

Yield Response of Pigeonpea to Staggered Sowing Dates Under Rainfed Conditions in the Deccan Plateau

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ABSTRACT

Pigeonpea (Cajanus cajan) is a deep-rooted, long-season legume grown on rainfed farms across the Deccan Plateau, and sowing date is one of the few management levers a smallholder can pull without buying anything. Advice on when to sow is nevertheless inconsistent, and field reports that compare staggered sowings often disagree. This narrative review asks why. It draws on published work on pigeonpea phenology and its response to photoperiod and temperature, on the general literature on planting date and crop yield, on monsoon variability in peninsular India, and on the biology of the main insect pest and diseases, and it reports no new data. The central difficulty is that the response to sowing date is not a property of the crop alone. It depends on the genotype and its photoperiod sensitivity, on how rainfall happens to fall in a given season, and on pod borer pressure, which shifts with the timing of flowering and with what else is flowering nearby. Because most field series are short, spanning few seasons and few sites, these effects are hard to separate from one another and from chance. We organise the evidence around a simple appraisal framework, explain why reported optima rarely transfer, and set out what a sowing-date series would need to record to be useful beyond the season in which it was run.

Keywords: Pigeonpea; *Cajanus cajan*; Sowing date; Rainfed agriculture; Deccan Plateau; Phenology; Narrative review

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1. Introduction

Pigeonpea (*Cajanus cajan*) is one of the main pulse crops of the semi-arid tropics, and the Deccan Plateau is among the regions where it is most closely woven into farm life. It is usually grown without irrigation, often in association with cereals or cotton, and it is valued as a protein source and as a legume that leaves some nitrogen and a better soil behind it [1, 2]. Its genome was sequenced only recently, and the crop is still described as an

orphan legume of resource-poor farmers [3]. For a household that cannot buy water or much else, the date on which the seed goes into the ground is one of the few decisions that costs nothing.

That makes the question of sowing date appealing, and slightly treacherous. Most agronomists would say that sowing date matters for rainfed pigeonpea, because it fixes the weather the crop meets at emergence, at flowering and at pod fill. Few would agree on a single best date. Field

comparisons of staggered sowings are common, yet their conclusions are uneven: an early sowing wins in one season and loses in the next, and a late sowing that looked like a mistake turns out well in a year when the rains linger.

This review looks at why. We do not report new field data, and we do not give yield figures from any trial. Instead we ask what the published literature says about how pigeonpea develops, how sowing date interacts with the rainfall of peninsular India, and how pod borer and disease pressure complicate the picture, and we ask what a staggered-sowing series would need to record before its result could be trusted beyond the season in which it was run. The aim is a fair account of what is known, and of what is merely repeated from one leaflet to the next.

The article is a narrative review. Much of the work on planting date comes from other crops and regions, and we say so where it matters. The pigeonpea-specific literature that we can cite with confidence is thinner than the confidence of some advisory messages would suggest, and part of the purpose of the review is to be clear about that gap.

2. Literature Review

2.1 Pigeonpea in Rainfed Systems

Pigeonpea is a perennial by origin, grown as an annual, with a deep taproot and an indeterminate habit that lets it keep flowering and setting pods while conditions allow. Cultivars span a wide range of duration, from short types that mature early to long types that occupy the field through the post-monsoon period and are harvested well after the cereals around them. The long types in particular are managed as a bet on stored soil water.

Several features explain the crop's role. It fixes atmospheric nitrogen through its root nodules, like other grain legumes [2, 4], and it has been described as unusually able to take up phosphorus from soils where the element is poorly available, which helps it in low-input systems [5]. Its genomic resources are now better than they were, and the breeding literature stresses how much of the crop's adaptation depends on flowering behaviour [3, 6]. Flowering behaviour, in turn, is what sowing date acts upon.

2.2 Phenology: Photoperiod and Temperature

Pigeonpea is generally described as a short-day plant, in which flowering is hastened when days shorten, but the strength of the response differs a great deal between genotypes. Work on predicting the flowering of pigeonpea has treated the

response to day length and temperature as two components that can be separated and modelled [7]. A cultivar with strong sensitivity will flower at close to the same calendar time whenever it is sown within a broad window, while a cultivar with weak sensitivity will flower after a more constant thermal duration, so that later sowing moves flowering later.

The practical consequence is large and often overlooked. For a photoperiod-sensitive type, sowing date changes the length of the vegetative phase far more than it changes the date of flowering, so an earlier sowing mostly buys a bigger plant. For an insensitive type, it shifts the whole crop calendar. A trial that compares dates for one cultivar therefore answers a question about that cultivar, and the answer should not be read as a statement about pigeonpea as a whole. The general literature on how annual crops time their flowering says the same [8, 9], and the molecular work on seasonal cues explains why variation in the response is so common [10]. Temperature adds to this: warmth hastens development, variability during flowering can affect yield independently of the mean [11], and extremes at sensitive stages leave marks that averages hide [12]. This is why the same crop can look excellent in one report and unremarkable in the next.

2.3 What the Wider Planting-Date Literature Shows

A global analysis of planting dates shows how strongly sowing is tied to climate, with farmers in most regions sowing when temperature or rainfall first allows [13]. Within that envelope, the effect of moving the date depends on the crop and the place. A study of maize in the central United States attributed part of the long-term yield increase to earlier planting, which shows how much of what looks like improved genetics or inputs can in fact be a change in timing [14]. For late-sown soybean, environmental and management effects on yield were quantified separately, which is the kind of decomposition that sowing-date trials in pigeonpea rarely attempt [15].

Planting date is also often named as an adaptation to a changing climate. A meta-analysis of crop yield under climate change and adaptation found that changes in planting date and cultivar can raise yields on average, though the benefit varied with crop and region [16], and analyses of food security stress the same uncertainty [17]. Neither singles out pigeonpea, and the lesson here is caution about borrowing a result from another

crop.

2.4 Rainfall Variability on the Deccan

Rainfed farming on the Deccan depends on the south-west monsoon, whose onset, breaks and withdrawal differ from one year to the next [18]. Analyses of Indian agriculture link much of the year-to-year variation in output to that rainfall and to temperature [19]. There is also evidence of a rising trend in extreme rain events over central India, which implies that the total received in a season can be delivered in an increasingly uneven way [20].

This matters for sowing date because the same calendar date is not the same agronomic event in two years. A crop sown on a fixed date after a late monsoon onset may have little moisture to emerge on, while the same date after an early onset may find the soil already wet and the first flush of weeds well advanced. Dry spells at flowering or pod fill are also unpredictable. The literature on crop water stress describes how drought affects growth, flowering and yield formation at different stages [21, 22], and on how crops might be managed when water is scarce [23]. A sowing-date series covering a handful of seasons samples only a few of the possible rainfall patterns. A recommendation that holds only in the wettest year on record is not one a farmer can plan around.

2.5 Pod Borer, Disease and Their Timing

The pod borer *Helicoverpa armigera* is widely regarded as the most damaging insect of pigeonpea, and a review of the crop's insect pests and their management gives it that place alongside several others [24]. The insect feeds on many hosts and moves between them as the season advances, so that the pressure on pigeonpea at flowering depends on what else is flowering and fruiting in the landscape [25]. Its capacity to spread was shown when it appeared in Brazil [26], and warming is expected to change the development rates and the synchrony of herbivorous insects with their hosts [27].

Sowing date therefore changes the match between flowering and pest populations, in a direction that cannot be stated in advance. A crop that flowers early may escape a late build-up, or it may flower into the first generation of the season; a late-flowering crop may face a population that has already grown on other hosts. Diseases add to the uncertainty. Sterility mosaic, a disease associated with a mite-transmitted virus [28], is influenced by the presence of infected plants and vectors nearby, so that the date of sowing relative to

neighbouring crops, as well as to the rainfall, can matter. Table 1 sets out the principal sources of confounding that these processes introduce.

2.6 Modelling and Genotype-by-Environment Thinking

Crop models are often proposed as a way around the shortage of multi-season field data, and they can help to say which processes could matter for a given sowing date [29, 30]. They are only as good as their inputs and the understanding built into them, and critiques of crop-climate models point to weaknesses in how they represent stress and phenology [31]. For pigeonpea, which has strong genotype-specific flowering and indeterminate growth, a model parameterised for one cultivar says little about another. The older genotype-by-environment tradition asks instead whether a response is stable across environments [32, 33], which treats sowing date as part of the environment, but it needs many environments, and most rainfed pigeonpea series supply few.

Table 1. Sources of confounding in short sowing-date series.

Source	How it distorts the comparison	What to record
Genotype	Photoperiod sensitivity differs; one optimum cannot serve all [6, 7]	Maturity group, flowering dates
Seasonal rainfall	Same sowing date meets different rain each year [18, 20]	Daily rainfall, dry spells, stored water
Pod borer pressure	Damage varies with flowering time and neighbours [24, 25]	Scouting counts, sprays, damage scoring
Disease	Sterility mosaic and wilt differ by season and site [28]	Incidence by plot and date
Few seasons	Chance cannot be told from signal [35]	Number of site-seasons, not only plots
Soil and fertility	Phosphorus supply modifies growth [5]	Soil test, amendments, previous crop

Note: The third column lists records that would let a later reader separate the effect of sowing date from the confounder.

3. Materials and Methods

3.1 Scope and Question

The review asks a single question in two parts. Why do reports of the yield response of pigeonpea to sowing date disagree under rainfed conditions on the Deccan Plateau, and what would a sowing-date series need to record to be informative beyond its own seasons? We divided it into sub-questions about phenology, rainfall, pests

and diseases, and the design and length of the series. None of these steps is hard, but each one is easy to leave out when a season is short of time.

3.2 Literature Assembly

The review draws on peer-reviewed work in five areas: pigeonpea biology, genomics and cropping systems; photoperiod and temperature control of flowering; planting date and yield in other crops; monsoon variability and rainfed agriculture in India; and the ecology of the main pod borer and the diseases of the crop. Sources were chosen for relevance, standing in the field and the clarity of their methods. Studies of other crops are used for what they teach about the structure of the problem, not as evidence of effects in pigeonpea.

We did not run a formal systematic search and we do not claim one. This is a narrative synthesis in the sense described for narrative reviews generally [34], and the selection of sources reflects the authors' judgement. The practical consequence is that the review is a better guide to how a sowing-date series should be designed and read than to the precise size of any effect, and it does not quote yield figures from individual pigeonpea trials that could not be checked against the primary papers for this article.

3.3 Appraisal Framework

To judge how much weight a sowing-date report can carry, we used four questions. Which genotype was grown, and is its flowering response described? What rainfall did each sowing date actually meet, including dry spells? Was pod borer or disease pressure recorded and managed in the same way across dates? And how many seasons and sites does the result rest on, given what is known about the unreliability of small bodies of evidence [35]? Table 2 collects the physiological expectations against which such reports were read.

4. Results

4.1 What Sowing Date Changes

The literature agrees on the mechanisms even where it disagrees on the optimum. Sowing date changes the length of the vegetative phase for sensitive types, the temperature and light the crop meets [7, 8], the moisture available at flowering and pod fill [18, 23], and the timing of flowering against insect populations [24, 25]. Each of these effects can raise or lower yield, and they can work in opposite directions in the same plot.

Table 2. Expected contrasts between early and late sowing in rainfed pigeonpea.

Attribute	Earlier sowing	Later sowing
Length of vegetative phase	Longer; more time to build frame [7]	Shorter; frame may be small [8]
Flowering time	Set mainly by genotype and day length [7, 9]	Pulled forward by short days and warmth [8]
Moisture during pod fill	Depends on how long the rains last [18]	Often on stored soil water only [23]
Early-season risk	Dry spell or waterlogging while small [21]	Weeds and crowding before canopy closes
Pod borer exposure	Flowering may precede or overlap peaks [24, 25]	Flowering may meet a built-up population [25]
Interaction with other crops	Longer overlap with a companion crop	Companion crop already well established

Note: Qualitative expectations drawn from the cited physiological literature; they are not measurements and their size varies with genotype and season.

Yield itself is the end product of radiation captured over the life of the crop and of how that biomass is partitioned to seed [36, 37]. A longer vegetative phase can mean more captured radiation and a bigger frame, but it does not guarantee more seed if the pod-filling period then falls into dry weather [22]. Traits that raise yield potential in one environment can fail in another [38], and the components of yield respond to environment with differing plasticity [39]. Pigeonpea, with its extended flowering, probably spreads these responses over a longer period than a determinate crop, which dilutes any single event but also makes the effect of a given date harder to read. Such differences look small in a single season, yet they decide whether a crop pays its way.

4.2 Why Reported Responses Disagree

Figure 1 sketches the situation in a way that makes the disagreement easier to follow. Three sowings meet the same seasonal rainfall at different crop stages, and the overlap of flowering with the build-up of pod borers also shifts. Which sowing is favoured depends on where the rain stops and where the pest peak falls in that particular season, neither of which can be fixed in advance. A series run in a season of late rain will favour later sowings, and one run in a season of early cessation will favour earlier ones. A result described as the best date for one site and year is, in effect, a description of that season. A farmer cannot choose the season, only the date, and the date has to be judged against a spread of seasons.

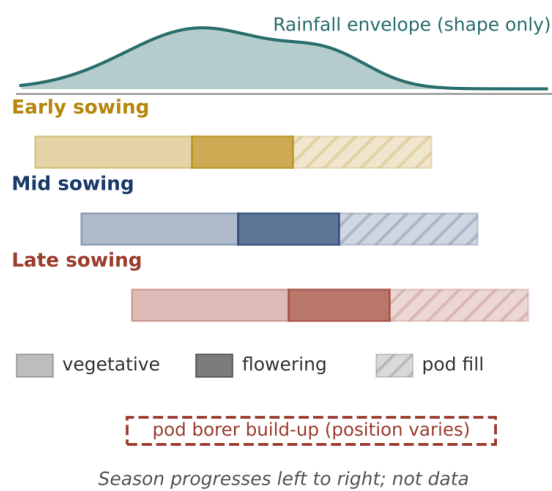


Figure 1. Schematic season timeline showing how staggered sowings meet rainfall, flowering and pest windows differently (not data; bar positions are illustrative).

Genotype adds a second source of disagreement. Because photoperiod sensitivity differs, trials with different cultivars are not comparing the same thing even when the dates match, and a recommended window for one maturity group should not be applied to another [6, 7]. Figure 2 shows, schematically, that the leading concern changes with both axes of the problem. Positions in the grid are illustrative, and the cell contents are not findings. Read this way, the absence of a clear date effect in a short series is not evidence that none exists.

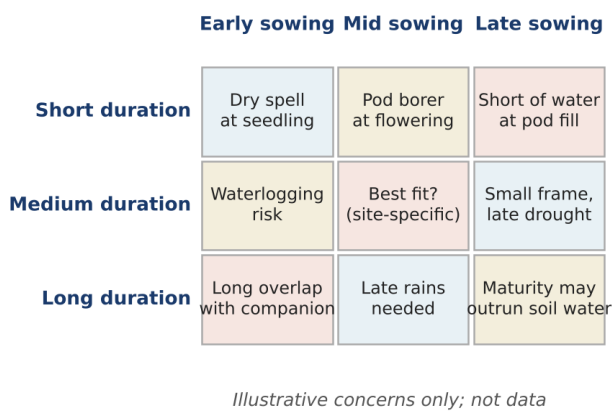


Figure 2. Qualitative matrix of genotype maturity group against sowing window, showing the dominant concern in each cell (schematic, not data).

A third source is the short length of most series. A study covering few seasons at a single site cannot separate a real response to date from the particular weather of those years, and small bodies of evidence tend to overstate effects when they reach significance [35]. The monsoon varies greatly [18] and extremes appear to be changing [20], so a few seasons are unlikely to sample it fairly. Table 3 sets out what each kind of evidence

can say.

Table 3. What each kind of evidence can and cannot say about sowing date.

Evidence type	Can say	Cannot say
Single-season staggered sowing	Which date did best that year	Whether it will in another year [16]
Multi-season series at one site	Spread of outcomes across rain patterns [18]	Whether other soils respond alike
Multi-site, multi-season trials	Stability of a response [32, 33]	Mechanism, without phenology records
Crop model simulation	Which processes could matter [29, 30]	Real outcomes if inputs are poor [31]
Farmer experience	Local fit and risk tolerance	Cause of a good or bad year

Note: A reading of the evidence types discussed in the text, not a ranking of individual studies.

4.3 Pest and Disease Interactions

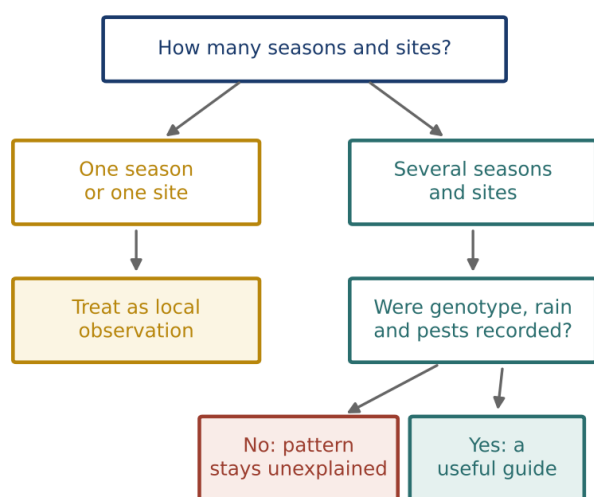
Pod borer pressure complicates every reading of a sowing-date series. If damage is not scored and sprays are not recorded in a uniform way, a difference in yield between dates may reflect a difference in damage and not in the crop’s potential. The pest is mobile and polyphagous [25, 26], so plots sown on different dates within one trial are not independent: moths move between them.

4.4 Interaction with Companion Crops and Fertility

Most pigeonpea on the Deccan is not grown alone, and the companion crop alters the effect of sowing date. A pigeonpea sown after a vigorous companion is shaded and slowed in its early growth, whereas one sown before it has more time to establish. Fertility matters as well, since the crop’s ability to mine phosphorus [5] and fix nitrogen [2, 4] influences how it responds to the soil it is sown into, and these differ between fields. Intensification of rainfed systems has to be judged against such site factors, not on yield alone [40].

4.5 Reading a Claim About the Best Date

A reader meeting a claim that a particular window is best can ask a short sequence of questions, set out as a path in Figure 3. How many seasons and sites support it? Were genotype, rainfall and pest pressure recorded well enough to explain the pattern? If the answer to the first question is a single season, the claim is best treated as a local observation. If several seasons and sites are involved, but the covariates were not recorded, the pattern may be real but remains unexplained, and the claim is a hypothesis for the next series.



Schematic decision path, not data

Figure 3. Decision path for reading a sowing-date report (schematic).

5. Discussion

5.1 Interpretation and Practical Reading

The main finding of this review is a conditional one. The response of rainfed pigeonpea to sowing date is not a fixed property of the crop. It is the product of the genotype and its photoperiod behaviour, the rainfall of the season, and the pest and disease pressure at the time of flowering, and each of these varies from year to year [7, 18, 24]. A single best date is therefore the wrong thing to look for in a short series, and a window with its conditions is more defensible. Nothing here argues against adjusting sowing date; it argues for recording enough to know what the adjustment achieved.

The second point concerns risk rather than average. A farmer with little margin may reasonably prefer a date that performs acceptably in most seasons to one that performs very well in a few and poorly in others. Short series report, at best, a mean; the spread across seasons is what the farmer needs [11, 32]. Staggering sowings across fields or across the weeks of the sowing window, which spreads exposure to dry spells and pest peaks, may be worth more than any single optimum, though the pigeonpea evidence is too thin to say so with confidence.

5.2 Limitations

This is a narrative review and shares the limitations of that form. The selection of sources reflects judgement, no formal search or quality scoring was done, and the review does not quote yield figures from individual pigeonpea trials, because these could not be checked against the primary reports for this article. A reader who

needs an effect size should consult the original studies, applying the appraisal questions above, or wait for a formal systematic review.

The review also relies on evidence from other crops and from general physiology, which are imperfect proxies for rainfed pigeonpea on the Deccan. The planting-date literature is richer for maize and soybean than for pulses [14, 15], and we have used it to frame hypotheses, not to transfer conclusions. The cited pigeonpea literature is also thin on direct field comparison of sowing dates, which is itself a finding. Reviews of this kind are more useful when they say where the evidence stops than when they smooth the edges over.

5.3 Implications for Trial Design

A series that could settle the question would run for many seasons and at several sites, with the number of site-seasons, not the number of plots, treated as the real sample size. It would include cultivars from at least two maturity groups, record flowering dates for each plot, keep daily rainfall, and score pod borer damage and disease in the same way across dates. It would be laid out so that plots sown on different dates are not spaced in a way that makes them share pest populations without that being noted, and it would include the companion crop where that is the local practice.

5.4 Directions for Future Work

Three needs stand out. First, a formal systematic review of sowing-date studies in pigeonpea, with a transparent search and quality appraisal. Second, coordinated multi-site trials on the Deccan that share a protocol and record the covariates listed in Table 1. Third, work that couples such trials with phenology models, so that the effects of photoperiod, temperature and rainfall can be separated rather than merely noted [7, 30]. A fourth, more practical need is for advisory material that states the conditions behind any recommended date, and, where possible, ties sowing to the first effective rain of the season instead of a fixed day [19]. These points apply with equal force to many rainfed legumes, not only to pigeonpea.

6. Conclusion

Sowing date matters for rainfed pigeonpea, but the published evidence does not support a single best date for the Deccan Plateau. The response depends on the genotype, on how the rains fall in a given season and on the timing of pod borer and disease pressure, and most of the available series are too short to separate these. What the literature does show is why the reported optima disagree,

what a more informative series would record, and how a reader can judge a claim about timing.

For the practitioner, the message is practical rather than discouraging. Sowing can be adjusted, preferably in response to the rains of the season and with a cultivar suited to their likely length, and a few simple records kept from year to year will say more about the farm than any general rule. For the researcher, the opportunity is a set of coordinated, longer, better-recorded series that turn an old agronomic question into one the evidence can answer.

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9. Conflict of Interest

The authors declare no conflict of interest.

10. Author Contributions

E.P. conceived the review and wrote the sections on rainfall and crop meteorology. S.Z. wrote the sections on agronomy and cropping systems. A.B. wrote the sections on crop physiology and trial design. All authors revised the manuscript and approved the final version.

11. Ethics Statement

This is a review of published literature. No human participants or animals were used and no ethical approval was required.

12. Data Availability

No new data were generated. All sources are cited in the reference list.

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