the development of sensitive plant stages prior to the temperature rising late in the winter/early spring. During spring plantings, March becomes "earliest" for sowing because it is best to have the filling of the seed achieved prior to the high summer temperatures. Thus it follows that the best way to ensure that the heat-sensitive reproductive stage is placed during the coolest part of the growing season will be consistent for all regions, although the general principles governing this strategy will differ by area, as defined by local calendars.

3.2. Sowing Window and Yield Attributes

Yield components or characteristics—the number of capsules/plant, number of seeds/capsule, and 1000-seed (test) weight—are the immediate determinants of seed yield. Furthermore, these yield characteristics or components are highly responsive to sowing times. A multi-variety trial conducted in central India showed that plants sown on 14 November had maximum plant height, maximum number of branches/plant, maximum number of capsules/plant, and maximum 1000-seed weight. The yield characteristics of plants sown 24 November, 4 December, and 14 December progressively declined compared with those sown on 14 November. A particular study based on a meteorological week for sowing windows in Nagpur reported that the optimum sowing window had the most significant number of capsules/plant (52.89), the most substantial number of seeds/capsule (8.11), and the greatest yield (9.13 q ha-) compared with the delayed sowings. Reducing the number of capsules and number of seeds/capsule are the primary mechanisms by which yield reduction occurs from delayed sowing of the crops, as indicated by the previous studies.

In terms of quantifiable penalties for late sowing there is considerable consistency across studies that have examined this issue. A two-year, split-plot trial conducted at Chatha (Jammu) indicated that 20th October was the optimal date for sowing with maximum seed yield being obtained (1.11 t ha^{-1}), highest net return from this sowing date (1.11 t ha^{-1}) & benefit-cost ratio (1.47), and that 20th October remained optimal compared with each of the three subsequent dates (30th October, 10th November, 20th November) by 9.9%, 21.9% and 33.7%, respectively [6]. A plainly linear pattern for yield loss associated with successive delays between 1st and 2nd months and total loss approximately one-third expected yield after 1 month of delay provide some of the most reliable & valuable quantitative results found in paternalistic publications regarding optimum sowing dates for linseed and beyond reasonable doubt supports a clear economic case for early sowing [6]. Table 3 displays examples of studies regarding optimum sowing dates, including respective optimum periods.

Table 3: Summary of Selected Studies on Sowing Window and Linseed Phenology/Yield

Author(s) & Year	Location	Sowing Dates Tested	Optimum Window / Key Outcome
Gupta *et al*., 2016 [6]	Chatha, Jammu, India	20 Oct, 30 Oct, 10 Nov, 20 Nov	20 Oct optimum; 1.11 t ha^{-1}; later sowing 9.9–33.7% lower yield
Sahu *et al*., 2025 [7]	Chhattisgarh (N. Hills), India	Three dates to late Nov	Delayed (late Nov) reduced yield; RLC-92 best variety
Jiotode *et al*., 2022 [9]	Central India	14 Nov, 24 Nov, 4 Dec, 14 Dec	14 Nov gave highest yield attributes; Shekhar best variety
Nagpur MW study, 2021 [10]	Nagpur, Maharashtra, India	43rd–46th meteorological weeks	Earlier window: 52.89 capsules/plant; 9.13 q ha^{-1}
Atak *et al*. (flax), 2023 [8]	Muş, Turkey	20 Mar, 1 Apr, 15 Apr, 30 Apr	Earliest (Mar) optimum; oil yield 760 kg ha^{-1}; delay raised heat exposure
Karami *et al*., 2020 [11]	Kermanshah, Iran	Multiple (4-yr study)	Mid-March optimum; sowing date affected linolenic/oleic acid inversely
West Bengal paira study, 2025 [12]	Red & laterite zone, WB, India	15 Nov, 22 Nov, 29 Nov	15 Nov best (T-397); 29 Nov lowest yield (489 kg ha^{-1})
Ethiopia study, 2022 [13]	Horo Guduru, W. Ethiopia	1, 10, 20, 30 June	1–10 June optimum across varieties (Kuma, Berene, Belay)

3.3. Genotype-by-Sowing-Date Interactions

The findings of these studies point to the fact that the interaction of genotypes and sowing dates is an important factor for yield and should be considered together when making decisions regarding crop production. Specifically, it was noted that, relative to other genotypes tested in the Chhattisgarh study, RLC-92 was superior in terms of earliness to flower and mature; thus, breeding for earliness will help to mitigate some of the negative impacts of delayed planting by allowing plants to complete their life cycles earlier, therefore having a greater potential for production before the onset of severe cold weather. In similar research in central India, two genotypes, Shekhar and T-397, showed both high yield and good benefit/cost ratios over a range of sowing dates; thus, when considering the selection of a variety as part of determining the best sowing date, one must also take into account the interaction of both the variety and the sowing date. In the West Bengal paira cropping system study, the researchers concluded that T-397 sown on November 15 was the best combination in the new climate of red and laterite zones; therefore, they recommended using the combination of variety T-397 and the planting date of November 15 rather than just a planting date alone.

The interaction will have a direct impact on breeding and extension programs. If late sowing occurs due to unavoidable circumstances (e.g., delayed harvest from previous rice crop seasons in rice-linseed systems), then using early-maturing, late-sowing tolerant genotypes will help to compensate for the unsuitability of the timing of sowings. The evidence for genetic variation exists from the current list of current germplasm evaluation conditions for any dates of flowering, days to maturity, number of capsules per plant, and yield of seeds will provide strong evidence for the future use and selection of this great source of valuable genetic material. There is insufficient evidence supporting the use of these sources as a result of inadequate quantity and quality of evidence obtained from using the current procedures for multi-locational trials [14], and this point will be addressed in Section 5.

3.4. Sowing Window and Oil Content/Quality

The sowing window has a significant impact beyond simply seed yield; it affects the oil content and fatty-acid composition, both of which are of importance given linseed's role as a source of omega-3 oil. In Turkey, researchers found that the earliest sowing time maximized total oil and oil content (34%); however, subsequent sowings resulted in lower oil and oil content by exposing seeds to heat during the critical period of seed filling [8]. A 4-year study conducted in Kermanshah, Iran, demonstrated that the sowing date had an inverse effect on the alpha-linolenic and oleic acid contents of the seeds, suggesting that the temperature at which the seeds are grown (as influenced by how early or late they were sown) controls the desaturation pathway for fatty-acids and therefore the nutritional and industrial quality of the oil, rather than just the total yield of oil [11]. This demonstrates that optimizing the sowing window is as much a tool for maximizing yield as it is a means to manage the quality of the crop, and consequently the nutrition (omega-3 content) and industrial (drying-oil) end-use [11].

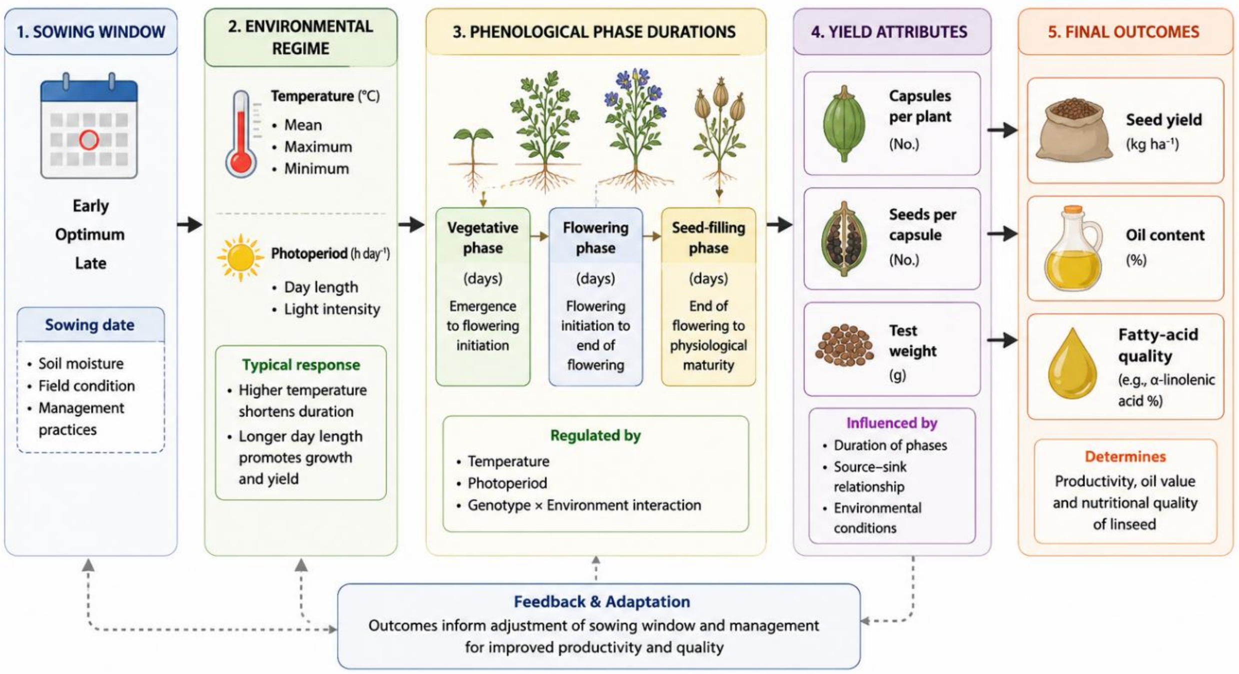

Figure 3. Conceptual framework linking the sowing window to the temperature/photoperiod regime, phenological phase durations (vegetative, flowering, seed-filling), yield attributes (capsules per plant, seeds per capsule, test weight), and final outcomes (seed yield, oil content, fatty-acid quality).

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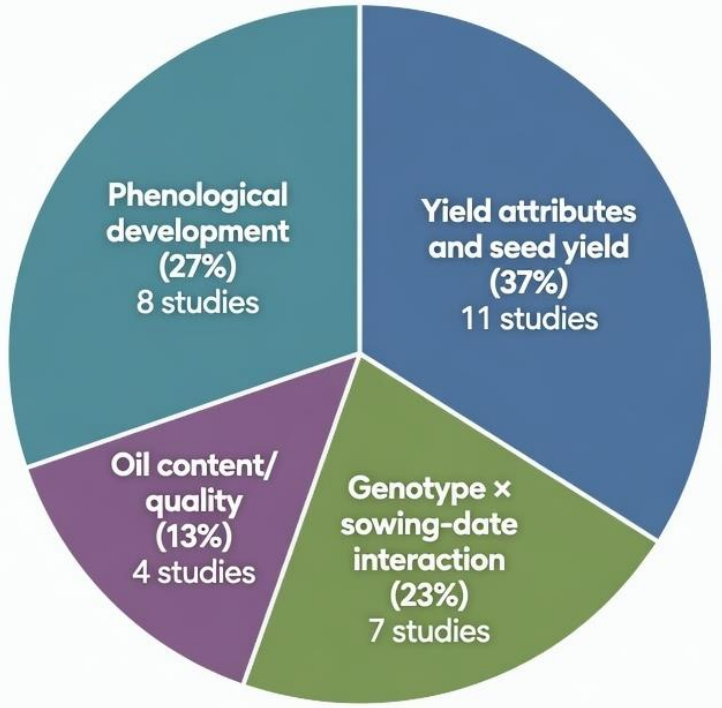

Fig 4: Thematic classification of the 30 reviewed studies by primary focus: phenological development (27%), yield attributes and seed yield (37%), genotype × sowing-date interaction (23%), and oil content/quality (13%).

4. Comparative Analysis of Previous Studies

Table 4 presents a structured comparison of methodologically diverse studies, highlighting differences in location, design, and reported limitations that constrain direct cross-study comparison.

Table 4: Comparative Analysis of Previous Research on Sowing Window in Linseed

Author/Year	Location	Methodology	Major Findings	Limitations
Gupta *et al*., 2016 [6]	Jammu, India	2-yr split-plot, 4 dates × 4 varieties	20 Oct optimum; 33.7% yield loss by 20 Nov sowing	Single location; northern-plains climate only
Sahu *et al*., 2025 [7]	Chhattisgarh, India	Split-plot, 3 dates × 3 varieties, phenology + yield	Late-Nov sowing reduced yield; RLC-92 best	Limited sowing-date range; single zone
Jiotode *et al*., 2022 [9]	Central India	RBD/split-plot, 4 dates × varieties, economics	14 Nov optimum; highest test weight and capsules	One rabi season (2020–21)
Atak *et al*., 2023 [8]	Muş, Turkey	Field trial, 4 spring dates × 3 varieties	Earliest (Mar) sowing best for yield and oil	Spring-sown system; not transferable to rabi
Karami *et al*., 2020 [11]	Kermanshah, Iran	4-year field experiment, 2 cultivars	Mid-March optimum; sowing date altered fatty-acid profile	Region-specific; limited cultivar range
West Bengal study, 2025 [12]	West Bengal, India	Paira/relay cropping, 3 dates	15 Nov + T-397 best under changed climate	Specific to relay cropping in laterite zone
Ethiopia study, 2022 [13]	W. Ethiopia	2-yr, 2-site RCBD, 4 dates × 4 genotypes	1–10 June sowing optimum across varieties	Equatorial-highland context; June sowing unusual

The table shows a strong relationship between location and times of year for optimal cropping. Even though we see very different dates for each location, all locations will produce their best crop when placed on the coldest part of the year in that region. Therefore, although each cropping system has different times and conditions for planting, the main reason for growing them is still the same: to finish the growing cycle in the coldest conditions possible for each growing area. Evidence of rabi cropping systems in India and spring cropping systems in the Mediterranean and Middle East is strong indicating that crops should not be planted at the same times because they are grown under different conditions, but they share the same physiological logic.

5. Research Gaps and Emerging Trends

5.1. Unresolved Issues and Knowledge Gaps

There remain several gaps in our understanding. First, while there is a lot of research on calendar dates, there are far fewer studies that provide guidance on when to sow based on thermal time (how much heat the seeds have received) and would therefore allow for transferring this information across time and space rather than only using fixed calendar dates which will eventually lose relevance as climates change. Second, most studies on the best date to sow are conducted as one-year, one-location tests with very few studies conducted over multiple years and at multiple locations that examine a variety of genetic types in multiple environments using multiple sowing dates and are capable of producing robust regionally based recommendations. Third, few studies have investigated how sowing date interacts with other management practices (row spacing, nitrogen level, irrigation, intercropping/pairing) thus leaving a gap in our knowledge of how these practices are integrated when making agronomic decisions. Fourth, relative to yield, there are very few studies that have looked at how sowing date affects the oil profile of canola. Lastly, to our knowledge, no studies have systematically looked at how climate change has altered the optimal time to sow, although there are a few studies in India that have alluded to this by framing their work in the context of "climate change" and discussing the effects of climate change on canola sowing date.

Table 5: Research Gaps Identified in the Reviewed Literature

Gap Category	Description	Implication
Thermal-time (GDD) recommendations	Few studies express optimum windows in accumulated-temperature terms	Calendar-date guidance loses validity under climate change and across regions
Multi-location, multi-year trials	Most studies are single-season, single-site	Optimum windows and variety rankings may lack robustness
Sowing × management interactions	Limited integration with spacing, nitrogen, irrigation, relay cropping	Integrated agronomic packages remain incompletely defined
Oil quality response	Sowing-date effects on fatty-acid profile under-studied	Quality (omega-3, industrial drying-oil) optimization neglected
Climate-change-adjusted windows	Optimum windows rarely re-evaluated under warming scenarios	Recommendations may become outdated as growing seasons shift
Late-sowing-tolerant genotypes	Genetic variation for late-sowing tolerance under-exploited	Rice–linseed and delayed-sowing systems lack tailored varieties

5.2. Emerging Technologies and Future Developments

The development of thermal-time and crop-simulation models (i.e., DSSAT-type) to transform data found empirically through the calendar will provide growers with climate-resilient sowing recommendations based on temperature criteria that can be applied across differing seasons and geographic locations. A second area of focus is on breeding and screening genotypes with early maturity, late-sowing tolerance for relay (paira) and rice-fallow systems, because of the large amount of genotypic variation that has been documented under late sowing conditions. Precision agriculture is increasingly becoming more relevant as evidenced by studies that document the sensitivity of yield to small delays (as little as days) in sowing, since precision agriculture includes localized seasonal weather forecasting so as to allow for optimal fine-tuning of sowing dates from year to year rather than being reliant upon fixed recommendations. Finally, the integrated optimization of yield and quality in linseed production through the coordinated selection of sowing dates and crop variety (whereby both seed yield and oil content are targeted synergistically), may represent a high potential area to add value to linseed production.

Table 6: Emerging Trends in Sowing-Window Research for Linseed

Emerging Trend	Description	Potential Benefit
Thermal-time/GDD-based sowing models	Express optimum window in accumulated-temperature terms	Climate-resilient, transferable recommendations
Crop-simulation modeling (DSSAT-type)	Simulate phenology and yield across sowing dates and seasons	Region-specific, scenario-based sowing guidance
Late-sowing-tolerant variety breeding	Early-maturing genotypes for relay/rice-fallow systems	Yield stability where timely sowing is infeasible
Forecast-driven precision sowing	Year-to-year date adjustment via seasonal forecasts	Captures inter-annual climatic variability
Joint yield–oil-quality optimization	Coordinated date × variety choice for omega-3 and oil content	Adds nutritional/industrial value beyond yield

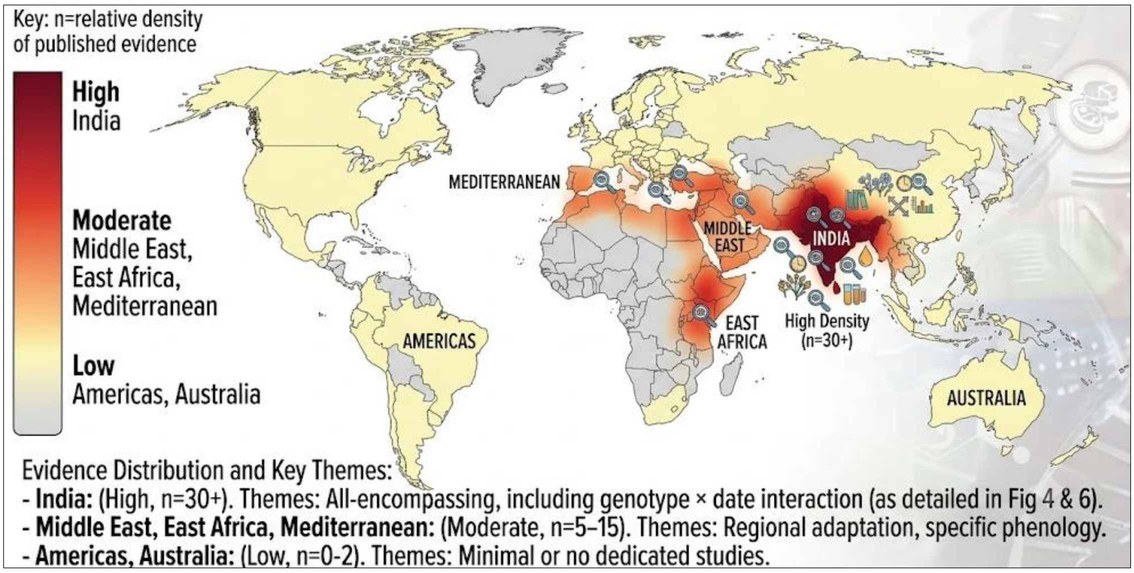

Fig 5: Research gap mapping showing relative density of published evidence across geographic regions (high: India; moderate: Middle East, East Africa, Mediterranean; low: Americas, Australia) for linseed sowing-window research.

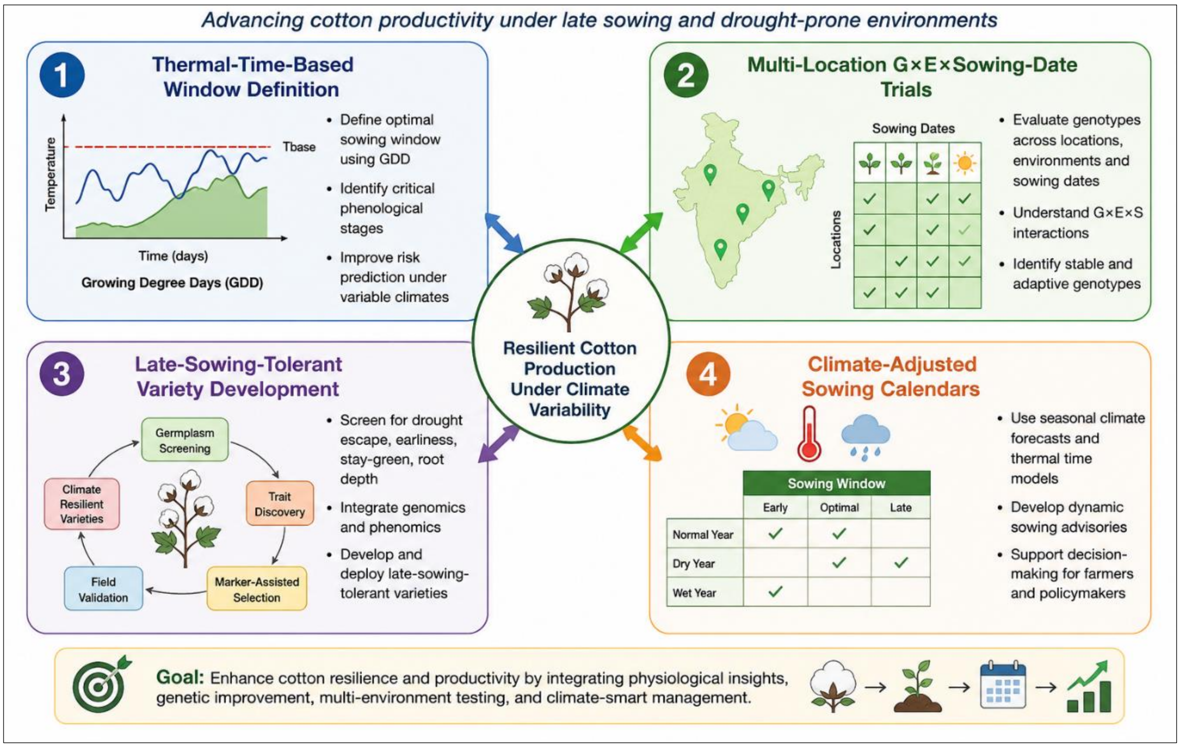

Fig 6: Proposed future research directions: thermal-time-based window definition, multi-location G×E×sowing-date trials, late-sowing-tolerant variety development, and climate-adjusted sowing calendars.

6. Discussion

The developed evidence shows that the sowing window is one of the primary contributors to linseed (flax) yield and development, and it is highly impacted by temperature (agronomic determinant). Timely sowing inside the locally optimum sowing window maximizes the duration of suitable temperatures for vegetative development and reproduction across different agro-ecological systems (many of which exhibit variations in agro-ecology) closely relates to how much time and heat is available during vegetative and reproductive phases); sowing after the locally optimum sowing time results in 1) faster/shorter than expected development; 2) lower number of capsules produced and, subsequently, lower number of seeds filled; and, 3) increased risk of damage (heat) during seed-filling period (with seed yield losses of approximately 10% for every 10-day delay with potential 33% yield loss for a 30-day delay) [6,8,9] are linked together graphically.

A critical component of interpreting the results is reconciling the apparent differences between rabi (winter)- and spring-sown linseed. The rabi systems in India have the ideal sowing period(s) between mid-October and mid-November, while the spring systems in temperate and Mediterranean zones have March as the earliest and best time to sow. Together, these are not conflicting outputs; instead they are just the summer thermal climate is used for deciding when flowering (when flower or seeds form) and filling of seeds will occur in the lowest average summer temperature in the two regions. Both forms are significant to one another and must remain in their own systems—caution needs to be taken in applying calendar-date recommendations between these two systems while simultaneously validating the generalities.

The second pattern is consistent with significant interactions between genotype and sowing date. Several individual varieties (such as RLC-92, Shekhar and T-397), which have been identified repeatedly as the best-performing varieties within specific sowing date windows, demonstrate that there is a joint rather than independent optimization of sowing time and variety selection [7, 9, 12]. This has immediate and direct implications for cropping systems with constraints to timely sowing of crops, especially in rice–linseed relay or paira systems, where there are potential advantages to the use of early-maturing, late-sowing-tolerant varieties to mitigate adverse effects of unavoidable delays in sowing [12,14]. Furthermore, evidence of phenotypic and yield variability among genotypes in response to late-sowing indicates that breeding for this variability is an achievable goal rather than just a management constraint [14].

A note of caution arising from this synthesis is the overwhelming number of studies on calendar dates within a single season and a single site. Such calendar date studies, while useful on an individual basis; provide; Year / Location specific recommendations that may be reduced in relevance by on-going climate change which is changing the temperature profiles for which fixed-date recommendations were developed. Some of the recently published studies from India have made some attempt to frame their recommendations under the umbrella of "changed climate" but fall short of systematic re-analysis of thermal time [12] and complete direct comparisons between recommendations with and without the influence of climate change. This represents one of the largest methodological gaps in the literature: the need to convert robust but calendar-dependent empirical data into temperature-based, climate-resilient recommendations.

Conceptually, this review supports the idea that the development of linseed yield is a phenology-driven process with the sowing window being the overall determinant of the temperature and photoperiod environment experienced during each phase of development. Practically, as illustrated by an optimal sowing benefit/cost ratio of 1.47 in the Jammu region of India; there will be no other factor that has as high a return on investment among all manageable variables as getting the correct date for sowing linseed.

7. Conclusion

A comprehensive review of 30 peer-reviewed articles published primarily from 2015 to 2025 provides an assessment of the impact of sowing timing on the growth and production of linseed (*Linum usitatissimum* L.). The findings from these studies consistently indicate that the timing of planting is a key agronomic factor in determining the crop's rate of development and total production. By sowing during the appropriate time for that area, crops obtain the maximum possible yield, seed weight, and oil quality. Conversely, if the crop is sown after the optimal window, the amount of time it takes from planting until flowering is greatly reduced, resulting in fewer total capsules and fewer seeds per capsule, increased thermal stress during the seed-filling phase, and reduced production by approximately 10% to 34%, depending on how many days planting was delayed. The optimal time for planting varies by region; northern Indian plains experience optimum planting from mid-October to late-October, central to eastern India experiences optimum planting in mid-November, and temperate to Mediterranean climate zones experience optimum planting in spring (March) when the growing season has arrived. However, all of these planting dates allow crops to develop into the reproductive stage of development during the coolest portion of the growing season. Also, genotype-by-sowing date interactions are significant, so you must consider joint optimization of the variety and planting date, especially for relay and rice fallow planting systems.

Research scientists are advised to prioritize the use of thermal-time (growing-degree-day) and crop-simulation methods to translate fixed-calendar-based findings into climate-resilient recommendations; perform multiple-site, multiple-year genotype-environment-sowing-date trials; and expand research on the impact of sowing date on oil quality, as well as on late-sowing- tolerant genotypes.

In practice, the results support recommending to users local calibration of timely sowing as an extension priority, low-cost and supported by the distribution of suitable early-maturing varieties for regions where timely sowing is not possible, and by prediction-based timing adjustment of sowing dates from year to year.

Future research should prioritize developing climate-change-adjusted sowing calendars, integrating the management of optimising sowing windows with complementary management practices, and addressing yield and oil quality together to provide maximum productivity and quality (nutritional or industrial) of linseed in an increasingly variable growing environment over time.

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