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## MAPPING SIX DECADES OF GLOBAL RESEARCH ON SOYBEAN BREEDING FOR DROUGHT TOLERANCE AND POD-SHATTERING RESISTANCE: A BIBLIOMETRIC ANALYSIS (1959–2025)

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### SUMMARY

Drought stress and pod shattering are critical constraints in soybean (*Glycine max*) cultivation. The independent breeding strategies have progressed for each trait, and their integration remains limited. The global bibliometric analysis of soybean improvement research from 1959 to 2025 focuses on drought tolerance and pod-shattering resistance. The analyzed Scopus-indexed articles using the Bibliometrix Biblioshiny R package and VOS-viewer totaled 914. The analysis comprised general information, top authors, core journals, affiliations, citation impact, conceptual framework, and research gaps. Results showed a significant increase in publications after 2010, driven by molecular tools (quantitative-trait loci [QTL] mapping, genome-wide association study [GWAS], and ribonucleic acid sequencing, or RNA-seq) and high-throughput phenotyping. China and the USA lead in productivity and collaboration, with Northeast Agricultural University and the University of Missouri as key institutions. Core journals include Crop Science and Frontiers in Plant Science, while J.E. Specht emerges as the most influential author. The analyses using conceptual and co-occurrence revealed that drought tolerance is central in soybean research, while pod shattering remains peripheral. This

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imbalance highlights a research gap and need for integrated, multi-trait studies. The study proposes a novel hypothesis linking both traits through ABA–auxin hormonal crosstalk, with the *PDH1* (*Pod Dehiscence1*) gene identified as a potential regulatory hub. Integrating these traits is essential for developing climate-resilient soybean cultivars.

**Keywords:** Bibliometric analysis, breeding strategies, conceptual structure map, drought stress, pod dehiscence, Scopus database

**Key findings:** The bibliometric analysis of 914 publications (1959–2025) revealed the research on soybean breeding for drought tolerance and pod-shattering resistance has significantly intensified since 2010, driven by advances in molecular tools and high-throughput phenotyping, with China and the USA emerging as leading contributors. Drought tolerance emerges as a dominant factor, while pod shattering remains comparatively underexplored.

## INTRODUCTION

Global agriculture faces increasing challenges from the escalating impacts of climate change (Farag *et al.*, 2025). Among the most critical threats is the rising frequency and severity of drought, which significantly limits crop production, particularly in dryland regions (Vila-Traver *et al.*, 2021; Dai *et al.*, 2023). In addition to climate risks, growing populations and rapid land-use changes intensify concerns over future food security (Berners-Lee *et al.*, 2018; Abbass *et al.*, 2022). With the global population projected to surpass 9.7 billion by 2050, boosting agricultural productivity on marginal lands, like drylands, is truly urgent (Arora, 2019; Verma *et al.*, 2025). Dryland areas, characterized by limited rainfall and extended dry seasons, require the cultivation of crop varieties adapted to water-limited and other abiotic stresses to support sustainable agricultural expansion (Dama *et al.*, 2022; Wang *et al.*, 2023; Chaffai *et al.*, 2024; Wibisono *et al.*, 2024).

Soybean (*Glycine max* L. Merr.), a key legume and major source of dietary protein and oil, plays a vital role in meeting global food and nutritional demands (Dilawari *et al.*, 2022). However, soybeans are susceptible to environmental stress, particularly during their reproductive phase. Drought during flowering and seed development reduces water content, root biomass, chlorophyll levels, and, ultimately, yield (Desclaux *et al.*, 2000; Dogan *et al.*, 2007; Darmadi *et al.*, 2021; Waqar *et*

*al.*, 2022). It also disrupts photosynthesis, nitrogen metabolism, and nutrient allocation (Wijewardana *et al.*, 2019; Basal *et al.*, 2020; Du *et al.*, 2020).

In addition to drought, pod shattering represents another critical issue in soybean cultivation. It means the dehiscence, or splitting of pods when exposed to dry, hot conditions, leading to significant yield losses during harvest (Dong and Wang, 2015; Liu *et al.*, 2019). Under favorable conditions, seed losses due to pod shattering may average around 10%, but in arid environments, losses can exceed 50%, and in extreme cases, the loss reaches 100% in susceptible varieties (Tefera *et al.*, 2009; Khan *et al.*, 2013; Funatsuki *et al.*, 2014; Zhang *et al.*, 2018).

Drought stress and pod shattering are interconnected challenges in soybean cultivation, as water deficit accelerates pod desiccation and increases the risk of seed loss through premature dehiscence. Recent findings show that pod indehiscence is not solely a mechanical trait but also an adaptive response shaped by precipitation patterns. Yong *et al.* (2023) reported loss-of-function alleles of the *PDH1* gene and its orthologs were independent choices in several warm-season legumes cultivated in dry regions. These alleles both reduce pod shattering and provide adaptive advantages in drought-prone environments, as indehiscent pods can retain seeds even when plants experience water deficit before harvest. This finding indicates the ecological and genetic relatedness between drought tolerance and

pod shattering, reinforcing the need to consider both traits simultaneously in soybean breeding.

Breeding for drought tolerance and pod-shattering resistance using physiological and genetic approaches has made significant progress in previous decades. However, understanding the global research landscape, collaboration patterns, evolving priorities, and gaps in this field remains limited. Therefore, this study aimed to map global research on soybean breeding for drought tolerance and pod-shattering resistance from 1959 to 2025 through a comprehensive bibliometric analysis.

## MATERIALS AND METHODS

### Data collection and search strategy

This study's methodology was quantitatively descriptive. The conduct of bibliometric analysis used the Scopus database to identify global scientific publications related to soybean breeding for drought tolerance and pod-shattering resistance (Sweileh, 2020; Caputo and Kargina, 2022). The data retrieval began on May 27, 2025, using a structured multi-step search and filtering strategy (Donthu *et al.*, 2021).

The initial query using keywords TITLE-ABS-KEY (soybean OR soybeans OR "*Glycine max*" OR "soy bean" OR soy) yielded 198,332 papers. Refining the results applied additional filters, including terms related to drought, pod shattering, and breeding. These were AND TITLE-ABS-KEY (drought OR "drought stress" OR "water stress" OR "water availability" OR "water content" OR droughts OR "drought tolerance" OR "drought tolerant" OR "water deficit" OR "pod shattering" OR "pod dehiscence" OR "pod cracking" OR "pod-shattering" OR pod OR pods OR dehiscence OR shattering). Another was AND TITLE-ABS-KEY (breeding OR "plant breeding" OR biotechnology OR technology), and they yielded 1,536 papers.

Further refinement continued by applying inclusion criteria, limiting the results to English-language journal articles published between 1959 and 2025 with a final publication

status. Exclusion criteria also ensued to remove papers with irrelevant keywords, such as "Nonhuman," "Priority Journal," "Human," "Unclassified Drug," "Computer Vision," "Antennas," and "Hexapoda." After applying all criteria, the final dataset consisted of 914 relevant articles for bibliometric analysis.

### Data export and pre-processing

The preparation of the dataset for analysis had the search results exported from Scopus in CSV (comma-separated value) format (Ejaz *et al.*, 2022). The CSV file was the primary format used in the Bibliometrix Biblioshiny R-package and VOS-viewer software. A data cleaning process helped remove duplicates and irrelevant entries (Chen *et al.*, 2009). However, no removal of records occurred, with all 914 articles retained for further analysis.

### Data analysis and visualization

The analysis sought to obtain comprehensive insights into various aspects of the research landscape, including general information on the bibliometric dataset, identification of core journals, most prolific authors and their scholarly impact, leading affiliations, and the most cited publications. Additionally, the study explored the evolution of research focus over time, mapped the conceptual structure of the field, and identified existing research gaps. All performed analyses used Microsoft Excel 2019, the Bibliometrix Biblioshiny R-package, and VOS-viewer, which supported data processing, visualization, and clustering (Ghorbani, 2024; Zhou *et al.*, 2024).

## RESULTS AND DISCUSSION

### General information of bibliometric dataset

The bibliometric profile of soybean breeding for drought tolerance and pod-shattering resistance research from 1959 to 2025 (Table 1), encompassing 914 Scopus-indexed articles across 344 journals, highlights a dynamically expanding field. A significant increase in

**Table 1.** Main information of articles included in the bibliometric analysis.

| Description                     | Results   |
|---------------------------------|-----------|
| Main information about data     |           |
| Timespan                        | 1959:2025 |
| Sources (Journals)              | 344       |
| Documents (Articles)            | 914       |
| Annual Growth Rate %            | 4.93      |
| Document Average Age            | 8.48      |
| Average citations per doc       | 18.92     |
| References                      | 36995     |
| Number of articles              |           |
| 2011-2025                       | 755       |
| 2001-2010                       | 100       |
| 1959-2000                       | 59        |
| Document contents               |           |
| Keywords Plus (ID)              | 2570      |
| Author's Keywords (DE)          | 2268      |
| Authors                         |           |
| Authors                         | 3611      |
| Authors of single-authored docs | 29        |
| Authors collaboration           |           |
| Single-authored docs            | 29        |
| Co-Authors per Doc              | 6.22      |
| International co-authorships %  | 19.04     |

publication output occurred after 2010, accounting for over 80% of the total articles and reflecting an annual growth rate of 4.93%. The research is notably collaborative, with an average of 6.22 co-authors per document and 19.04% of publications involving international co-authorship, underscoring the global and interdisciplinary nature of soybean studies. The average citation rate of 18.92 citations per article and a cumulative reference count exceeding 36,000 indicate strong academic influence and engagement. With an average document age of 8.48 years, the dataset reflects a balance between foundational literature and recent advances, positioning soybean breeding for drought tolerance and pod-shattering resistance research as a mature yet continually evolving domain.

### Core journals in the field

The source impact analysis identifies Crop Science as the leading journal in soybean breeding research for drought tolerance and pod-shattering resistance (Table 2), based on the highest h-index (21), g-index (37), and

total citations (1643). Frontiers in Plant Science emerged as a rapidly growing and influential platform, distinguished by the highest m-index (1.462), reflecting strong annual citation performance since its launch in 2013. Established journals, such as Theoretical and Applied Genetics and Field Crops Research, demonstrate a sustained contribution to the field, while journals like Euphytica and Breeding Science offer moderate, focused outputs. Recent entries, including Agronomy and the Journal of Plant Registrations, show emerging potential and suggest a diversification of publication venues for soybean research. These findings highlight both the foundational and evolving publication landscape within this research sphere.

### Most prolific authors and their impact

The author impact analysis identifies key contributors in soybean breeding research addressing drought tolerance and pod-shattering resistance (Table 3). Wang, X., from Jilin Agricultural University, China, leads in both h-index and m-index, indicating

**Table 2.** Source impact of the top 10 journals publishing on soybean breeding research for drought tolerance and pod-shattering resistance.

| Journals                             | h_index | g_index | m_index | TC   | NP | PY_start |
|--------------------------------------|---------|---------|---------|------|----|----------|
| Crop Science                         | 21      | 37      | 0.568   | 1643 | 37 | 1989     |
| Frontiers in Plant Science           | 19      | 32      | 1.462   | 1096 | 47 | 2013     |
| Theoretical and Applied Genetics     | 13      | 21      | 0.295   | 715  | 21 | 1982     |
| Field Crops Research                 | 12      | 19      | 0.343   | 732  | 19 | 1991     |
| BMC Plant Biology                    | 10      | 14      | 0.625   | 568  | 14 | 2010     |
| Euphytica                            | 10      | 16      | 0.333   | 269  | 20 | 1996     |
| Journal of Plant Registrations       | 8       | 13      | 0.571   | 226  | 35 | 2012     |
| Agronomy                             | 7       | 11      | 1.4     | 147  | 31 | 2021     |
| Breeding Science                     | 7       | 7       | 0.333   | 123  | 7  | 2005     |
| Journal of Agronomy and Crop Science | 7       | 11      | 0.175   | 190  | 11 | 1986     |

h\_index: the number of articles from that journal with at least the same number of cited and referenced articles; g\_index: give more weight to highly-cited journals; m\_index: takes into account years since the first publication and is more relevant to an earlier career of the journal than the h-index; TC: times cited; NP: number of publications; and PY\_start: year started.

**Table 3.** Top 10 contributing authors in the field of soybean breeding research for drought tolerance and pod-shattering resistance.

| Author      | Affiliation                       | Country | h_index | g_index | m_index | TC  | NP | PY_start |
|-------------|-----------------------------------|---------|---------|---------|---------|-----|----|----------|
| Wang X      | Jilin Agricultural University     | China   | 14      | 21      | 1.167   | 472 | 30 | 2014     |
| Purcell LC  | University of Arkansas            | USA     | 13      | 17      | 0.5     | 848 | 17 | 2000     |
| Li Y        | Northeast Agricultural University | China   | 11      | 20      | 0.917   | 419 | 27 | 2014     |
| Chen P      | University of Missouri            | USA     | 10      | 22      | 0.476   | 506 | 32 | 2005     |
| King CA     | University of Missouri            | USA     | 10      | 12      | 0.526   | 658 | 12 | 2007     |
| Li H        | Jilin Agricultural University     | China   | 9       | 15      | 0.6     | 431 | 15 | 2011     |
| Li S        | University of Missouri            | USA     | 9       | 17      | 1.125   | 297 | 25 | 2018     |
| Sinclair TR | University of Missouri            | USA     | 9       | 11      | 0.257   | 621 | 11 | 1991     |
| Wang Y      | Northeast Agricultural University | China   | 9       | 14      | 0.6     | 411 | 14 | 2011     |
| Zhang Y     | Northeast Agricultural University | China   | 9       | 15      | 1.125   | 254 | 15 | 2018     |

h\_index: the h-index identifies the highest number of an author's papers with the same or higher number of citations; g\_index: the g-index attempts to give more weight to highly-cited papers; m\_index: the m-index takes into account years since the first publication and is more relevant to an earlier career of the researcher than the h-index; TC: times cited; NP: number of publications; and PY\_start: year started.

consistent and high-impact contributions since 2014. Purcell, L.C., from the University of Arkansas, records the highest total citations, reflecting long-standing influence. Several early-career researchers—including Li Y, Li S, and Zhang Y—demonstrate rapid impact accumulation, as shown by their high m-index values. The University of Missouri emerges as a prominent institution, with five authors in the top 10, highlighting its central role in the research network. Overall, the dominance of Chinese and American authors underscores the leadership of these countries in advancing multi-trait soybean improvement.

### Analysis of the most relevant affiliation

The analysis of institutional affiliations in soybean breeding research for drought tolerance and pod-shattering resistance reveals China leads in publication output, with seven of the 10 most productive institutions (Table 4). Northeast Agricultural University ranks first with 254 articles, followed closely by the University of Missouri (USA) with 240 articles and the University of Arkansas (USA) with 199 articles. These three institutions collectively represent a significant portion of global research in this area. Other major agricultural

**Table 4.** Most relevant affiliation in publications of soybean breeding research for drought tolerance and pod-shattering resistance.

| Affiliation                               | Country | Number of articles |
|---|---------|--------------------|
| Northeast Agricultural University         | China   | 254                |
| University of Missouri                    | USA     | 240                |
| University of Arkansas                    | USA     | 199                |
| Nanjing Agricultural University           | China   | 149                |
| Jilin Agricultural University             | China   | 108                |
| Institute of Crop Sciences                | China   | 108                |
| Heilongjiang Bayi Agricultural University | China   | 58                 |
| Guangzhou University                      | China   | 53                 |
| Iowa State University                     | USA     | 47                 |
| Northeast Normal University               | China   | 41                 |

**Table 5.** Most globally cited documents on soybean breeding research for drought tolerance and pod-shattering resistance.

| Paper                              | Total Citations | TC per Year | Normalized TC |
|------------------------------------|-----------------|-------------|---------------|
| Specht JE, 2001, CROP SCI          | 435             | 17.40       | 6.53          |
| Ni Z, 2013, PLANT MOL BIOL         | 283             | 21.77       | 8.18          |
| Pandey P, 2017, FRONT PLANT SCI    | 211             | 23.44       | 6.55          |
| Iizumi T, 2016, ENVIRONRESLETT     | 176             | 17.60       | 5.61          |
| Gilbert ME, 2011, J EXP BOT        | 167             | 11.13       | 3.38          |
| Li H, 2011, BMC PLANT BIOL         | 158             | 10.53       | 3.20          |
| Liu S, 2013, AGRIC WATER MANAGE    | 153             | 11.77       | 4.42          |
| Sinclair TR, 2007, FIELD CROPS RES | 151             | 7.95        | 4.61          |
| Jin J, 2010, FIELD CROPS RES       | 150             | 9.38        | 3.17          |
| Hufstetler EV, 2007, CROP SCI      | 139             | 7.32        | 4.24          |

universities and national institutes, reflecting a broad and coordinated research infrastructure, further support China's prominence. In contrast, the United States has fewer representative institutions, but those involved demonstrate high individual productivity, reinforcing their status as key global contributors to soybean improvement research.

Agroecological challenges in its major soybean-growing regions largely drive China's dominance in this field. Climate change has notably impacted agriculture in Northeast China, a key soybean-producing region, through rising temperatures and increased drought frequency, especially during the crop-filling stage (August-September). Between 1998 and 2017, drought frequency rose by 25% compared to 1961–1980, leading to substantial yield losses in soybean—up to 21.8% during severe drought years (Wang *et al.*, 2020).

### Most cited papers

The analysis discloses a mix of foundational and rapidly emerging studies in the most globally cited documents on soybean breeding for drought tolerance and pod-shattering resistance research (Table 5). Specht, J.E. *et al.* (2001) holds the highest total citation count (435), underscoring its long-standing influence. Although more recent studies, such as Ni, Z. *et al.* (2013) and Pandey, P. *et al.* (2017), demonstrate greater annual and normalized impact, with normalized TC values of 8.18 and 6.55, respectively. These findings emphasize the growing visibility of recent publications, particularly those addressing molecular and physiological responses to drought stress. High-impact journals, such as *Crop Science*, *Plant Molecular Biology*, and *Frontiers in Plant Science*, consistently serve as platforms for widely cited research. The data

suggests a trend toward increasing citation velocity for newer studies, reinforcing the urgency and relevance of research on climate-resilient soybean traits.

### Evolution of research focus in the field

The thematic trend map illustrates a significant evolution in soybean research terminology from 1990 to 2024 (Figure 1). Some terms (e.g., "seed filling," "relationship," and "stress") appeared earlier but with lower frequency or limited growth, indicating they are either niche topics or foundational but less central in current discourse. A clear upward trend exists in the diversity and frequency of terms used since 2000, with a sharp increase after 2010, suggesting accelerated growth in soybean research. The emergence of terms such as "phenotyping," "high-throughput," "GWAS," and "RNA-seq" indicates a strong shift toward molecular and data-intensive approaches. Meanwhile, core agronomic themes like "drought," "resistance," and "yield" remain dominant, underscoring their continued relevance. This trend signifies a growing emphasis on integrating advanced technologies with key traits, which points to the importance of multi-trait strategies to address future challenges in soybean improvement.

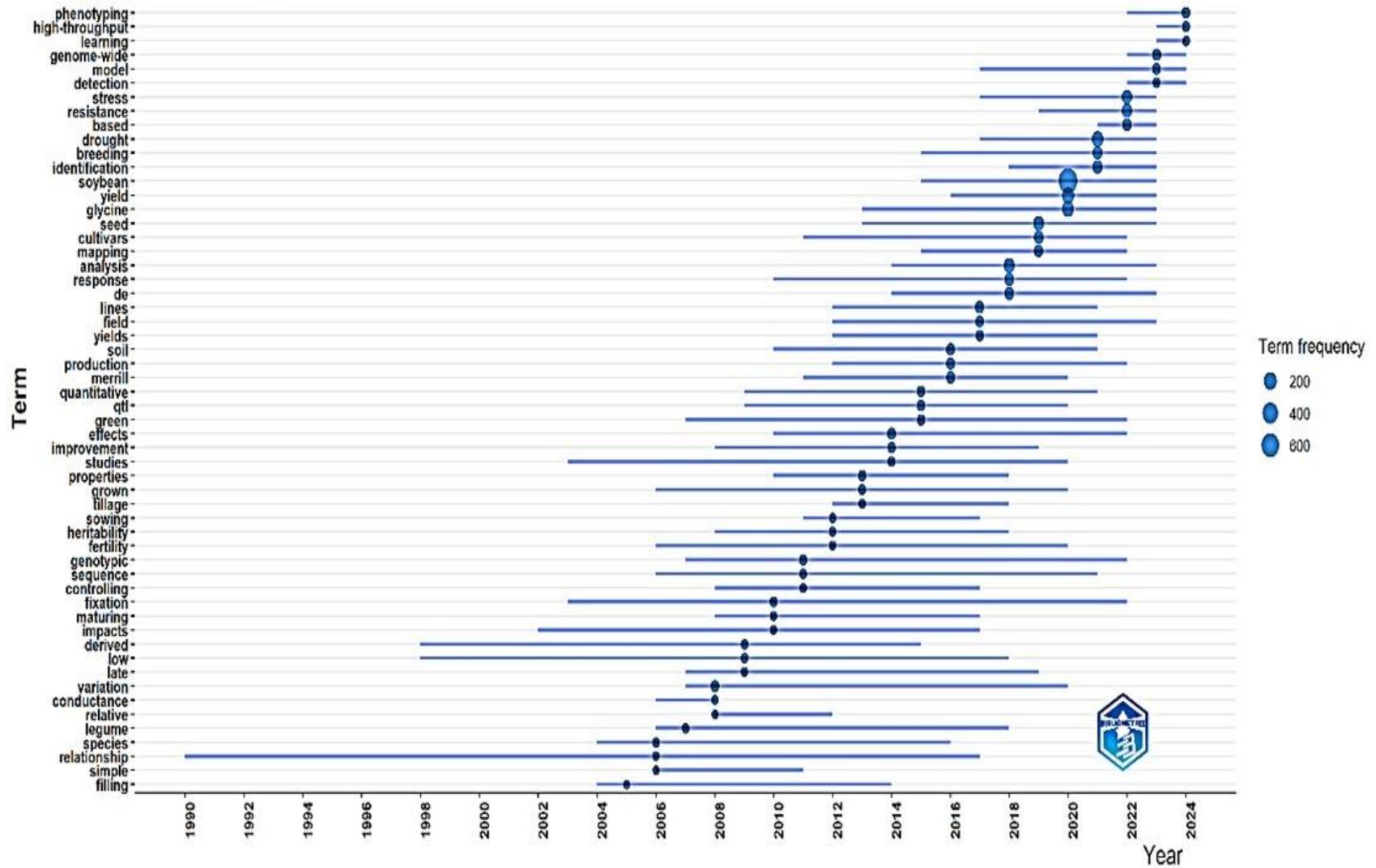
As breeding shifts toward integrating genomics with field performance, high-throughput phenotyping (HTP) technologies, such as hyperspectral imaging, thermal imaging, and automated root scanning, enable rapid, non-destructive, and scalable evaluation of plant responses within stress conditions. These tools provide precise quantitative data on physiological, morphological, and biochemical traits, which are critical for identifying drought-resilient genotypes and evaluating pod structural integrity. Moreover, the rise of phenomics complements genomic approaches, allowing researchers to better understand genotype-phenotype relationships. This convergence of phenotyping and molecular breeding reflects the broader trend toward precision agriculture and accelerates the development of climate-resilient soybean cultivars (Bhat and Yu, 2021).

### Conceptual structure map and research gaps

The conceptual structure map offers an overview of the structural landscape of soybean research by classifying themes based on their centrality (relevance degree) on the x-axis and density (development degree) on the y-axis (Figure 2A). In this analysis, themes related to drought tolerance and pod shattering reached a grouping within the "soybean," "*Glycine max*," and "genotypes" cluster (green color with red outline). Likewise, they incur positioning in the basic themes quadrant, indicative of their high relevance and frequent citation across studies. However, they lack depth as independent research topics.

This receives further support from the co-occurrence network (Figure 2B), where the terms "drought stress" and "pod dehiscence" appear within the same cluster (blue color with red outline) yet exhibit no direct interaction. In canola, drought stress also exacerbates pod shattering, resulting in significant yield loss (Ahmad *et al.*, 2022). The connectivity of "drought stress" with physiology, metabolism, and gene-expression regulation confirms that drought tolerance has gained extensive investigations. In contrast, "pod dehiscence" appears as a relatively small and isolated node, reflecting that shattering remains underexplored and rarely connected to drought research. The lack of direct co-occurrence between drought stress and pod shattering underscores a noteworthy research gap, pointing to the need for integrated studies that simultaneously address both traits to enhance soybean resilience in dryland environments.

This disconnection may be due to the traditional separation of breeding targets, where drought tolerance has typical linkages with root architecture, stomatal control, or water use efficiency (Ranjan *et al.*, 2022), while the study of pod shattering transpires through pod structural or anatomical features (Zhang *et al.*, 2018). The bridging of this gap has a hypothesis suggesting a novel physiological and molecular framework linking both traits through shared hormonal pathways, particularly involving abscisic acid (ABA) and



**Figure 1.** Trend analysis based on the usage of terms in article titles over time reveals the evolving research focus in soybean breeding for drought tolerance and pod-shattering resistance.



auxin, with the *PDH1* gene as a regulatory hub.

Drought stress usually increases ABA levels as part of the plant's adaptation to water deficit (Gupta *et al.*, 2020). However, high ABA concentrations can suppress auxin biosynthesis and transport, which are essential for both root development and the maintenance of cell wall integrity (Rowe *et al.*, 2016; Guo *et al.*, 2022). Auxin plays a central role in promoting lateral root formation and primary root elongation, key traits for drought tolerance. Similarly, it maintains pod structure by regulating cell wall-modifying enzymes like cellulase (CE) and polygalacturonase (PG), responsible for degrading the abscission layer (AL), a key trigger of pod shattering (Guo *et al.*, 2022). This suggests that drought-induced hormonal changes may simultaneously weaken root systems and increase pod-shattering susceptibility, linking the two traits through a shared regulatory pathway.

Studies in *Medicago ruthenica* showed a lower activity of auxin biosynthesis genes, such as *YUCCA*, *TDC*, and *ALDH*, in pod-shattering-susceptible genotypes (Guo *et al.*, 2022). Lower auxin levels indicate an association with increased activities of cell wall-modifying enzymes, such as CE and PG, which accelerate the AL degradation. As a result, the AL became weakened and degraded prematurely, making the pods more prone to shattering. Translating this to soybean, it is a hypothesis that drought-induced ABA accumulation may reduce auxin levels in root and reproductive tissues, leading to weaker root systems and higher susceptibility to pod shattering. Since no existing review explicitly linked pod shattering and drought via ABA-auxin crosstalk, formalizing this model fills a conceptual gap and generates testable hypotheses for soybean improvement under climate stress.

Within this hormonal framework, we hypothesized that the *PDH1* gene acts as a central regulator linking drought-stress responses with pod shattering. *PDH1* encodes a dirigent-like protein involved in secondary cell wall modification and has been validated as a major gene controlling pod shattering in

soybeans (Funatsuki *et al.*, 2014). Under drought or ABA-related stress, *PDH1* expression may increase, leading to higher CE and PG activity, as well as excessive lignin deposition in pod walls. As lignin normally provides mechanical strength, excessive or uneven lignification creates torsional stress during drying, ultimately promoting pod rupture. At the same time, *PDH1* could influence auxin biosynthesis directly or indirectly through ABA-auxin crosstalk, thereby suppressing auxin levels critical for both root development and pod-wall stability. This places *PDH1* at the intersection of ABA-mediated drought adaptation and auxin-mediated structural regulation, making it a key regulator of soybean susceptibility or resistance to pod shattering under drought conditions.

## CONCLUSIONS

As pod shattering remains underexplored, this study reveals a growing focus on drought tolerance in soybean research. The findings highlight key contributors, influential journals, and dominant institutions, with China and the USA leading global efforts. The proposed link between drought tolerance and pod shattering via ABA-auxin hormonal crosstalk—potentially mediated by *PDH1*—offers a new conceptual framework for integrated trait improvement. Despite the robust dataset, reliance on Scopus-indexed literature constrains the analysis, potentially omitting relevant studies from other databases or gray literature. Future research should focus on multi-trait integration strategies and experimental validation of the hypothesized hormonal linkages to support the development of climate-resilient soybean cultivars for dryland environments.

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## REFERENCES

- Abbass K, Qasim MZ, Song H, Murshed M, Mahmood H, Younis I (2022). A review of the global climate change impacts, adaptation, and sustainable mitigation measures. *Environ. Sci. Pollut. Res.* 29(28): 42539–42559. <https://doi.org/10.1007/s11356-022-19718-6>.
- Ahmad Z, Barutçular C, Zia Ur Rehman M, Sabir Tariq RM, Afzal M, Waraich EA, Ahmad A, Iqbal MA, Bukhari MA, Ahmad K, El Sabagh A (2022). Pod shattering in canola reduced by mitigating drought stress through silicon application and molecular approaches-A review. *J. Plant Nutr.* 46(1): 101–128. <https://doi.org/10.1080/01904167.2022.2027972>.
- Arora NK (2019). Impact of climate change on agriculture production and its sustainable solutions. *Environ. Sustain.* 2: 95–96. <https://doi.org/10.1007/s42398-019-00078-w>.
- Basal O, Szabó A, Veres S (2020). Physiology of soybean as affected by PEG-induced drought stress. *Curr. Plant Biol.* 22: 1–8. <https://doi.org/10.1016/j.cpb.2020.100135>.
- Berners-Lee M, Kennelly C, Watson R, Hewitt CN (2018). Current global food production is sufficient to meet human nutritional needs in 2050 provided there is radical societal adaptation. *Elem. Sci. Anth.* 6: 1–14. <https://doi.org/10.1525/elementa.310>.
- Bhat JA, Yu D (2021). High-throughput NGS-based genotyping and phenotyping: Role in genomics-assisted breeding for soybean improvement. *Legum. Sci.* 3(3): 1–15. <https://doi.org/10.1002/leg3.81>.
- Caputo A, Kargina M (2022). A user-friendly method to merge Scopus and Web of Science data during bibliometric analysis. *J. Market Anal.* 10: 82–88. <https://doi.org/10.1057/s41270-021-00142-7>.
- Chaffai R, Ganesan M, Cherif A (2024). Plant hormones and their regulatory roles in abiotic stress response. In: R. Chaffai, M. Ganesan, and A. Cherif (Eds.). *Plant Adaptation to Abiotic Stress: From Signaling Pathways and Microbiomes to Molecular Mechanisms*. Springer, Singapore, pp. 249–274. [https://doi.org/10.1007/978-981-97-0672-3\\_11](https://doi.org/10.1007/978-981-97-0672-3_11).
- Chen Y, Wang W, Liu Z, Lin X (2009). Keyword search on structured and semi-structured data. *ACM.* 9: 1005–1010. <https://doi.org/10.1145/1559845.1559966>.
- Dai M, Zhang Y, Lu X, Wang D, Zhang Y, Zhou N, Wu Z, Liu L, Rui C, Wang X, Cui R (2023). Starch granules of the sugar-pathway were eliminated under the stress of PEG-drought compared with soil-drought. *Ind. Crops Prod.* 193: 1–15. <https://doi.org/10.1016/j.indcrop.2022.116158>.
- Dama H, Aisyah SI, Sudarsono S, Dewi AK, Wibisono K (2022). Identification, selection, and response of radiation induced towuti mutant rice (*Oryza sativa* L.) in drought stress conditions. *Atom Indones.* 48(2): 107–114. <https://doi.org/10.17146/aij.2022.1198>.
- Darmadi D, Junaedi A, Sopandie D, Lubis I (2021). Water-efficient rice performances under drought stress conditions. *AIMS Agric. Food.* 6(3): 838–863. <https://doi.org/10.3934/agrfood.2021051>.
- Desclaux D, Huynh TT, Roumet P (2000). Identification of soybean plant characteristics that indicate the timing of drought stress. *Crop Sci.* 40(3): 716–722. <https://doi.org/10.2135/cropsci2000.403716x>.
- Dilawari R, Kaur N, Priyadarshi N, Prakash I, Patra A, Mehta S, Singh B, Jain P, Islam MA (2022). Soybean: A key player for global food security. In: S.H. Wani, N.U.R. Sofi, M.A. Bhat, and F. Lin (Eds.). *Soybean Improvement*. Springer, Cham, pp. 1–46. [https://doi.org/10.1007/978-3-031-12232-3\\_1](https://doi.org/10.1007/978-3-031-12232-3_1).
- Dogan E, Kirnak H, Copur O (2007). Deficit irrigations during soybean reproductive stages and CROPGRO-soybean simulations under semi-arid climatic conditions. *Field Crops Res.* 103(2): 154–159. <https://doi.org/10.1016/j.fcr.2007.05.009>.
- Dong Y, Wang YZ (2015). Seed shattering: From models to crops. *Front. Plant Sci.* 6: 1–13. <https://doi.org/10.3389/fpls.2015.00476>.
- Donthu N, Kumar S, Mukherjee D, Pandey N, Lim WM (2021). How to conduct a bibliometric analysis: An overview and guidelines. *J. Bus. Res.* 133: 285–296. <https://doi.org/10.1016/j.jbusres.2021.04.070>.
- Du Y, Zhao Q, Chen L, Yao X, Xie F (2020). Effect of drought stress at reproductive stages on growth and nitrogen metabolism in soybean. *Agronomy.* 10(2): 1–21. <https://doi.org/10.3390/agronomy10020302>.
- Ejaz H, Zeeshan HM, Ahmad F, Bukhari SNA, Anwar N, Alanazi A, Sadiq A, Junaid K, Atif M, Abosalif KOA, Iqbal A (2022). Bibliometric analysis of publications on the omicron variant from 2020 to 2022 in the Scopus database using R and VOS-viewer. *Int. J.*

- Environ. Res. Public Health.* 19(19): 1–25. <https://doi.org/10.3390/ijerph191912407>.
- Farag PF, Alkhalifah DHM, Ali SK, Tagyan AI, Hozzein WN (2025). Impact of climate change on the potential global prevalence of *Macrophomina phaseolina* (Tassi) Goid. under several climatological scenarios. *Front. Plant Sci.* 16: 1–13. <https://doi.org/10.3389/fpls.2025.1512294>.
- Funatsuki H, Suzuki M, Hirose A, Inaba H, Yamada T, Hajika M, Komatsu K, Katayama T, Sayama T, Ishimoto M, Fujino K (2014). Molecular basis of a shattering resistance boosting global dissemination of soybean. *PNAS.* 111(50): 17797–17802. <https://doi.org/10.1073/pnas.141728211>.
- Ghorbani BD (2024). Bibliometrix: Science mapping analysis with R Biblioshiny based on Web of Science in applied linguistics. In: H. Meihami and R. Esfandiari (Eds.). *A Scientometrics Research Perspective in Applied Linguistics*. Springer, Cham, pp. 197–234. [https://doi.org/10.1007/978-3-031-51726-6\\_8](https://doi.org/10.1007/978-3-031-51726-6_8).
- Guo MW, Zhu L, Li HY, Liu WP, Wu ZN, Wang CH, Liu L, Li ZY, Li J (2022). Mechanism of pod shattering in the forage legume *Medicago ruthenica*. *Plant Physiol. Biochem.* 185: 260–267. <https://doi.org/10.1016/j.plaphy.2022.06.013>.
- Gupta A, Rico-Medina A, Caño-Delgado AI (2020). The physiology of plant responses to drought. *Sci.* 368(6488): 266–269. <https://doi.org/10.1126/science.aaz7614>.
- Khan MH, Tyagi DS, Dar ZA (2013). Screening of soybean (*Glycine max* [L.] Merrill) genotypes for resistance to rust, yellow mosaic and pod shattering. In: H.A. El-Shemy (Ed.). *Soybean Pest Resistance*. InTech, Rijeka, pp. 173–183. <https://doi.org/10.5772/54697>.
- Liu X, Tu B, Zhang Q, Herbert SJ (2019). Physiological and molecular aspects of pod shattering resistance in crops. *Czech J. Genet. Plant Breed.* 55(3): 87–92. <https://doi.org/10.17221/104/2018-CJGPB>.
- Ni Z, Hu Z, Jiang Q, Zhang H (2013). *GmNFYA3*, a target gene of miR169, is a positive regulator of plant tolerance to drought stress. *Plant Mol. Biol.* 82: 113–129. <https://doi.org/10.1007/s11103-013-0040-5>.
- Pandey P, Ge Y, Stoerger V, Schnable JC (2017). High throughput in vivo analysis of plant leaf chemical properties using hyperspectral imaging. *Front. Plant Sci.* 8: 1–12. <https://doi.org/10.3389/fpls.2017.01348>.
- Ranjan A, Sinha R, Singla-Pareek SL, Pareek A, Singh AK (2022). Shaping the root system architecture in plants for adaptation to drought stress. *Physiol. Plant.* 174(2): p.e13651. <https://doi.org/10.1111/ppl.13651>.
- Rowe JH, Topping JF, Liu J, Lindsey K (2016). Abscisic acid regulates root growth under osmotic stress conditions via an interacting hormonal network with cytokinin, ethylene and auxin. *New Phytol.* 211(1): 225–239. <https://doi.org/10.1111/nph.13882>.
- Specht JE, Chase K, Macrander M, Graef GL, Chung J, Markwell JP, Germann M, Orf JH, Lark KG (2001). Soybean response to water: A QTL analysis of drought tolerance. *Crop Sci.* 41(2): 493–509. <https://doi.org/10.2135/cropsci2001.412493x>.
- Sweileh WM (2020). Bibliometric analysis of peer-reviewed literature on food security in the context of climate change from 1980 to 2019. *Agric. Food Secur.* 9(11): 1–15. <https://doi.org/10.1186/s40066-020-00266-6>.
- Tefera H, Bandyopadhyay R, Adeleke RA, Boukar O, Ishaq M (2009). Grain yields of rust resistant promiscuous soybean lines in the Guinea savanna of Nigeria. *Afr. Crop Sci. J.* 9: 129–134. <https://hdl.handle.net/20.500.12478/2860>.
- Verma KK, Song XP, Kumari A, Jagadesh M, Singh SK, Bhatt R, Singh M, Seth CS, Li YR (2025). Climate change adaptation: Challenges for agricultural sustainability. *Plant Cell Environ.* 48(4): 2522–2533. <https://doi.org/10.1111/pce.15078>.
- Vila-Traver J, Aguilera E, Infante-Amate J, González De Molina M (2021). Climate change and industrialization as the main drivers of Spanish agriculture water stress. *Sci. Total Environ.* 760: 1–10. <https://doi.org/10.1016/j.scitotenv.2020.143399>.
- Wang C, Linderholm HW, Song Y, Wang F, Liu Y, Tian J, Xu J, Song Y, Ren G (2020). Impacts of drought on maize and soybean production in northeast China during the past five decades. *Int. J. Environ. Res. Public Health.* 17(7): 1–10. <https://doi.org/10.3390/ijerph17072459>.
- Wang H, Liu Y, Wang Y, Yao Y, Wang C (2023). Land cover change in global drylands: A review. *Sci. Total Environ.* 863: 1–13. <https://doi.org/10.1016/j.scitotenv.2022.160943>.
- Waqar A, Bano A, Ajmal M (2022). Effects of PGPR bioinoculants, hydrogel and biochar on

- growth and physiology of soybean under drought stress. *Comm. Soil Sci. Plant Anal.* 53: 826-847. <https://doi.org/10.1080/00103624.2022.2028818>.
- Wibisono K, Dama H, Dewi AK (2024). Multivariate analysis and preference selection index to selecting rice genotype adaptive on drought stress environment during generative stage. *AIP Conf. Proc.* 2957(1): 1-8. <https://doi.org/10.1063/5.0183906>.
- Wijewardana C, Reddy KR, Bellaloui N (2019). Soybean seed physiology, quality, and chemical composition under soil moisture stress. *Food Chem.* 278: 92-100. <https://doi.org/10.1016/j.foodchem.2018.11.035>.
- Yong B, Zhu W, Wei S, Li B, Wang Y, Xu N, Lu J, Chen Q, He C (2023). Parallel selection of loss-of-function alleles of *Pdh1* orthologous genes in warm-season legumes for pod indehiscence and plasticity is related to precipitation. *New Phytol.* 240(2): 863-879. <https://doi.org/10.1111/nph.19150>.
- Zhang Q, Tu B, Liu C, Liu X (2018). Pod anatomy, morphology and dehiscing forces in pod dehiscence of soybean (*Glycine max* [L.] Merrill). *Flora.* 248: 48-53. <https://doi.org/10.1016/j.flora.2018.08.014>.
- Zhou Z, Li J, Gao Y, Wang X, Wang R, Huang H, Zhang Y, Zhao L, Wang P (2024). Research on drought stress in *Medicago sativa* L. from 1998 to 2023: A bibliometric analysis. *Front. Plant Sci.* 15: 1-16. <https://doi.org/10.3389/fpls.2024.1406256>.